

Analysis of the use of buriti and wood waste in the production of multilayer panels

Análise do uso dos resíduos de buriti e madeira na produção de painéis multicamadas

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Abstract

Agro-industrial residues are generated in large quantities and have the potential to be repurposed for the development of materials. Currently, there are few studies on the use of residues from the oil extraction process of buriti (*Mauritia flexuosa*) in the development of sustainable panels. Therefore, this study aimed to evaluate and characterize the addition of buriti residue in panels produced with wood and polyurethane resin. The buriti residue has a high extractive content (72%), while the wood residue has an extractive content of 10.14%. Multilayer panels with the addition of buriti residue showed a reduction in the Modulus of Rupture (MOR) value (2.17 MPa) compared to wood panels (9.11 MPa). Despite the reduction in mechanical properties, the panels exhibited low thickness swelling (~5%), demonstrating their potential for use in non-structural humid conditions, interior design, or furniture for outdoor areas.

Keywords: Agroindustrial residue. *Mauritia flexuosa*. Medium density panels. Sustainability.

Resumo

Os resíduos agroindustriais são gerados em grandes quantidades e têm potencial para serem reaproveitados no desenvolvimento de materiais. Atualmente, há poucos estudos sobre a utilização de resíduos do processo de extração do óleo de buriti (*Mauritia flexuosa*) no desenvolvimento de painéis sustentáveis. Portanto, este estudo teve como objetivo avaliar e caracterizar a adição de resíduo de buriti em painéis produzidos com madeira e resina poliuretânica. O resíduo de buriti possui alto teor extrativo (72%), enquanto o resíduo de madeira possui teor extrativo de 10,14%. Painéis multicamadas com adição de resíduo de buriti apresentaram valor do Módulo Estático de Ruptura (MOR) diminuiu com a adição do resíduo de buriti (2,17 MPa), em comparação aos painéis de madeira (9,11 MPa). Apesar da redução nas propriedades mecânicas, os painéis apresentaram um baixo valor de inchamento em espessura (~5%), o que demonstra o seu potencial para utilização em condições úmidas não estruturais, design de interiores ou mobiliário para áreas externas.

Palavras-chave: Resíduo agroindustrial. *Mauritia flexuosa*. Pannel de média densidade. Sustentabilidade.

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Introduction

In the Amazon region, there is a large amount of wood and non-wood waste, which are economical and sustainable alternatives to produce multilayer panels. In relation to wood waste, it is estimated that the total volume of waste per log is approximately 60 % (Numazawa *et al.*, 2017). This large amount of waste has shown promise in terms of application in the development of new materials with sustainable characteristics (Santos *et al.*, 2023).

On the other hand, among the non-timber wastes from the agro-industrial sector, we can mention the wastes generated in the extraction of buriti oil. According to IBGE (2024), 407 tons of buriti were produced in 2023. In the buriti oil extraction industry, around 8,500 tons of agro-industrial waste are produced per year (Resende; Franca; Oliveira, 2019), consisting of bark, endocarp, mesocarp and seed. However, it still has a certain percentage of oil, usually this waste is used in the animal food industry (Barboza *et al.*, 2022).

Buriti oil has several applications, including the pharmaceutical and food industries (Barboza *et al.*, 2022; Koolen *et al.*, 2018). In addition, it is reported in the literature that buriti oil has potential use in polymeric packaging, as it has antioxidant and antimicrobial capacity, as well as reduced permeability to water vapor, showing promise in the development of biodegradable active packaging (Anjos *et al.*, 2023). Among the few studies involving buriti waste, it stands out that buriti waste was used as raw material for bioenergy production and showed a 38% reduction in gaseous emissions when compared to coal (Silva *et al.*, 2023).

On the other hand, these wastes have the potential to be used in the development of sustainable panels, mainly of the MDP (Medium density particleboard) type, with characteristics similar to those already available on the market, paying attention to the sustainable nature, adding value to these wastes and being alternative sources in relation to virgin wood (Baharuddin *et al.*, 2023).

Currently, there is a lot of research involving the development of sustainable panels reinforced from agro-industrial lignocellulosic waste, such as curauá fiber, jute, sugar cane bagasse, coconut, piassava (Fiorelli *et al.*, 2018; Rabelo Aparício *et al.*, 2024) which have satisfactory properties that meet regulatory requirements for certain applications. Sustainable panels can be of the multilayer type, this type of panel is made up of 3 layers or more, with the aim of acquiring physical-mechanical properties that are superior to single-layer panels. The most common configuration contains two outer faces and an inner core between them. The panels can be produced from particles or fibers of lignocellulosic or synthetic origin, which are generally bonded by a resin or glue, having applications in several areas (Fiorelli *et al.*, 2018; Fiorelli; Bueno; Cabral, 2019).

