



Mix Sustentável

Modeling and characterization of modular panels produced with residues from butiá fruits

Modelagem e caracterização de painéis modulares produzidos com resíduos dos frutos de butiá

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Abstract: Butiá trees are native to South America and are recognized for their biodiversity, historical-cultural relevance and landscape importance. The residues of butiá fruits are used handcrafted to decorate recipient and produce decorative objects. The production and characterization of modular panels can be an alternative for new applications of the material. The modeling of the panels was carried out using only fruit waste and water, and the molds were produced in acrylic, using the laser cutting technique. The characterization of the panels was carried out using scanning electron microscopy (SEM) and tests of apparent density, water absorption and swelling in thickness. It was found that the material is easy to model and stands out for not requiring binders, just water. With the help of electron microscopy it was possible to visualize the intertwined fibers, surrounded by the remains of dry pulp, which justifies the adhesion of the panels. The panels have low density (0.173g/cm³) and high water absorption rates, characterizing

ARTIGO ORIGINAL -
SEÇÃO CIENTÍFICA

Editor responsável pelo
artigo: Lisiane Ilha Librelotto, Dr. Eng., Paulo Cesar Machado Ferroli, Dr. Eng.

Recebido em

19/11/2025

Aprovado em

19/01/2026

Publicado em

23/02/2026

PID

10.29183/2447-

3073.MIX2025.v11.n4.220-235



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themselves as hydrophilic. The thickness swelling results were 12.41 % after two hours, with little variation occurring after 22 hours immersed in water.

Keywords: Butiá waste; modular panels; characterization.

Resumo: Os butiazeiros são nativos da América do Sul e são reconhecidos por sua biodiversidade, pela relevância histórico-cultural e pela importância paisagística. Os resíduos dos frutos de butiá são utilizados de forma artesanal para decorar recipientes e produzir objetos decorativos. A produção e a caracterização de painéis modulares pode ser uma alternativa para novas aplicações do material. A modelagem dos painéis foi realizada usando apenas os resíduos dos frutos e água, e os moldes foram produzidos em acrílico, pela técnica de corte a laser. A caracterização dos painéis foi feita através da microscopia eletrônica de varredura (MEV) e dos ensaios de densidade aparente, absorção de água e inchamento em espessura. Constatou-se que o material é de fácil modelagem e se destaca por não necessitar de aglomerantes, apenas água. Com auxílio da microscopia eletrônica foi possível visualizar as fibras entrelaçadas, envoltas pelos resquícios de polpa seca, o que justifica a aderência dos painéis. Os painéis possuem baixa densidade ($0,173\text{g/cm}^3$) e altos índices de absorção de água, caracterizando-se como hidrofílicos. Os resultados do inchamento em espessura foram de 12,41% após duas horas, ocorrendo pouca variação depois de 22h imersos na água.

Palavras chave: Resíduos de butiá, painéis modulares, caracterização.

Resumen: Los butiazeiros son nativos de América del Sur y son reconocidos por su biodiversidad, su relevancia histórico-cultural y su importancia paisajística. Los residuos de los frutos de butiá se utilizan de forma artesanal para decorar recipientes y producir objetos decorativos. La producción y caracterización de paneles modulares puede ser una alternativa para nuevas aplicaciones del material. El modelado de los paneles se realizó utilizando únicamente los residuos de los frutos y agua, y los moldes fueron producidos en acrílico mediante la técnica de corte láser. La caracterización de los paneles se llevó a cabo a través de microscopía electrónica de barrido (MEB) y de los ensayos de densidad aparente, absorción de agua e hinchamiento en espesor. Se constató que el material es de fácil modelado y se destaca por no requerir aglutinantes, sino solamente agua. Con la ayuda de la microscopía electrónica fue posible visualizar las fibras entrelazadas, envueltas por restos de pulpa seca, lo que justifica la adherencia de los paneles. Los paneles presentan baja densidad ($0,173\text{ g/cm}^3$) y altos índices de absorción de agua, caracterizándose como hidrofílicos. Los resultados del hinchamiento en espesor fueron de 12,41 % después de dos horas, con poca variación tras 22 horas de inmersión en agua.

Palabras clave: Residuos de butiá, paneles modulares, caracterización.

