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ORIGINAL ARTICLE

New organic substrates for seedling production in the transition zone between the Amazon-Cerrado biomes[1]

Novos substratos orgânicos para a produção de mudas na zona de transição entre os biomas Amazônia-Cerrado

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HIGHLIGHTS:

Decomposed biomass from palm trees like babassu (BDB) and carnauba (BDC) is an alternative substrate for seedling production.
The substrate of BDB and BDC has physicochemical characteristics like those of a commercial substrate.
The physicochemical characteristics of the decomposed biomass of the buriti palm restrict its use as an alternative substrate.

ABSTRACT: In the Amazon-Cerrado ecotone, increased costs from non-organic inputs and transportation render substrates more expensive, prompting the use of decomposed biomass from native palm stem for seedlig production. The study was carried out with the objective of evaluate the physicochemical characteristics of the decomposed biomass of babassu palms (BDB), carnauba (BDC), and buriti (BBU) compared to the commercial substrate (SC) via multivariate analysis. This study employed a database comprising 90 substrates, obtained from Maranhão, Brazil farms. These samples underwent physicochemical characterization following the Brazilian protocol for seedling substrates. The substrates based on BDB and BDC have pH and nutrient contents at acceptable values, in addition to lower potential acidity and high base saturation compared to BBU and SC substrates. Principal component analysis and hierarchical clustering revealed similarities between BDB, BDC and SC. Biomass decomposed from the stems of babassu and carnauba palms is recommended as an alternative substrate for seedling producers in the in the Amazon-Cerrado ecotone.

Key words: chemical indicators, sustainable agriculture, seedling production, sustainability

RESUMO: No ecótono Amazônia-Cerrado, o aumento dos custos com insumos não orgânicos e transporte torna os substratos mais caros, estimulando o uso da biomassa decomposta do caule da palmeira nativa para a produção de mudas. O estudo foi realizado com o objetivo de avaliar as características físico-químicas da biomassa decomposta de babaçu (BDB), carnaúba (BDC) e buriti (BBU) comparado ao substrato comercial (SC) via estatística multivariada. O estudo utilizou um banco de dados composto por 90 substratos, obtidos em fazendas do Maranhão, Brasil. Essas amostras passaram por caracterização físico-química seguindo o protocolo brasileiro para substratos de mudas. Os substratos à base de BDB e BDC apresentam pH e teores de nutrientes em valores aceitáveis, além de menor acidez potencial e elevada saturação por bases em comparação aos substratos BBU e SC. A análise de componentes principais e agrupamento hierárquico revelou similaridades entre BDB, BDC e SC. A biomassa decomposta dos caules das palmeiras babaçu e carnaúba é recomendada como substrato alternativo para produtores de mudas no ecótono Amazônia-Cerrado.

Palavras-chave: indicadores químicos, agricultura sustentável, produção de mudas, sustentabilidade

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Introduction

In the production of seedlings, the substrate is a porous material used in its pure form or mixed with other materials with the potential to provide supporting conditions and adequate levels of nutrients, humidity, and aeration for the development of cultivated plants (Gomes-Júnior et al., 2019). The choice of substrate in rural enterprises is a complex task and must be based on factors such as regional availability, price, and agronomic feasibility for the production of high-quality seedlings (Pascual et al., 2018).

In South America, there is a general trend in the trade of substrates based on expanded vermiculite associated with organic compounds, such as fibers from *Pinus elliottii*, *Cocos nucifera*, rice straw, and peat (Cavalcante et al., 2011; Costa et al., 2021; Leite et al., 2023). On transition zone between the Amazon-Cerrado biomes, the added value of non-organic inputs and transportation costs make these substrates more expensive (Silva-Matos et al., 2016). Consequently, the decomposed stem biomass of native babassu (*Attalea speciosa* Mart.), buriti (*Mauritia flexuosa* L. f.), and carnauba (*Copernicia prunifera* Mill.) has been utilized for fostering fruit tree growth (Cordeiro et al., 2019), forest species (Cavalcante et al., 2021), and in the production pre-sprouted seedlings (Andrade et al., 2021).