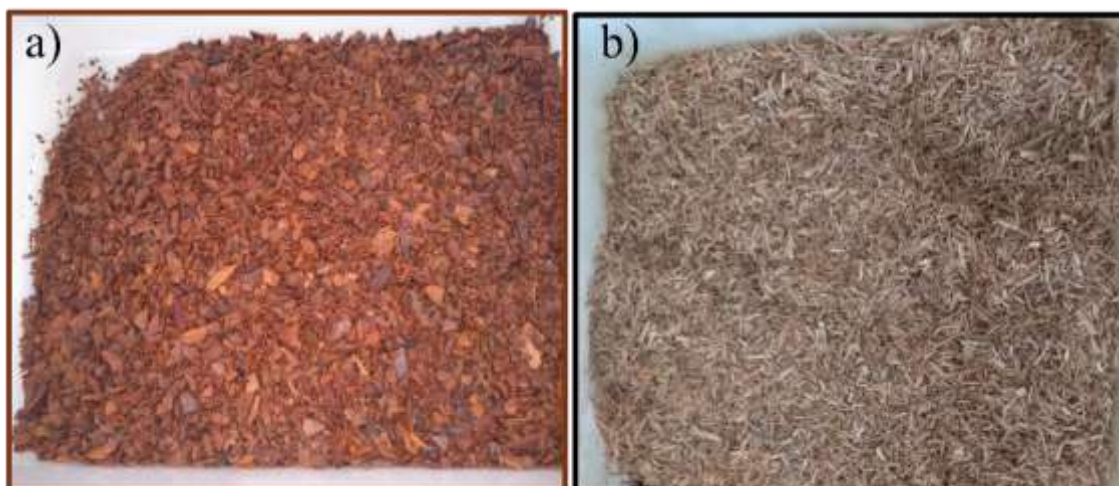
In this context, the use of buriti and wood waste for the development of multilayer panels guarantees the sustainable development of communities that aim to use renewable raw materials to produce new materials through recycling and that have biodegradable characteristics, minimizing environmental impacts, reducing the amount of waste that does not have adequate disposal (Baharuddin *et al.*, 2023). To add value and provide alternatives for buriti waste applications, the main objective of this research was to analyze the addition of buriti waste in the production of multilayer panels with wood waste.

Materials and methods

Materials

The buriti (Figure 1a) and wood wastes (Figure 1b) were used without any type of treatment, both residues were not ground, but sieved, in order to keep the process as simplified as possible so that it would be feasible to reproduce it in local communities in Amazonas. The waste from the extraction of buriti oil, after being mechanically processed to remove the oil, was donated by the Association of Agroextractive Workers of Eirunepé. The wood waste was supplied by the company Mil Madeireira Preciosas Ltda. The wood waste supplied does not have a specific species, it is a mixture of unidentified species, aiming to better reuse this waste. The polyurethane resin based on castor oil (bi-component) was donated by Plural Indústria e Comercio de Produtos Químicos Ltda, located in São Carlos. It consists of the following components: polyol, a vegetable product derived from castor oil and prepolymer, from the mixture of isocyanate, from a petroleum source, and castor bean polyol.

Figure 1- Buriti (a) and wood (b) waste



Methods

Three types of sandwich panels were produced, varying the concentration of wood and buriti waste: Homogeneous buriti, homogeneous wood and hybrid wood and buriti. It was necessary to measure the moisture content of each material, as this water retained in the lignocellulosic reinforcement can affect the mechanical and physical properties of polyurethane composites. Therefore, it was crucial to quantify and control humidity to ensure adequate production of the panels. The Moisture Content Test was performed in the Ohaus Moisture Halogen Analyzer, used in automatic mode at 105 °C. The particle size distribution was performed using a set of sieves 4,16, 20,28, 48 and 80 Tyler.

The chemical composition of the lignocellulosic material directly affects the adhesion with the polyurethane matrix, therefore, it is crucial to quantify these elements to understand the adhesion mechanisms of the composite produced. It chemically characterized the buriti and wood waste through the extractive content by means of TAPPI 204 cm-97 in triplicate (TAPPI, 2004), with adaptation of the use of ethanol-toluene solution 1:2 (v/v). Cellulose content was carried out in triplicate according to Leão (2008). Ash content was performed according to the TAPPI T211 standard (TAPPI, 2002). Fourier transform infrared spectroscopy (FTIR) was performed using a Shimadzu IRAffinity-1 spectrophotometer, in transmittance mode, using KBr (Potassium Bromide) pellets produced by pressing.