Como citar: JOBIM, Silvie Janis Mossate; NEJELISKI, Danieli Maehler; DUARTE, Lauren da Cunha. . **Mix Sustentável**, Florianópolis, v. 11, n. 4, p. 220-235, 2026. DOI: <https://doi.org/10.29183/2447-3073.MIX2025.v11.n4220-235>.

Contribuição dos autores segundo a Taxonomia CRediT

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Conflito de interesses

Nothing to declare.

Fonte de financiamento This study was supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq - Bra- zil) and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES – Brazil).

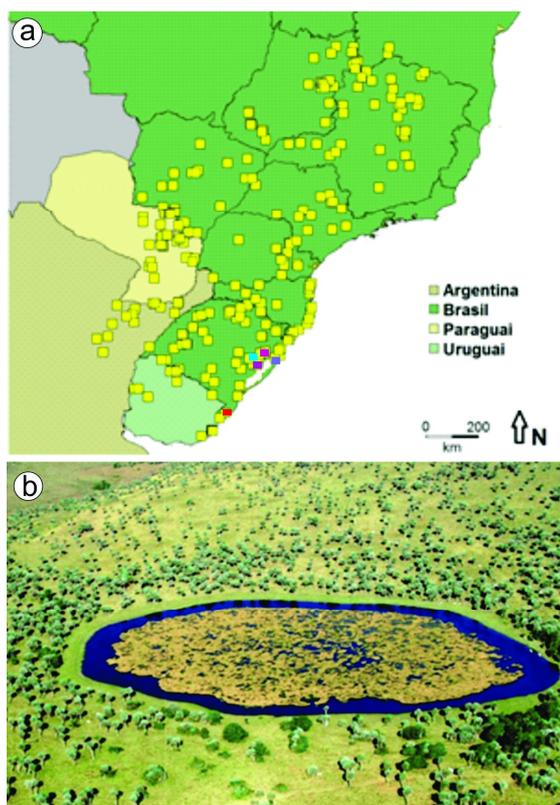
1 INTRODUÇÃO

Palm trees of the genus (*Butia (Becc.) Becc. (Arecaceae)*), native to South America, are recognized for their high landscape, biodiversity and historical-cultural value. Several species have economic and ornamental value, besides providing humans with food, fiber and oils. The genus brings together 20 native species distributed throughout Brazil, Uruguay, Argentina and Paraguay, in the Pampa, Atlantic Forest and Cerrado Biomes, with the greatest diversity of species in the genus found in Brazil (Lorenzi, et al, 1996; Rivas; Barbieri, 2014).

In Brazil, there were extensive butiazais in areas close to the coast of Rio Grande do Sul. However, from the 1970s onwards, there was a great deal of devastation in order to establish monocultures and expand urban areas. Due to monocultures, extensive livestock farming and real estate speculation, a large part of natural cultivation of butiá have been reduced and face the risk of extinction (Rivas; Barbieri, 2014).

Butiá trees stand out for forming communities called butiazais or palm trees (Barbieri, 2015), composed of concentrations of butiá trees that can reach 600 palm trees per hectare in some locations (Figure 1).

Figura 1 – a) Geographic distribution of the Butiá genus in South America; b) Aerial view of the butiazal in Tapes, Rio Grande do Sul, Brazil.



Source: a) Eslabão, M. P. et al. 2016; b) Barbieri, 2015.

Currently, the largest butiazais are concentrated in the department of Rocha (southeast of Uruguay) and in the municipalities of Tapes, Barra do Ribeiro, Palmares do Sul, Barão do Triunfo and Santa Vitória do Palmar, Rio Grande do Sul, Brazil (Silva, 2009).

Butiá trees (Figure 2a) produce clusters of fruits (Figure 2b) that are sweet and slightly acidic. The commercialization of these fresh fruits and various derivatives represents a source of resources for the inhabitants of the Castillos area, in Rocha (Uruguay), and Santa Vitória do Palmar (Brazil). The highlights are liqueur, jelly, sweet and sour sauce, syrup for desserts and ice cream, juice, vinegar, chocolates, pulp for ice cream and baked goods.

Figura 2 – a) Butiá tree; b) Cluster of Butiá; c,d,e) Delicacies made with butiá fruits (mustard, jelly and liqueur).