Among the main advantages pointed out by these studies, the natural fertility of these materials, regional availability, and low purchase costs stands out. The physicochemical characterization of the biomass of these native palm trees in the periphery of the Amazon remains outside of scientific investigation, especially through a multivariate approach (Cordeiro et al., 2019). Studies with alternative substrates are complex and can only be explained from the perspective of multivariate analysis because all characteristics are biologically correlated (Oliveira et al., 2021a).

A multivariate approach allows for a more complete and optimized interpretation of the results (Alonso et al., 2022). This study was carried out with the objective of evaluate the physicochemical characteristics of the decomposed biomass of babassu, carnauba, and buriti compared to the commercial substrate (SC) via multivariate analysis, thereby contributing to a more rational use of these inputs as substrates for seedlings in the transitional zone between the Amazon-Cerrado biomes in Northeast Brazil.

Material and Methods

The experiment was conducted at the Chapadinha Science Center of the Universidade Federal do Maranhão, Chapadinha, Brazil, between July 2021 and January 2022. The treatments consisted of the use of the commercial substrate (control) and the substrates constituted entirely of the decomposed biomass of the babassu palm (BDB), the decomposed biomass of the carnauba palm (BDC), and the decomposed biomass of the buriti palm (BBU). A simple random probabilistic sample collection was carried out in 30 farms in the state of Maranhão, located in the municipalities of Vargem Grande (15 farms) (03°67′18″ S, 43°96′75″ W and 100 m a.s.l) and Itapecuru Mirim (15 farms) (03°39′99″ S, 44°35′16″ W and 100 m a.s.l) in the transition zone between the Amazon-Cerrado biomes (Figure 1).