The thermogravimetry analysis (TGA) on lignocellulosic materials aims to analyze the composition and thermal stability of these materials. Furthermore, this information is important to understand the thermal degradation of the reinforcement and ensure the effective manufacture of these composites by thermopressing. The TGA was performed on the SDT Q 600 equipment from TA Instruments. The experiment used a 10 mg sample in a 90 µL alumina crucible, without a lid. With a temperature ramp of 10 °C/min to 700 °C, under a flow rate of 30 ml/min. Nitrogen 5.0.

Scanning electron microscopy (SEM) was used to observe the surface of lignocellulosic materials, including roughness and texture. This information was important to understand how surface properties affect adhesion, interaction with other materials and their mechanical and physical performance. The morphology of buriti and wood wastes was performed using an Scanning Electron Microscope (SEM) of the brand ORFORD INSTRUMENTS X-ACT, PentafET precision, model: 51-ADD0007, resolution of 5.9 keV.

The three types of panels were produced with three layers according to Fiorelli *et al.* (2019) methodology with adaptations. The first called Homogeneous wood, in which the inner and outer layer were made using wood waste, the second called buriti homogeneous produced with inner and outer layer with buriti waste, and finally the hybrid panel, which consists of the wood in the inner layer and outer layers with buriti waste, as illustrated in Figure 2. The thickness of the inner layer has been designed with 0.8 cm thickness and possessing particles with the dimensions between 4.75 ~ 1.18 mm and 20% polyurethane resin in the 1:1 ratio. While the outer layer was reinforced with 18% polyurethane resin in a 1:1 ratio and has particles with a diameter of 1.18–0.30 mm and a thickness of 0.4 cm and a target density of 750 kg/m³. To form the three layers in the multilayer panels, the layers were added successively in a mold with a dimension of 40 x 40 x 1.6 cm, then the mattress formed by overlapping layers was transferred to the thermo-hydraulic press, where

the pressure was controlled at 5 MPa and temperature of 100 °C for 20 min. Afterwards, it was removed from the press, and the panels were stored in an airy place for 72 h, in order to provide total cross-linking of the resin.

Aiming to verify whether panels produced from waste from the Amazon region have the potential to be used as input to produce medium density panels, the Brazilian standard NBR 14810 (ABNT, 2018) was used for the physical and mechanical characterization of the specimens. The tests were performed through thickness swelling, density and 3-point flexion, using 10 specimens in each test. The difference between the means was verified using the Tukey test, using the Excel 2016 data analysis tool. The surface of the hybrid buriti and wood specimen was verified using the Scanning Electron Microscope (SEM) of the brand ORFORD INSTRUMENTS X-ACT, *PentalFET precision*, model: 51-ADD0007, resolution: 5.9 keV.

Results and discussions

Characterization of waste

Buriti and wood wastes had moisture content of 5.16% and 28.15%, respectively. A high moisture content in the reinforcement can cause voids in the polymer matrix due to the evaporation of gases during processing, resulting in losses of mechanical Properties (Barbosa *et al.*, 2019; Fiorelli; Bueno; Cabral, 2019; Maloney, 1996). On the other hand, an excessively low moisture content can lead to anisotropic properties in the panel, due to the reduction in heat transfer between the reinforcement and the matrix (Barbosa *et al.*, 2019; Fiorelli *et al.*, 2019; Maloney, 1996). The buriti waste showed three predominant granulometries, represented by Tyler 4 (22.45%), Tyler 16 (20.16%) and Tyler 48 (28.7%). While in the Tyler sieve 20 (7.56%), 28 (10.26%) and 80 (10.85%) a smaller amount of particles was retained. Only 22.45% of buriti waste was not reused, as it was retained in the 4 tyler sieve due to the particle size adopted in this methodology to produce the panels. Particle size is one of the factors that can influence the properties of panels. This distribution of particles with different grain sizes of the buriti waste provides a reduction of voids, as the smaller particles fill the voids between the larger particles, implying better compaction (Barbosa *et al.*, 2019).

Table 1 shows the extractives, cellulose, and ash contents of buriti and wood wastes.