Source: Dutra et al., 2021.

For preparing food, the first step is the pulping process, carried out with the aid of the pulper (Figure 3a). The machine separates the fruit pulp (Figure 3c) from the waste (Figure 3d), which are fibers, peels and pits. The waste still goes through another stage, where the fruit pits are separated from the fibers and peels for different uses.

Jobim and Duarte (2021) carried out research on the possibilities for using butiá fruit waste (fibers and peels) in a sustainable way. They found that the residues are used in the production of handicrafts, in the composition of butiá flour, which is manufactured with dehydrated fiber and incorporated into biscuit recipes and also in composts to be applied as fertilizers.

Based on research into empirical applications of butiá waste, Jobim and Duarte (2021) proposed the production of egg packaging using the raw material. The packages were produced through artisanal modeling of waste and natural drying. The resulting product is biodegradable and can be replicated by hand.

According to Matos (2014), the processing of agro-industrial activities such as the processing of fibers, foods, among others, are related to the generation of products and result in the production of waste. The use of this waste is an opportunity to develop by-products with added value and sustainable use (Costa Filho et al, 2017).

In this context, the research aims to develop modular panels made from butiá waste, more specifically the fibers and fruit peels. The waste used comes from the processing of butiá trees fruits from agro-industries.

Figura 3 – a) Pulp machine used in the process; b) Butiá fruits; c) Butiá pulp; d) Waste from butiá fruits.



Source: Venturin; Meireles, 2014.

The panels were characterized by scanning electron microscopy (SEM) and density, water absorption and thickness swelling tests.

2 MATERIALS AND METHODS

The residues of butiá fruits used to model the panels were supplied by an agroindustry located in Gravataí, metropolitan region of Porto Alegre, RS, Brazil.

2.1 Modular panel modeling methods

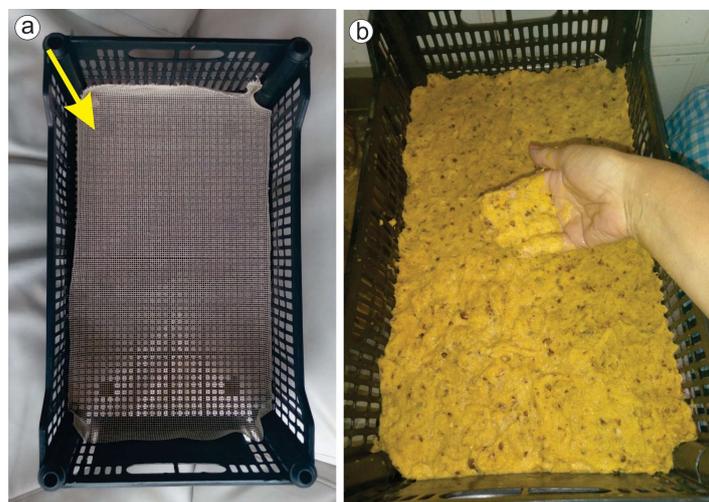
To analyze the agglutination behavior of the fibers, the modeling and the texture of the panels, two modeling tests were carried out: the first using plastic boxes to transport fruits, and the second using molds produced in acrylic.

To prepare the waste in the first test, a Britânia turbo 900w blender, a 30cm graduated ruler and drinking water were used. The waste was processed with the aid of a blender, until a homogeneous paste was obtained.

The bottom of the plastic box was lined with etamine fabric (Figure 4a), aiming to make the surface of the box more homogeneous. Next, the paste produced with waste and water was distributed at the bottom of

the plastic box, over the fabric (Figure 4b), using the ruler to maintain the same thickness throughout.

Figura 4 – a) Bottles decorated with butiá fiber; b) notebook cover made with butiá fiber; c) Butiá fiber pot.



Source: Adapted from Jobim and Duarte, 2021.

After this process, the boxes were exposed to solar radiation for two consecutive days, for 4 hours in the morning, remaining outdoors until approximately 5 pm. The water accumulated at the bottom of the boxes and it was necessary to remove the panels from inside the molds to optimize the drying process. Afterwards, the panels remained drying in the open air for another 15 days, outside the boxes, until they were completely dry. The panels were produced between January and February 2022, and the ambient temperature varied between 20° - 36° C.