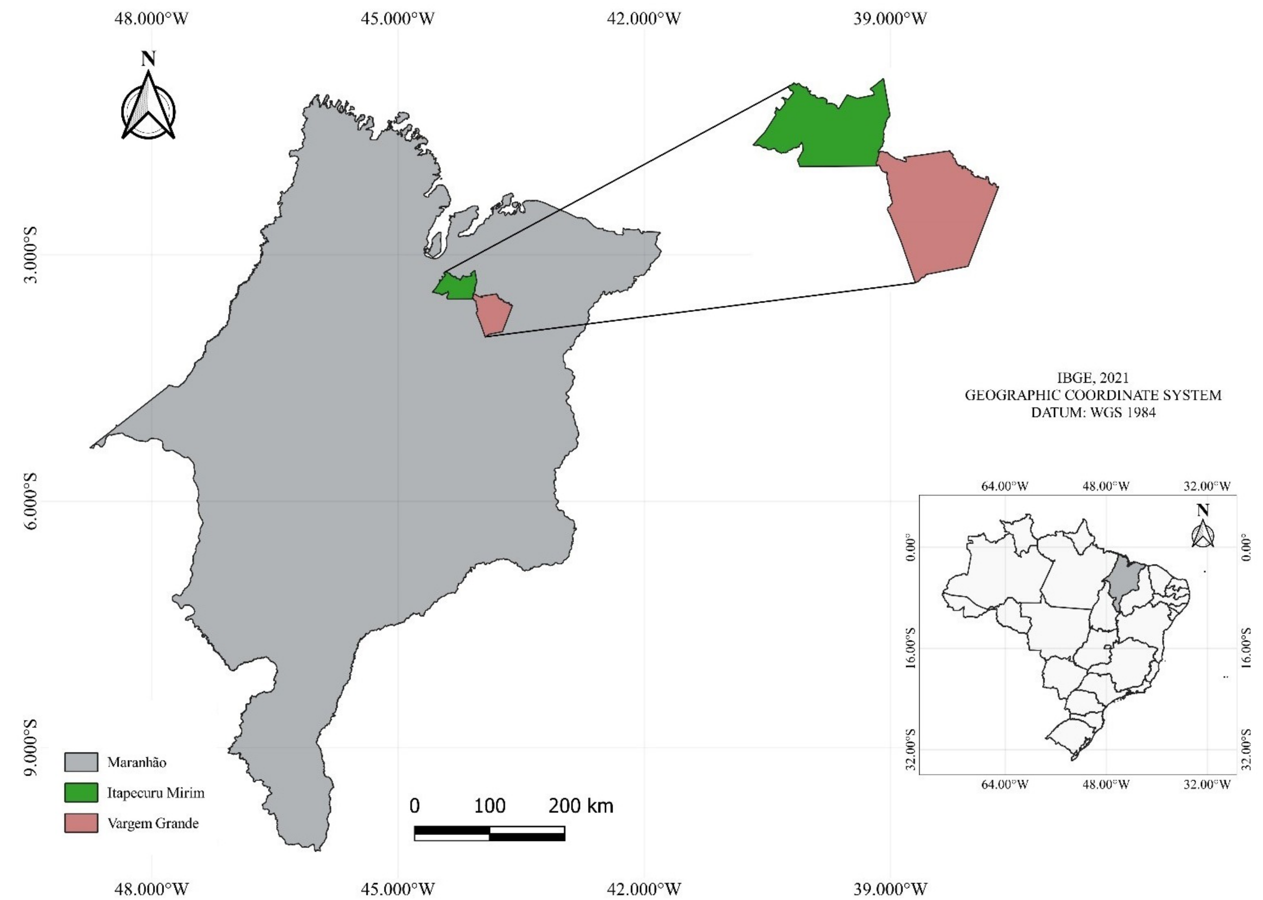


Figure 1. Location of municipalities where substrates were collected

According to Köppen, the climate pattern of the region is Aw type, hot and humid equatorial (Alvares et al., 2013). The farms were selected based on the database of the Rural Workers Union of the municipalities of Vargem Grande and Itapecuru Mirim. At each farm, 90 subsamples of approximately 300 ± 50 g of the target substrate were collected at various points on the property. These subsamples were homogenized and then 30 samples weighing 400 ± 65 g were collected, stored in medium-density polyethylene packages, and identified for subsequent analysis. Hence, a total of 30 samples were employed for laboratory analyses on each substrate and included in the statistical procedures. In this study, the commercial substrate used was the most common substrate in the region and consisted of a mixture of ground pine fibers and vermiculite. The material was collected from the stems of naturally fallen palm trees whose stem decomposition processes were visible.

The samples were subjected to chemical characterization in accordance with Normative Instruction No. 17 of the Ministry of Agriculture, Livestock, and Supply of Brazil (Brasil, 2007). The pH was determined by direct measurement in a substrate solution with distilled water in a 1:2.5 ratio using a pH meter (Simpla®, PH140, São Caetano, SP, Brazil). Electrical conductivity was measured after obtaining the soil solution using the paste saturation method with vacuum extraction by direct reading with an electrode using a conductivity meter (CDH222, São Caetano, SP, Brazil).

The nitrogen content was determined using the Kjeldahl method, with digestion in H_2SO_4, followed by steam distillation with an NaOH solution, using a boric acid solution as an indicator. After distillation, a titration was performed using a standard solution of hydrochloric acid (HCl). Potassium and sodium contents were determined using a flame photometer (Digimed®, DM-63, São Paulo, SP, Brazil). The phosphorus and sulfur contents were extracted with a Mehlich^{-1} solution (HCl 0.05 mol L^{-1} + H_2SO_4 0.0125 mol L^{-1}) and then quantified with a photocolorimeter (Alfakit®, AT 100P II, Florianópolis, SC, Brazil).

The carbon content was determined by the Walkley-Black method using the wet redox principle. The calcium and magnesium contents were determined by atomic absorption spectrometry (Konica Minolta®, CM-3600A, Tokyo, Japan), and the exchangeable aluminium content by titration with 0.025 mol L^{-1} NaOH, both after extraction with 1 mol L^{-1} of KCl. The potential acidity (H+Al) was obtained by titration with 0.025 mol L^{-1} NaOH after extraction with a calcium acetate solution at pH 7.0. The sum of bases (SB) was obtained by adding the exchangeable bases, whereas the cation exchange capacity (CTC) was obtained by adding the sum of bases with potential acidity. Base saturation (V) was determined as the ratio of the sum of the bases to the cation exchange capacity.