Figure 2- Multilayer Panels

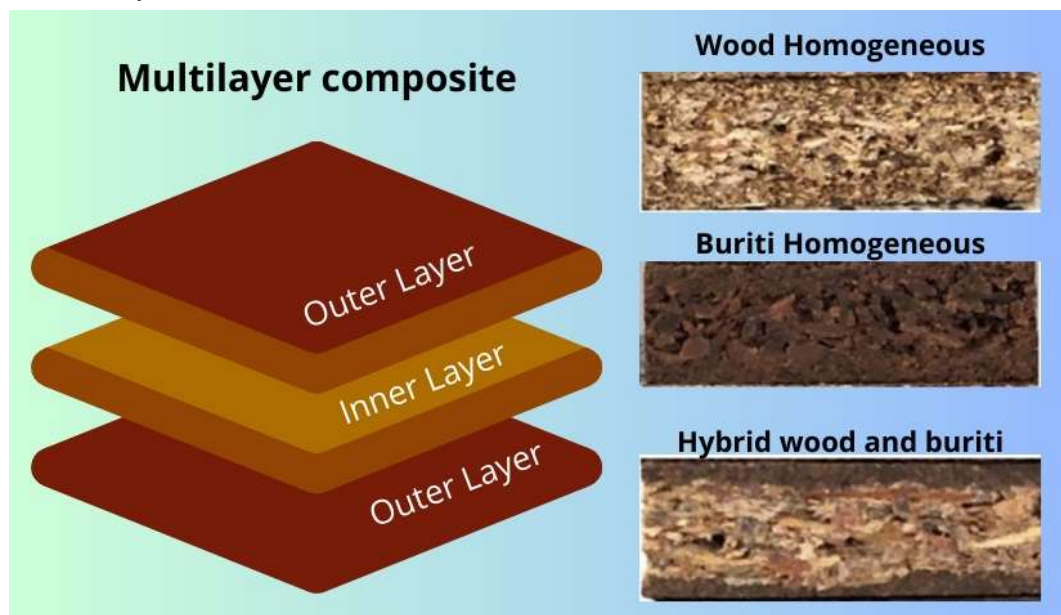


Table 1- Chemical characterization

Type of waste	Extractive [%]	Cellulose [%]	Ashes [%]
Buriti	72.49 ± 0.69	23.26 ± 2.03	3.57 ± 0.43
Wood	10.14 ± 0.17	49.55 ± 0.04	1.17 ± 0.03

The buriti waste has an extractive content of 72.49%, significantly higher than comparable lignocellulosic materials, such as açai seed ($16.64 \pm 0.73\%$) (Barbosa *et al.*, 2019), sugarcane fiber (6.7%), curauá (9.5%), and jute (3%) (Fiorelli *et al.*, 2018). This high content is attributed to the presence of residual oil impregnated in the particles during the process of extracting the oil from the fruit. There are studies that investigate the use of extractives as adhesives and natural preservatives in wood panels, focusing on the tannins present in the bark of some species (Nemli; Kirci; Temiz, 2004; Nemli *et al.*, 2006; Hashim *et al.*, 2009).

In addition, extractives are used to increase the durability of lignocellulosic panels because they favor the presence of agents that prevent the proliferation of fungi and bacteria, being related to lignin-free phenolic groups (Nemli; Kirci; Temiz, 2004; Nemli *et al.*, 2006; Hashim *et al.*, 2009). The impregnation of tung oil on the surface of panels made from rice husk and soybean resin reduced the moisture content, swelling and absorption of the panels, in addition to meeting the requirements of the ANSI A208.1 standard (Chalapud *et al.*, 2020). The extractives of *Cerbera odollam* showed activity against fungi and did not affect the physical and mechanical properties of panels produced from sawdust (Hashim *et al.*, 2009). Thus, the significant extractive content found in buriti waste, at the same time, positively impact the physical properties of the panels produced, even if it can adversely influence their mechanical properties.

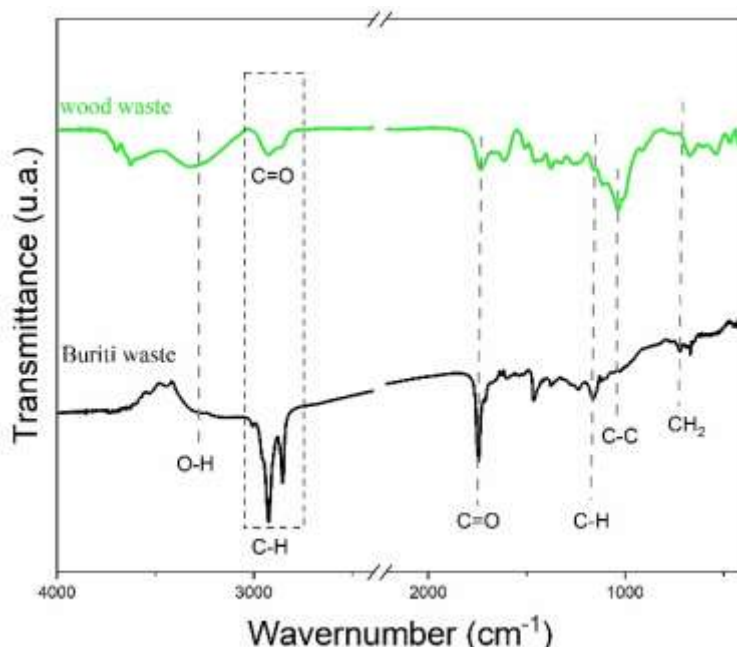
The wood waste had a cellulose content of 49%, while the buriti waste had 23%. In wood, cellulose is the main constituent of a natural fiber, it is responsible for strength, rigidity, stability, so the greater the amount of cellulose present, the greater the mechanical properties of these fibers (Kabir *et al.*, 2012). Fiber-reinforced composites with high percentages of cellulose and hemicellulose positively influence the properties of Static Modulus of Rupture (MOR) and modulus of elasticity (MOE) (Fiorelli *et al.*, 2018).