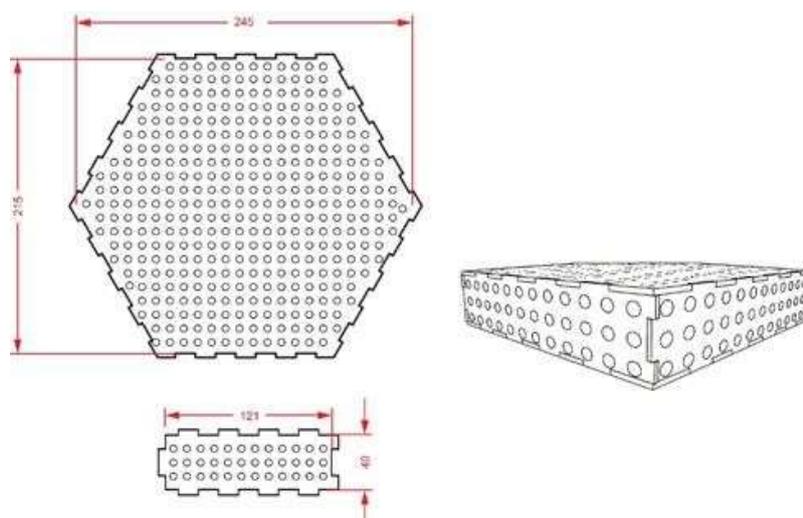
During the modeling of the panels with plastic boxes, some negative aspects were observed in the process. The rectangular shape and dimensions of the boxes were not suitable for production, resulting in large and unstable panels, as well as the large amount of raw material required to produce a panel. Another negative factor were the protrusions along the structure of the boxes, which ended up creating an irregular texture on the surfaces, especially on the sides.

Aiming to improve the conditions of the first test, hollow hexagonal molds were produced for the second test (245mm x 215mm with x 40mm thickness) made of 3mm thick acrylic (Figure 5) with the aid of a laser cutting machine 1000x600 - MC1060, at the Innovation and Digital Manufacturing Laboratory of the School of Engineering (LIFEELAB) at the Federal University of Rio Grande do Sul (UFRGS).

In the second test, two different procedures were used to prepare butiá waste. In the first, the fibers from butiá residues were only hydrated with drinking water, without undergoing further processing, and were called PRUB – panels with residues from unprocessed butiá fruits. In the second process, the fibers were processed in a blender with drinking water to obtain a more homogeneous material, and were called PRB – panels with residues from processed butiá fruits.

Around 1 kg of waste was used to model the panels (weighed before being diluted). Next, the hexagonal molds were filled with small amounts of waste until they were completely covered. After being filled, the molds

Figura 5 – Technical drawing of the molds.



Source: Authors, 2026.

were weighed on a digital scale, weighing approximately 1.5 kg.

For the drying process, the molds were placed on a smooth, hollow surface in order to drain the water, leaving them exposed to solar radiation in the morning for approximately 3 hours (Figure 6). Every hour the panels were rotated so that the water did not accumulate or create mold. Even without the sun, they remained outdoors until approximately 5pm (Figure 6).

After three days, the panels were removed from the molds to strengthen the drying process and remained in the open air for another 15 days until they were completely dry. This process was carried out between the months of February and March 2022, and the ambient temperature varied between 20° and 38° C.

Drying time (days) is variable, as the more heat and sun received by the panels, the faster the drying process occurs. After drying, the panels were sized and weighed again. There were produced 10 panels from hexagonal molds to analyze the manufacturing process and material behavior.

2.2 Methods for characterizing modular panels

Scanning electron microscopy was carried out at the Materials Design and Selection Laboratory – LDSM, at the Federal University of Rio Grande do Sul (UFRGS), using a bench-top Scanning Electron Microscope (SEM), Hitachi brand, model TM3000, which enables analysis microscopic images using back-scattered electrons (BSE), with magnification of up to 30,000 times, with beams of 5 and 15 keV.

For the tests to determine the apparent density of the panels, PRUB were used and carried out based on ABNT NBR 15316-2 Wooden Structures Project, with some necessary adaptations depending on the peculiarities of the material. To prepare the specimens, a Model Verry Omega square machine was used. Five specimens of the material were removed, measuring 50 mm wide, 50 mm high and 30 mm thick, on average.