The analyses followed the guidelines established by the analysis protocol for substrates of Normative Instruction No. 17 of the Ministry of Agriculture, Livestock, and Supply of Brazil (BRASIL, 2007). Thus, to determine the global density, the samples were inserted into a volumetric ring of known volume (PSPTRADOS®, Trado Castelinho, Curitiba, PR, Brazil). Then, the samples were conditioned in an oven with forced air circulation (SolidSteel®, MBSSDCR40L, Piracicaba, SP, Brazil), with a temperature of 65 °C for 48 hours. The global density was determined based on the relationship between the volume and weight of the sample. After drying in an oven, the samples were transferred to a 50 ml volumetric flask containing ethyl alcohol, and the particle density and porosity of the samples were obtained by the volumetric flask method using Eqs. 1 and 2, respectively.

$$\text{Particle density}\left(\text{g cm}^{-3}\right) = \frac{\text{weight of oven-dried sample (g)}}{50 - \text{volume of alcohol (cm}^3\text{)}} \quad (1)$$

$$\text{Porosity}\left(\%\right) = \frac{\text{Global density (g cm}^{-3}\text{)}}{\text{Particle density (g cm}^{-3}\text{)}} \quad (2)$$

The validity of the assumption of normality of the residues was verified by the Shapiro-Wilk test and analysis of variance was performed. The averages were compared using the Tukey-Kramer test. Statistical level of $p < 0.05$ was adopted as the significance limit for all tests.

A descriptive analysis of the data was performed using the UNIVARIETE procedure to obtain the mean, median, standard deviation, coefficient of variation, and minimum and maximum values. Following this, with the objective of characterizing the substrates from a multivariate perspective, principal component analysis was carried out using the PRINCOMP procedure, and a biplot was prepared using the PRINQUAL procedure. Finally, a cluster analysis was performed using the cluster procedure, using the hierarchical method of the mean distance between treatments (UPGMA) and the Euclidean distance as a measure of dissimilarity. All analyses were performed using the software Statistical Analysis System® (SAS, 2012).

Results and Discussion

The results obtained for the physicochemical characteristics of the substrates are presented in Table 1. No significant differences were observed in the particle density between the alternative substrates. However, both substrates showed higher average values than the commercial substrate. Such results express the ability of the seedlings to facilitate growth, as values below 0.4 g cm^{-3} can cause the seedlings to fall (BRASIL, 2007). Additionally, the substrates of decomposed babassu and carnauba biomass showed lower global density values and, consequently, lower porosities. However, all alternative substrates exhibited porosity values between 50 and 80%, which are considered ideal for substrates (Pascual et al., 2018). These results suggest that substrates composed of decomposed biomass from native palms have suitable conditions for water and oxygen flow for seedling formation (Costa et al., 2021).

The substrate decomposed biomass of buriti palm had the highest average pH, followed by substrates of decomposed babassu and buriti biomass, which were higher than those of the commercial substrates. In organic substrates, pH values ranging between 5.0 and 6.5 suggest ideal conditions to promote greater seedling development, with greater solubility being related to nutrient availability (Boaro et al., 2014). For

Table 1. Averages of physical-chemical characteristics of the commercial substrate (SC), babassu decomposed biomass (BDB), carnauba decomposed biomass (BDC) and buriti decomposed biomass (BBU)