The buriti waste presented 3.57% of ash content, while the wood presented the value of 1.17%, these contents are related to the inorganic wastes after combustion.

Figure 3 shows the FTIR graph of buriti and wood waste.

Figure 3 shows bands that indicate the presence of lignocellulosic components and oils. In the curve of the buriti waste CH_2 banding at 721 cm^{-1} , it is observed the CH_2 banding, present in fatty acids and triglycerides (Albuquerque *et al.*, 2003). However, this band is not observed for the wood, reinforcing that the buriti waste has residual oil, reaffirming its high content of extractives ($72.49 \pm 0.69\%$) reported in the chemical characterization.

Figure 3 - FTIR of buriti waste



The band close to 1045 cm^{-1} referring to the C-C stretching (Oushabi *et al.*, 2017) related to presence of hemicellulose in wood waste (Mwaikambo; Ansell, 2002), which is absent in buriti residue. The band at 1164 cm^{-1} is related to the C-H deformation in the plane with the guaiacyl lignin (Albuquerque *et al.*, 2003), and the presence of oleic acid molecules with glycerol (Yang *et al.*, 2007), this band is more intense for the buriti waste than for the wood waste. The band at 1238 cm^{-1} may be related to the deformation of the aromatic ring present in guaiacyl lignin, associated with the $=\text{C}-\text{O}-\text{C}$ stretch commonly present in phenolic groups (Henrique *et al.*, 2013; Yang *et al.*, 2007), and may be associated with the presence of hemicellulose (Long *et al.*, 2012). At 1377 cm^{-1} there are bands related to the presence of cellulose (Long *et al.*, 2012). At 1600 cm^{-1} is related to the aromatic ring present in the lignin structure (Poletto; Zattera, 2013), this bands are presents in buriti and wood waste, reinforcing that in the compositions of both residues there is the presence of hemicellulose, cellulose and lignin.

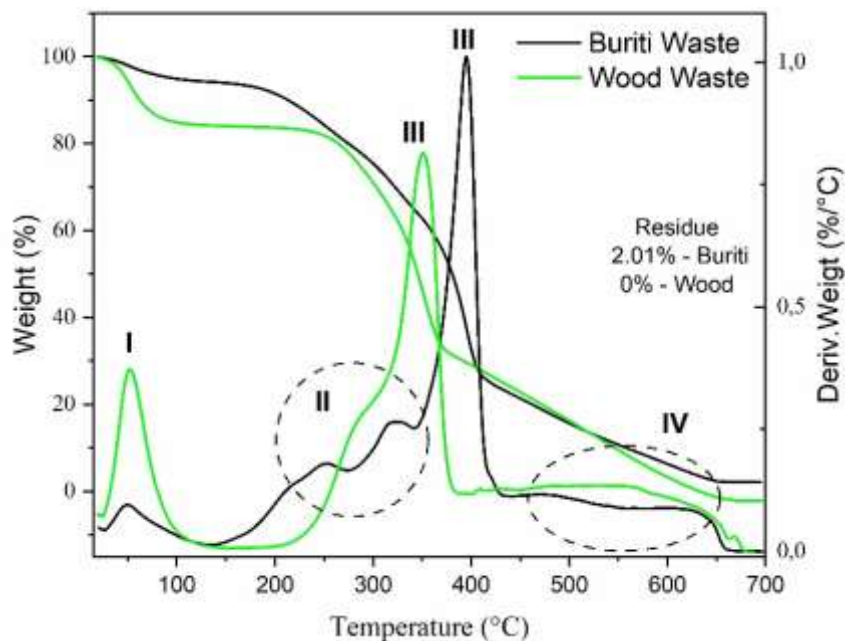
At 1745 cm^{-1} , it may be the presence of hemicellulose present in wood waste and the C=O stretch of the carboxylic group present in the oil, related to methyl esters and triglycerides, to fatty acids in buriti waste (Long *et al.*, 2012). In wood waste, the bands 2852 cm^{-1} and 2924 cm^{-1} may be related to the C-H and C=O stretch present in lignin (Poletto; Zattera, 2013; Wang *et al.*, 2019). In buriti waste, this range is also related to the presence of the fatty acids and triglycerides related to the C-H stretch of the methyl (CH_3) and methylene (CH_2) group (Albuquerque *et al.*, 2003).