Figura 6 – Panel drying process.



Source: Authors, 2026.

The specimens were stabilized in a climatic chamber until reaching equilibrium humidity, under conditions of (65 ± 5) % relative humidity and temperature of (20 ± 3) °C.

A caliper was used to measure the sample, and a scale was used to weight it with a minimum resolution of 0.1g. The tests were carried out at the Wood Engineering Laboratory - LAPAM at UFPel.

For the water absorption and swelling test, samples of the PRUB panels and the specimens resulting from the density test were used. As a reference for carrying out the tests, the Brazilian MDF standard, ABNT NBR 15316:2015, was used. It consisted of measuring the increase in mass (in water) that the specimens of the material present, after being immersed in water at 20 ± 1 °C. They were weighed before being immersed in water and after 2 hours they were weighed again. The expression of the results follows the calculation, according to equation 1:

$$A = \frac{M1 - M0}{100} \times 100 \quad (1)$$

Where:

A = moisture content of the specimen expressed (%);

M1 = wet mass of the specimen, expressed in grams (g);

M0 = dry mass of the specimen expressed in grams (g).

The swelling test is similar to the absorption test, the specimens were weighed before being immersed in water, after 2 hours a new weighing was done and after 22 hours a new weighing was done concluding 24 hours of testing. The expression of the results follows the calculation, according to equation 2:

$$I = \frac{E1 - E0}{E0} \times 100 \quad (2)$$

Where:

I – is the swelling in thickness of the specimen (%);

E1- is the thickness of the test piece after the immersion period considered in millimeters (mm);

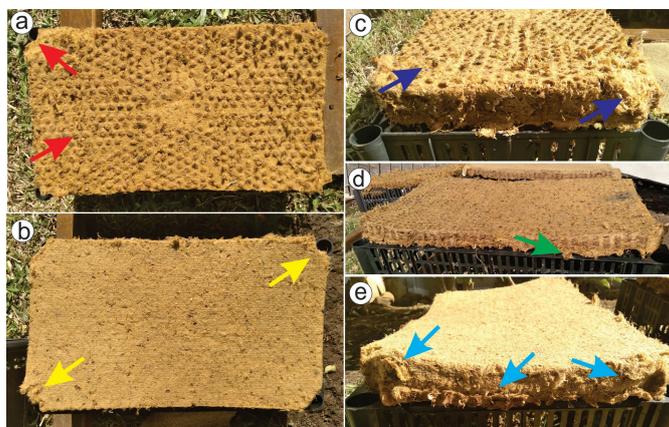
E0 - is the thickness of the test piece before immersion in millimeters (mm).

3 RESULTS AND DISCUSSION

3.1 Modeling of modular panels

Regarding the first panel production test where plastic boxes were used as molds, the result was unsatisfactory (Figure 7). The panels showed irregularities in the surface finishing (Figure 7 a,b) and thickness (Figure 7 c,d,e). However, the paste produced with butiá residues and water proved to be easy to handle and suitable for modeling.

Figura 7 – Panels produced with plastic boxes after the drying process.



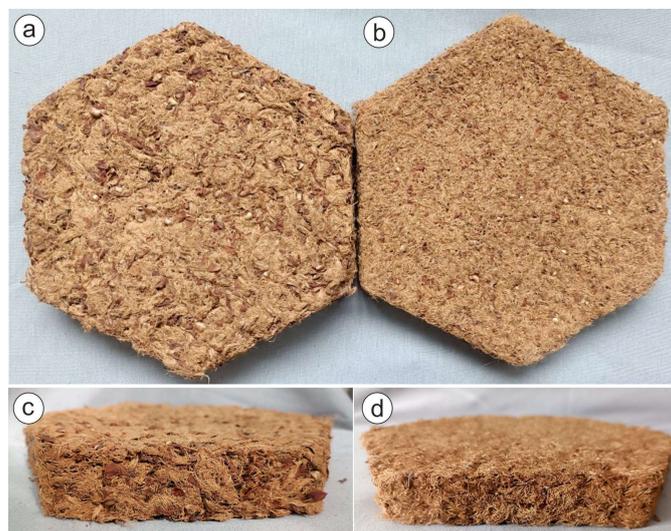
Source: Authors, 2026.