Item	Treatments				CV
	SC	BDB	BDC	BBU	(%)
pH	4.83 c	5.29 b	5.08 b	6.27 a	2.86
EC (dS m^{-1})	2.63 b	4.30 a	0.65 d	1.69 c	18.4
N (g kg^{-1})	3.07 d	5.78 b	4.11 c	23.61 a	6.23
P (mg kg^{-1})	55.10 b	33.10 c	88.00 a	51.42 b	4.58
K ($cmol_c$ kg^{-1})	2.86 b	3.64 a	3.76 a	1.50 c	6.71
Ca ($cmol_c$ kg^{-1})	22.66 a	20.59 b	19.67 b	8.82 c	3.34
Mg ($cmol_c$ kg^{-1})	3.43 d	15.24 a	10.52 b	7.32 c	4.06
S ($cmol_c$ kg^{-1})	29.41 c	41.29 a	34.35 b	17.50 d	2.55
Na ($cmol_c$ kg^{-1})	0.58 b	2.06 a	0.54 b	0.61 b	4.37
C (g kg^{-1})	89.28 d	145.08 c	347.25 b	365.57 a	2.65
H+Al ($cmol_c$ kg^{-1})	15.68 b	11.09 d	12.06 c	20.66 a	2.95
Al ($cmol_c$ kg^{-1})	0.23 d	3.27 a	0.65 c	0.94 b	7.42
SB ($cmol_c$ kg^{-1})	29.39 c	41.52 a	34.49 b	18.25 d	2.53
T ($cmol_c$ kg^{-1})	45.07 c	52.61 a	46.55 b	38.91 d	2.01
V (%)	65.22 c	78.92 a	74.09 b	46.91 d	2.18
DG (g cm^{-3})	0.55 a	0.34 c	0.27 d	0.37 b	3.22
DP (g cm^{-3})	0.85 c	0.95 a	0.91 b	0.91 b	1.92
Porosity (%)	32.24 d	65.06 b	70.56 a	65.06 b	3.10

Averages with different letters in the same line are significantly different by the Tukey-Kramer test ($p \leq 0.05$). CV - coefficient of variation; DG - global density; DP - particle density; H+Al - potential acidity; T - potential cation exchange capacity; V - base saturation; SB - sum of bases; EC - electrical conductivity

this parameter, it is observed that with the exception of the commercial substrate (pH 4.83), the other substrates presented values within this range (Table 1). However, according to Epstein & Bloom Arnold (2006), at a pH lower than 5.5, plants are more vulnerable to the toxicity of cationic micronutrients and may affect the integrity of the cell membrane of the epidermal and cortical cells of the roots. From this point of view, the only substrate with pH value greater than 5.5 was decomposed biomass of buriti palm (6.27).

Another important variable in the evaluation of the quality of inputs for substrates is electrical conductivity, which is strongly influenced by a wide combination of physical and chemical properties of the soil, such as soluble salts, amount of water present in the soil, density, and organic matter. A higher electrical conductivity was observed for the substrate of decomposed biomass of babassu palm than for the commercial substrate. The substrates of decomposed buriti and carnauba solutions exhibited significantly lower values of this parameter (Table 1). According to Cavins et al. (2000) electrical conductivity can be classified as very low (0 to 0.25 dS m^{-1}), low (0.26 to 0.75 dS m^{-1}), normal (0.76 to 1. 25 dS m^{-1}), high (1.26 to 1.75 dS m^{-1}), very high (1.76 to 2.25 dS m^{-1}), and extreme (above 2.25 dS m^{-1}). Thus, the evaluated substrates fit the thresholds of low (carnauba decomposed biomass), high (buriti decomposed biomass), and extreme (babassu decomposed biomass and commercial substrates) electrical conductivities.

The nitrogen content was higher the substrate of decomposed biomass of buriti palm (+20.54 g kg^{-1}), followed by decomposed biomass of babassu palm (+2.07 g kg^{-1}), and decomposed biomass of carnauba palm (+1.04 g kg^{-1}) compared to the commercial substrate. However, the highest phosphorus content was observed in decomposed biomass of carnauba palm, followed by decomposed biomass of buriti palm and the commercial substrate (Table 1). Additionally, the substrates derived from the decomposed biomass of native palm trees exhibited a notably higher potassium content when compared to the commercial substrate.

Higher concentrations of magnesium, sulfur, sodium, and aluminum were obtained in decomposed biomass of babassu palm than in the other substrates. In addition, decomposed biomass of babassu palms showed the lowest potential acidity, higher sum and base saturation values, and higher cation exchange capacity. The commercial substrate had the highest Ca content, followed by substrates of decomposed babassu and carnauba biomass. The organic carbon content was higher in decomposed biomass of buriti palm (+276.29 g kg^{-1}) followed by decomposed biomass of carnauba palm (+257.97 g kg^{-1}) and decomposed biomass of babassu palm (+55.80 g kg^{-1}) compared to the commercial substrate.