At 3007 cm^{-1} there is vibration of $=\text{C}-\text{H}$ present in vegetable oils. In the range surrounding 3007 cm^{-1} may be related to the CH band of the $=\text{C}-\text{H}$ bond, commonly present in vegetable oils (Albuquerque *et al.*, 2003). The band at 3286 cm^{-1} is related to the presence of hydroxyls in both wastes, it is noted that the wood waste presents a higher intensity than the buriti waste, which is related to the hydrophilicity of the wood, as well as the hydrophobicity of the buriti waste that presents residual oil (Silva *et al.*, 2023; Mwaikambo; Ansell, 2002).

Figure 4 shows the results of thermogravimetry, and its respective derivative, of buriti and wood wastes.

The first event ($26 \sim 120^\circ\text{C}$) refers to the loss of moisture, related to the evaporation of water present in the waste. Buriti waste loses less moisture than wood waste, because buriti waste has residual oil, which makes it hydrophobic (Silva *et al.*, 2023).

Figure 4 - TGA/DTG thermal curves of buriti and wood waste



The decomposition of hemicellulose occurs as a second event, between 237 and 304 °C for wood waste and between 143 and 281 °C for buriti waste. The thermal displacement in buriti oil is attributed to the presence of residual oil (Lei *et al.*, 2019; Rego *et al.*, 2019; Yang *et al.*, 2007). Regarding event three, the decomposition of cellulose in the buriti waste was well defined at the peak between temperatures of 281 and 345 °C, while for the wood waste it is not evidenced, suggesting that it occurs in overlap with the lignin peak around 304 °C. The fourth event is related to the breakdown of lignin. Regarding the buriti waste, an event between 439–700 °C is observed, which may be related to the decomposition of inorganic material or residual lignin, occurring between temperatures 405–632 °C in the wood waste (Poletto; Zattera, 2013; Rego *et al.*, 2019; Yang *et al.*, 2007).

The inorganic waste content of buriti (2.13%) is higher than that of wood (0.015%), being in accordance with the ash content previously discussed in the chemical analysis, which is correlated with the presence of inorganic substances, these probably come from the type of soil, climate and environment of origin of the plant or environment in which the wastes were collected (Deboni *et al.*, 2019). The decomposition temperatures of the lignocellulosic components are in accordance with the literature, observed a more accentuated decomposition between 200 and 450 °C, indicating the possibility of using these wastes in processes of temperatures below 200 °C (Rebelo *et al.*, 2019).

Figure 5 shows the surface of the wastes.

The buriti waste (Figure 5a) is composed of granules, with different dimensions. This result agrees with what was observed in the particle size analysis, indicating dimensional variations of the particles (Bispo-Junioret *et al.*, 2018). It is assumed that the surface of the buriti waste has a rough aspect, which may be related to the presence of oil and a high percentage of extractives present, which also influences agglomeration (Bispo-Junioret *et al.*, 2018). There are particles with different sizes are agglomerated, probably due to the presence of oil (Silva *et al.*, 2023). Figure 5b shows the surface of the wood, which presents rough characteristics, the presence of a rough surface in fibers and particles favors a good adhesion between the components present in the panels produced with lignocellulosic material (Barbosa *et al.*, 2019; Mesquita *et al.*, 2018; Rebelo *et al.*, 2019).

Characterization of panels

Table 3 shows the results of the physical analyses.

Figure 5 - SEM of the waste - (a) Buriti waste, 200 µm, SEM MAG: 500x; (b) Wood waste 100 µm, SEM MAG: 833x