The panels produced in the second test, with hexagonal molds, presented satisfactory results. After the drying process, the panels were sized and weighed again and it was possible to observe a decrease in volume, both in thickness and width, due to water evaporation. The panels showed a reduction of approximately 20 mm in width, while the reduction in thickness varied.

After the drying process, the PRB panels showed variations of approximately 2 mm in thickness, reaching between 26 mm and 28 mm in the same piece. In the PRUB panels, although the same amount of waste was used, they showed variations of 4 mm in thickness, ranging from 28mm to 32mm (Figure 8c, d). This reduction corresponds to approximately 10 mm decrease in initial thickness.

The variation in thickness can be attributed to the dimensions and processing of the waste (whether processed or not) and the way in which the material is deposited in the molds, since, despite the attempt to maintain the standard in production, it is a handcrafted process.

Figura 8 – Textures of PRUB and PRB panels.



Source: Authors, 2026.

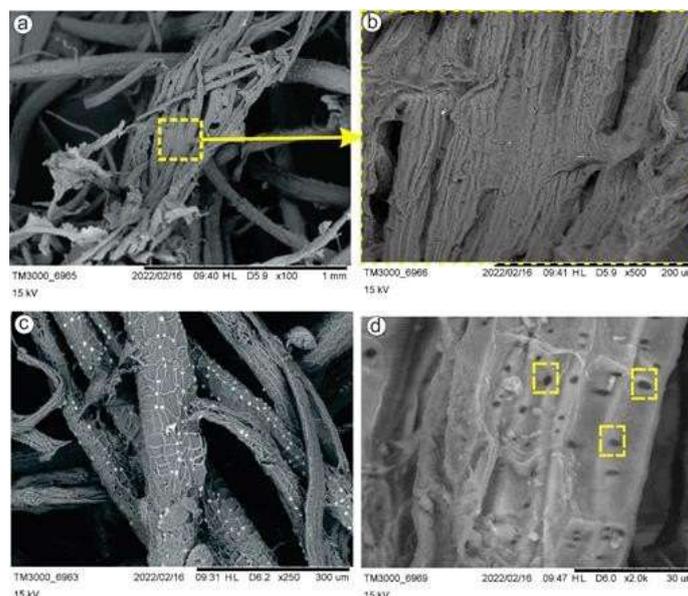
The surface finishing results were different in the panels with unprocessed waste compared to those produced with processed waste. The PRUB panels have a rustic appearance due to the fibers and fruit peels that did not fall apart in the process of obtaining the pulp, creating organic figures that highlight the random weaves of the fibers (Figure 8 a,c). On the other hand, the appearance in PRB panels is more homogeneous due to the second processing using the blender (Figure 8 b,d).

3.2 Characterization of modular panels

The characterization of the panels with the aid of scanning electron microscopy aimed to analyze how the fibers adhere at the microscopic level. The morphology of the dried residues of butiá fruits can be seen in Figure 9 (a, b) where we can observe the intertwined dry fibers, surrounded by the remains of dry pulp that also help in adhering the material. Small multifaceted crystals are also observed (Figure 9 c, d), consisting of silica, which make up a stegmate - characteristic cells that surround the surface of the conductive beams and present ergastic substances consisting of druse-type crystals, with a chemical composition of silica.

These same crystals were also identified in the characterization of tururi (*Manicaria saccifera*) fibers (Oliveira, 2010) and in the fibers of Palmeira Leque (*Livistona chinensis*), where with the aid of EDS (Energy Dispersive System) it was possible to identify silica not only in the form of a stegmate, but also embedded in the cell walls (Jobim, 2018). According to Costa et al. (2006), these elements serve as protection against insect attacks.

Figura 9 – Electron microscopy of butiá fruit residues.



Source: Authors, 2026.

Furthermore, in the morphology of the butiá fibers, it is possible to identify communication channels (Figure 9 d, circled in yellow) in the cell walls. This morphological characteristic indicates a hydrophilic material with high levels of water absorption, as is the case with Porongo (*Lagenaria siceraria*) (Nejeliski, 2015).