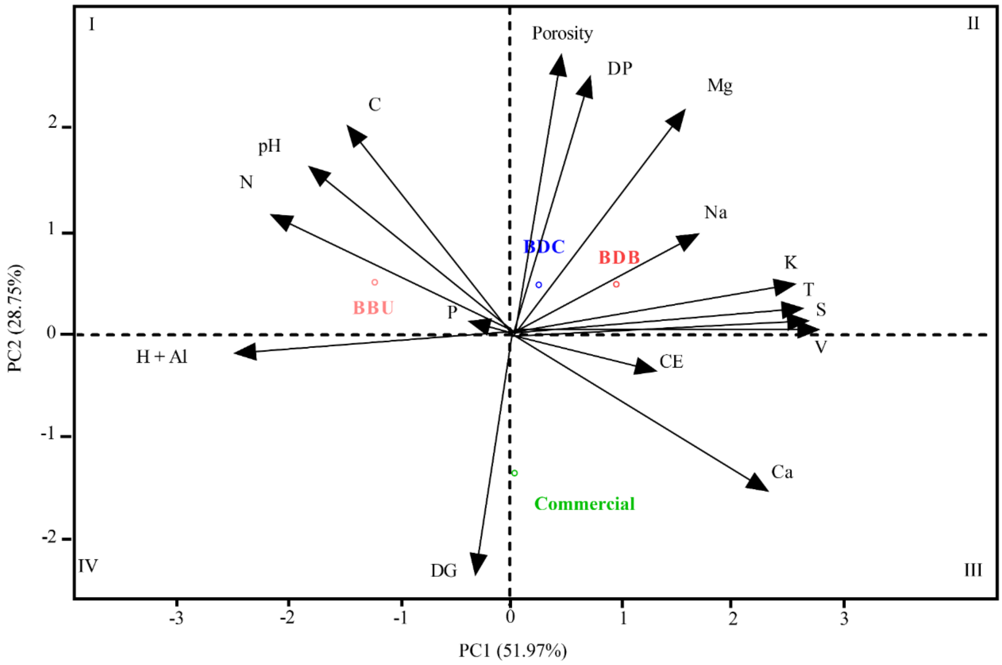
The eigenvectors, eigenvalues and total variation explained by each principal component from the studied variables are presented in Table 2. The two principal components represented 80.71% of the data variance. Component 1 (CP1) was primarily associated with potassium, sulfur, potential acidity, cation-exchange capacity, and base saturation. In contrast, component 2 (CP2) was linked to global density, particle density, porosity, magnesium, and carbon, suggesting a variation attributable to the association between the physical characteristics and concentrations of magnesium and organic carbon in the substrates.

Furthermore, the substrates can be characterized based on their location in the biplot, considering the mean vectors incident in the opposite quadrant and in the quadrant where the treatment was positioned (Vicini et al., 2018). Thus, the decomposed biomass of buriti palm substrate was allocated in quadrant I, characterized by high pH values, nitrogen, phosphorus, and organic carbon contents, and low calcium content and electrical conductivity (Figure 2). The substrates of decomposed babassu and carnauba biomass were in

Table 2. Eigenvalues, eigenvectors and total variation explained by each principal component from the studied variables

Variable	Principal component (PC)	
	PC1	PC2
pH	-0.257	0.268
Electric conductivity	0.182	-0.588
Nitrogen	-0.289	0.200
Phosphorus	-0.043	0.015
Potassium	0.323*	0.019
Calcium	0.288	-0.239
Magnesium	0.217	0.352*
Sulfur	0.345*	0.032
Sodium	0.236	0.155
Organic carbon	-0.193	0.325*
H+Al	-0.335*	-0.049
T	0.342*	0.039
V	0.342*	0.014
Global density	-0.061	-0.432*
Particle density	0.099	0.433*
Porosity	0.079	0.438*
Eigenvalues	8.3146	4.599
Variation (%)	51.97	28.75
Accumulated variation (%)	51.97	80.71