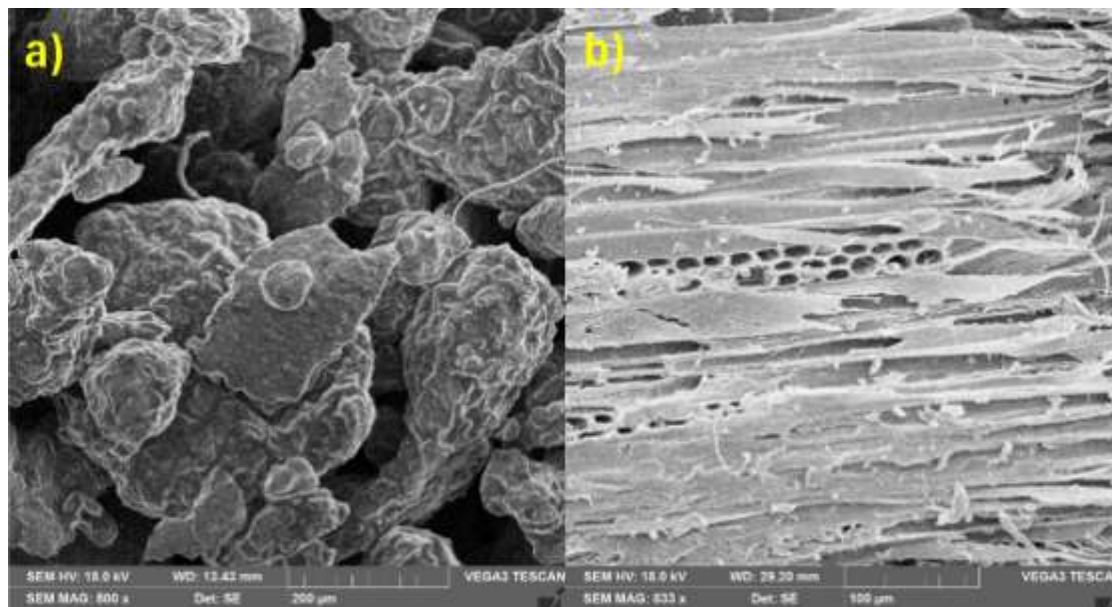


Table 3 -Physical properties of panels developed with buriti waste

Composite	Density [Kg/m ³]	Thickness swelling [%]
Wood	735.60 ± 57.21 ^a	5.09 ± 1.83 ^a
Buriti	788.40 ± 39.48 ^a	3.72 ± 0.81 ^a
Hybrid Wood/Buriti	741.75 ± 34.30 ^a	4.94 ± 1.24 ^a

Note:the letters Means followed by the same letter did not present statistically significant variation for Tukey's test ($p < 0.05$).

The homogeneous composites of wood, buriti and hybrid do not present significant differences between them in terms of density. Both can be classified as medium density panels, as they are within the normative value of NBR 14810 (ABNT, 2018), which dictates that the values must be between 551 and 750 Kg/m³. The composites produced do not present a significant difference in thickness swelling between them, the value obtained was around 5% and is below the maximum value of 22% required by the NBR 14810 standard, being in accordance with the conditions for medium density panels.

The buriti waste contain a high amount of extractives to the particles of the panels results in a loss of mechanical properties but improves physical properties such as reduced of thickness swelling and water absorption (Chalapud *et al.*, 2020; Hashim *et al.*, 2009; Nemli *et al.*, 2006). When applied to the surface of the panel, extractives act as a barrier against the diffusion of water into the interior, due to their hydrophobic and non-polar nature, composed of oils and waxes (Chalapud *et al.*, 2020; Hashim *et al.*, 2009; Nemli *et al.*, 2006).

The low thickness swelling values is a positive factor, which may be related to the hydrophobic characteristics of the polyurethane matrix derived from castor oil, as 20% resin was used in the outer layer and 18% in the inner layer (Sawpan, 2018). The multilayer panels produced in this study showed lower thickness swelling values when compared to the literature, which demonstrates their potential for use in non-structural conditions in humid conditions such as panels used for interior design temporary buildings or furniture for outdoor areas (Farak *et al.*, 2020).

Monolayer panels produced with raw material from olive oil extraction and 20% polyester resin, presented 18% of thickness swelling, although this waste has common characteristics with buriti waste, in terms of both coming from the oil extraction process, he observed that there was no significant reduction in thickness swelling, suggesting that the effect is more related to the type of resin adopted in this research, due to the intrinsic hydrophobic characteristics of the polyurethane resin derived from castor oil (Farak *et al.*, 2020).

Multilayer panels produced with medium density sugarcane bagasse (outer layer) and coconut fiber (inner) showed a thickness swelling of 23%, which was associated with the presence of pores on the surface of the fibers, which facilitated the diffusion of water through capillarity (Fiorelli; Bueno; Cabral, 2019). Therefore, it was observed that there was no significant difference in the thickness swelling properties when using wood or buriti waste, even though the latter presented a high extractive content, but when compared with the literature it suggests that the low thickness swelling of the composites produced may be related to the high percentage of resin used in the outer (20%) and inner (18%) layers.

Table 4 shows the results of MOR (Static Modulus of Rupture) and MOE (Modulus of Elasticity), statistically significant difference was observed between panels.

Analyzing the MOR values in Table 4, it was observed that the homogeneous wood panel (9.11 MPa) differs from the homogeneous buriti panel (0.44 MPa) and hybrid panel (2.17 MPa), ditto for the MOE values of the homogeneous wood panel (1157.26 MPa), buriti (41.94 MPa) and hybrid (217.28 MPa). The presence of wood in the hybrid panel increased the value of MOR and MOE when compared to the homogeneous buriti panel, but it was not enough to overlap the value of the homogeneous wood panel, indicating that the presence of buriti in the hybrid panel tends to decrease the mechanical properties. In this context, no panel produced met the minimum requirements for MOR regarding the NBR14810 (ABNT, 2018) (11 MPa) and ISO 16893 (ISO, 2016) (11.5 MPa) standards.