Regarding the results found for the density of the panels, according to the method adopted to calculate the density, the values obtained are found in Table 1, and indicate that the butiá fruit waste panels have a low density.

Tabela 1 – Values obtained in the density test.

Sample	g/cmS
1	0,146
2	0,198
3	0,179
4	0,188
5	0,168
Average	0,173

Source: Authors, 2026.

The density values found for the panels 0.173 g/cm³ are similar to the density of some polymeric foams, such as PVC (0.09 to 0.130 g/cm³) and PU foam (0.08 to 0.150 g/cm³). When compared to other natural materials from renewable sources, it has a lower density than bamboo (0.8 g/cm³) and cork (0.3 g/cm³), with the density of balsa wood having the most similar values. (0.2 g/cm³). The results found for the water absorption tests (AA) and the thickness swelling tests (IE) are shown in Table 2.

There is no specification of maximum values for water absorption in the standard. It is possible to

observe that the panels showed high levels of water absorption after the first weighing, carried out after two hours of immersion. The results indicate that the panels are hydrophilic and the water absorption process occurs quickly.

Tabela 2 – Values obtained in the water absorption (AA) and thickness swelling (IE) tests of the panels.

Sample	Esp. 2h (g)	IE (%)	AA 2hs	Esp. 24h (g)	IE (%)	AA 24hs
1	33,81	11,36	546,65	34,89	14,92	555,28
2	34,35	11,09	541,74	35,13	13,62	547,40
3	34,55	14,06	576,59	33,58	10,86	563,72
4	33,37	11,57	531,33	33,4	11,67	535,37
5	34,61	13,25	573,51	33,91	10,96	559,24
Average	34,14	12,27	553,96	34,18	12,41	552,20

Source: Authors, 2026.

Regarding swelling in thickness, according to NBR 15316-2, with regard to requirements for non-structural panels for use in dry conditions, it specifies a value of 10% for thicknesses >19 to 30 mm, as a maximum requirement after 24 hours. In the case of PRUB, the value of swelling in thickness after two hours was 12.27%, with little variation occurring after 22 hours and presenting an average of 12.41%. It is worth highlighting that PRUBs do not use resin in their production, only residues from the butiá fruit pulping process and drinking water.

4 CONSIDERAÇÕES FINAIS

This study aimed to produce modular panels with butiá fruit residues and characterize them, in order to direct them to possible applications. Two molds and two different waste processes were used to produce the panels. After modeling and drying, the quality of the surface finishing and the variation in panel thickness were analyzed. The characterization was carried out based on morphology analysis and tests to define density, water absorption capacity and swelling in thickness.

Regarding the panel modeling process, it was found that butiá waste is easy to handle and model and does not require binder, just dilution in drinking water. Regarding the drying of the panels, the greater the solar incidence, the faster the drying process occurs, as it accelerates the evaporation of water. When manufacturing the hexagonal panels, it was possible to estimate the amount of waste needed to produce each panel. It was also observed that after drying, there is a reduction in dimensions, both in thickness and width, due to the evaporation of water. As for the surface finishing, PRB presented a more homogeneous appearance, whereas PRUB had a rustic appearance attributed to the pulping process.

The results of the fiber microstructure images showed that the morphology of the butiá fibers is similar to that of the tururi and fan palm fibers, with small multifaceted crystals, consisted of silica. Communication channels between cells were also identified resulting in a material with high levels of water absorption, which was confirmed with water absorption and swelling tests.

According to the method adopted to calculate the density, the average of the values obtained was 0.173 g/cm³, which indicates that the butiá fruit waste panels are low density. Regarding water absorption, the specimens showed high absorption rates, which indicates that the panels are hydrophilic and the water absorption process occurs quickly. As for swelling in thickness, the panels presented an average of 12.41% and the NBR 15316-2 standard, on which the test was based, specifies a value of 10% for thicknesses >19 to 30 mm.

It is noteworthy that the production of modular panels from butiá waste does not require the addition of any resin or binder, just the addition of water to the waste. From the modeling and definition of the physical properties of the material, the application of the panels as coverings can be directed, given that fibrous and low-density materials are used as acoustic and thermal insulators, and as natural artisanal raw materials, the lack of knowledge of the properties is a condition for their use.

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