*Relevant eigenvector in the formation of the CP (> 0.30). DG - global density; DP - particle density; H+Al - potential acidity; T - potential cation exchange capacity; V - base saturation; SB - sum of bases; CE - electrical conductivity



DG - global density; DP - particle density; H+Al - potential acidity; T - potential cation exchange capacity; V - base saturation; SB - sum of bases; CE - electrical conductivity

Figure 2. Biplot for the first two principal components of the physical-chemical characteristics of the commercial substrate (SC), babassu decomposed biomass (BDB), carnauba decomposed biomass (BDC) and buriti decomposed biomass (BBU)

quadrant II, characterized by high values of particle density and porosity; high levels of magnesium, sodium, potassium, and sulfur; and high values of cation exchange capacity and base saturation associated with low values of potential acidity and global density. In contrast, the commercial substrate shifted to quadrant III, superimposed by the average vectors of electrical conductivity and calcium associated with low pH values and nitrogen, phosphorus, and organic carbon contents (Figure 2).

Furthermore, in the biplot, the correlation between the variables was clearly visualized (Figure 2). The cosine of the angles formed between the mean vectors revealed positive, negative, or absent correlations between the variables (Almusallam et al., 2021). There was an inverse correlation between the global density, particle density, and porosity, and a positive linear correlation was also observed between the potential cation exchange capacity, saturation, and sum of bases with the potassium content, and with more moderate intensity with sodium and magnesium and electrical conductivity.

The hierarchical clustering revealed two groups of substrates based on their physicochemical characteristics (Figure 3).

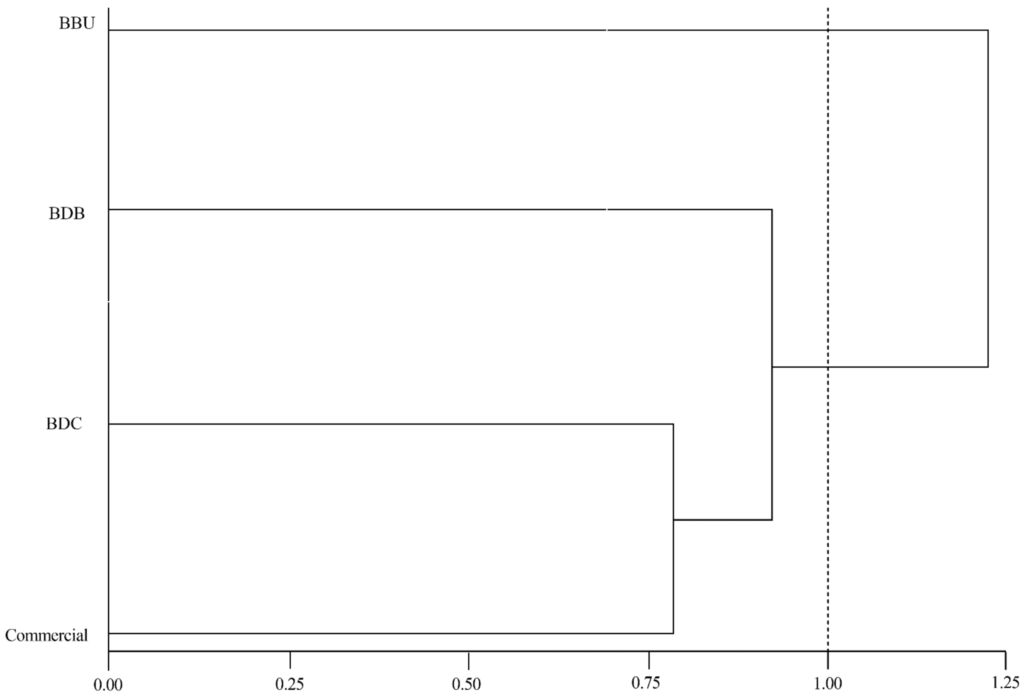


Figure 3. Dendrogram of dissimilarity between substrates based on Euclidean distance of the physical-chemical characteristics of the commercial substrate (SC), babassu decomposed biomass (BDB), carnauba decomposed biomass (BDC) and buriti decomposed biomass (BBU)

Upon cutting the dendrogram, the buriti decomposed biomass formed a distinct group (Group 1), while a second group comprised the commercial substrate, decomposed biomass of the carnauba palm stem, and decomposed biomass of the babassu palm stem (Group 2). This suggests a higher similarity of the input substrates from decomposed carnauba and babassu biomass with the commercial substrate, indicating a closer resemblance to the characteristics of the standard commercial substrate. This finding highlights their potential use in commercial applications.