In the hybrid panel, the reduction of mechanical properties may be related to the interaction of the reinforcements (wood and buriti), due to the high amount of extractives in the buriti waste, which are composed of wax, oils and greases. These components may be inactivating the surface of the reinforcements, hindering the penetration of the resin in the particles of the outer and inner layer. Since, in the thermopressing process, the oil waste retained in the buriti particles may be migrating to the core of the panel, this causes it to act as a "release agent", consequently favoring the decay of mechanical properties,

due to the low adhesion between reinforcement and matrix (Hashim *et al.*, 2009; Nemli *et al.*, 2006). In addition, there may have been a pre-curing of the reinforcement and matrix in the mattress formation process, due to the presence of the extractives, forming weak bonds that were broken in the thermopressing process, which resulted in a low adhesion between the layers (Nemli *et al.*, 2006).

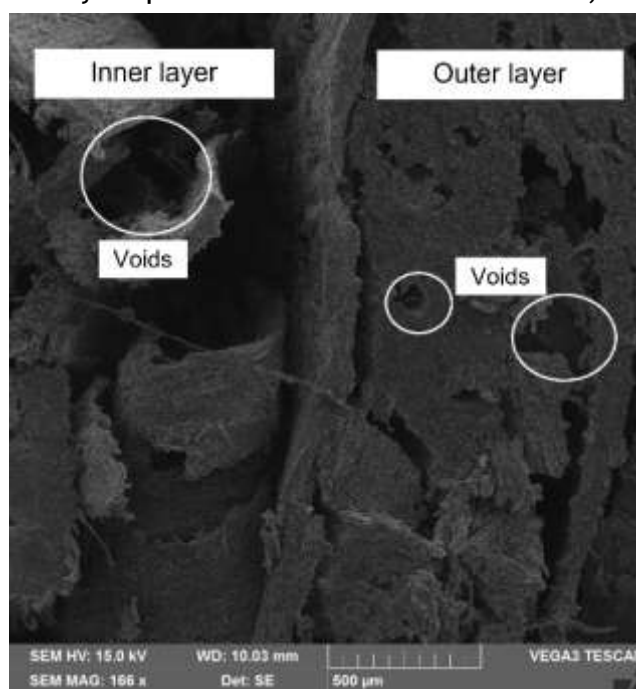
Figure 6 illustrates the Electron Microscopy image of the hybrid composite, in the inner layer the presence of voids and absence of resin is observed, which highlights the low adhesion between reinforcement and matrix, in the outer layer it is observed that the buriti waste and the resin are uniform with each other. However, it was observed the presence of pores in both layers. This factor, associated with the intrinsic characteristics of the buriti waste (high extractive content), resulted in low values of MOR and MOE due to a weak interaction between the resin and the reinforcement, as previously discussed. This may be related to the residual oil diffusing into the innermost layers, triggering weak chemical bonds.

Table 4 -Mechanical properties of panels developed with buriti waste

Multilayer Panels	Static Flexural Strength (MOR) [MPa]	Modulus of elasticity (MOE) [MPa]
Wood	9.11 ± 2.72^a	1157.26 ± 257.76^a
Buriti	0.44 ± 0.17^b	41.94 ± 6.94^b
Hybrid Wood/Buriti	2.17 ± 0.40^c	217.28 ± 26.64^c
NBR 14810 (ABNT, 2018)	11 (minimum)	1800 (minimum)
ISO 16893 (ISO, 2016)	11.5 (minimum)	-

Note: the letters Means followed by the same letter did not present statistically significant variation for Tukey's test ($p < 0.05$).

Figure 6 - Morphology of the hybrid panel obtained from SEM. SEM HV 15 kV, MAG 166x



Conclusions

The waste from the extraction of buriti oil had a moisture content of 5.16%, lower than the wood waste. The high content of extractives ($72.49 \pm 0.69\%$) present in the waste is related to the residual oil intrinsic to the processing of this raw material. The FTIR indicated bonds related to residual oil, lignin, cellulose, and hemicellulose in accordance with the literature. Through thermal degradation it is possible to state that the waste can be used in processes with temperatures below 200 °C. The addition of buriti waste in the multilayer panel layer reduced the static flexural strength and modulus of elasticity, probably due to the high extractive content, implying low adhesion between reinforcement and matrix. On the other hand, the panels produced showed excellent results in terms of thickness swelling, favoring its use in humid environments, which demonstrates their potential for use in non-structural conditions such as panels used for interior design or furniture for outdoor areas. Finally, the investigation of the use of these wastes in medium density panels provides information not yet reported in the literature, contributing to adding alternative uses of buriti waste, adding economic, social and technological value in the Amazon Region. Becoming a pioneer in future studies aimed at the use of these wastes in medium density panels.

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