This research is the first to provide insights into the physicochemical properties of decomposed biomass from palm trees that are native to the Amazon-Cerrado ecotone, using a multivariate approach. The findings demonstrate that babassu and carnauba have the potential to be used as substrate inputs. These results can be explained by the natural fertility of the evaluated substrates, which, in general, highlights the potential of using the decomposed biomass of these palm trees, particularly babassu and carnauba. The values reported for cation exchange capacity, base sum, and base saturation indicate good availability of nutrients from these organic compounds, especially in terms of nitrogen, potassium, calcium, magnesium, and sulfur content (Table 1). However, the electrical conductivity of babassu biomass and the high sodium content documented for this compound, which is 73.8% higher than that of other substrates, may limit the absorption of water and nutrients (Pascual et al., 2018).

Recent studies have demonstrated promising results regarding the use of decomposed babassu biomass. Andrade et al. (2021), in a study with cassava seedlings, evaluated the effect of the inclusion of decomposed babassu biomass (20, 40, 60, 80, and 100%) with soil on the biometric variables of the seedlings and verified an improvement in the fertility of the substrate and in the growth and development of seedlings, recommending substrates composed entirely of BDB. Cordeiro et al. (2019) evaluated the inclusion of decomposed babassu biomass (20, 40, 60, 80, and 100%) in soil compared to commercial substrate in the vegetative growth of yellow passion fruit seedlings and found the greatest growth and root volume, dry matter of the root system, and Dickson quality index in seedlings produced in substrates with 80% decomposed babassu biomass, promoting greater accumulation of nutrients (e.g., nitrogen, phosphorus, potassium, and boron) compared to the commercial substrate.

However, information on the use of the decomposed biomass of carnauba and buriti palms, especially decomposed biomass of carnauba, is incipient. Most studies on carnauba have evaluated the carnauba bagana waste generated from the agro-industrial process of extracting wax from carnauba leaves (Albano et al., 2017). Oliveira et al. (2021b) tested the inclusion of decomposed biomass of buriti palm (20, 40, 60, 80, and 100%) with soil on the biometric parameters of cassava seedlings and observed better conditions for shoot development and survival, and higher levels of nitrogen, phosphorus, K, Ca, and Mg in seedlings. The authors concluded that decomposed biomass of buriti palm is a viable and sustainable input for cassava seedling production.

In his study, Albano et al. (2014) evaluated the effect of decomposed biomass of buriti on the formation of papaya seedlings cv. Caliman. These authors concluded that decomposed biomass of buriti can be partially used as a substrate for the formation of papaya seedlings in a proportion of up to 20% in the formulation without causing damage to seedling height, stem diameter, leaf area, leaf chlorophyll, root diameter, shoot dry matter mass, and root dry matter mass. Matos et al. (2015) recommended the use of decomposed biomass of buriti as a substrate for yellow passion fruit seedling formation.

This study may aid in the rational utilization of these organic compounds in family farming in the Amazon and pre-Amazon region by assisting technicians and seedlings in making informed decisions about the acquisition, utilization, and effectiveness of these inputs. However, further studies should be conducted to test the associations of decomposed biomass from native palms with the soil and other organic sources (e.g., manure and peat, among others), as well as mineral fertilizers or inert inputs, to ensure the incorporation of more technical information about these alternative substrates.

Conclusions

1. Decomposed palm tree biomass in the transition zone between the Amazon-Cerrado biomes has the potential to be used as a substrate input for the formation of seedlings.

2. The decomposed biomass of babassu and carnauba palm stems has greater potential to meet the conditions for being commercialized.

3. Multivariate analysis proved to be efficient for analysing the physicochemical characteristics related to the quality of alternatives substrates.

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