ACOUSTIC PERFORMANCE OF PANELS PRODUCED WITH BUTIÁ FRUIT RESIDUES

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ABSTRACT

The butiazal is an ecosystem in South America and is on the verge of extinction. The use of fruits (butiá) and other parts of plants is an alternative to generating income for farmers and a way of preserving butiazais. The fruits are used in the production of delicacies such as jellies, juices and liqueurs. To do this, the fruits go through a pulping process where the skins and fibers are transformed into waste. The use of this waste is an opportunity to develop by-products with added value and sustainable use, which enables territorial appreciation and local identity. For this, acoustic panels were produced and its potential for sound absorption was analyzed using an impedance tube. The results were close to or better than the performance of panels produced with synthetic materials. Panel samples with a thickness of 30 mm achieved the best performance in relation to acoustic absorption, when compared to those with a thickness of 25 mm, except for frequencies of 2000 Hz and 3000 Hz, where the 25 mm butiá sample was superior.

KEYWORDS*: Butiá waste, Acoustic panels, Acoustic performance, Impedance tube.*

I. INTRODUCTION

The palm family *Arecaceae* (*Palmae*) is among the oldest plants used by humans [1]. In South America, there is the genus *Butia*, which brings together 20 native species distributed throughout Brazil, Uruguay, Argentina and Paraguay, in the Pampa, Atlantic Forest and Cerrado Biomes. These species are popularly known as butiazeiros and their fruits are popularly called butiá [2].

Butiazeiros form communities called butiazais or palm trees [3] are composed of concentrations that can reach 600 palm trees per hectare in some locations (Figure 1a). The largest butiazal areas are currently concentrated in the Departamento de Rocha (southeast Uruguay) and in the municipalities of Tapes, Barra do Ribeiro, Palmares do Sul, Barão do Triunfo and Santa Vitória do Palmar, in Rio Grande do Sul, South Brazil [4].

The Butiazeiros (Figure 1b) produce clusters of sweet and slightly acidic fruits (Figure 1c), which turn yellow, orange or reddish when they ripe (Figure 1d). Inside the fruit there is an edible seed which contains the oilseeds (or almonds).

The sale of 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, bittersweet sauce, syrup for desserts and ice creams, juice, nectar, vinegar, chocolates, liqueur with honey, pulp for ice cream and baked products [5].
To produce these delicacies, the fruits go through a pulping process, where the pulp of the fruits is obtained and the fibers are left over, along with the skin and coconuts. Butiá fibers are used in crafts, such as decorating bottles, pots, masks, composting and also in the production of flour [6].

Figure 1: a) Aerial view of Butiazal in Tapes, Rio Grande do Sul, Brazil. (3). b) Butiazeiro; c) Bunch of butiás; d) Genetic variability for the color of butiá fruits. (4); e) Fruits with different shapes and colors. (4); d) Fruit, red arrow indicating the perianth, blue arrow - exocarp, pink arrow - mesocarp, green arrow - endocarp and the yellow arrow indicating the almond.

According to Barbieri [3], threatened by the expansion of agricultural and urban areas, extensive butiazais are becoming increasingly rare. Bellé [7] highlights that one of the aspects that can generate a process of conservation of native species is to make them more useful, whether in family nutrition, in alternative medicine (herbal medicines), or other forms of income-generating for farmers. These actions have contributed to reducing threats to butiazais and valuing these ecosystems as providers of environmental services [3].
According to Matos [8], the processing of agro-industrial activities such as fiber processing and food processing among others, are directly linked to the generation of products and consequently, the generation of waste. The use of waste is an opportunity to develop by-products with added value and sustainable use [9]. New scenarios are emerging in relation to product design and the use of materials

with the reuse of waste, such as product redesign, more sustainable products, etc. One of the interesting points is the development of products with local identity and territorial appreciation, as they are related to the social context where they are produced and are strongly linked to the community that generated them and also associated with the conservation of biodiversity. This is part of the national SDG movement (Sustainable Development Goals).

In general, a property of vegetable fiber waste is its low density (citation), making it a promising raw material for the production of acoustic panels. According to the Brazilian Association for Acoustic Quality (15), sound propagates through waves with a certain periodic repetition, through the rarefaction and compression of particles in the middle. The rate of this repetition defines the frequency and will determine whether we hear lower or higher sounds. To make things easier, audible frequencies are normally classified as low frequencies, between 20 Hz and 200 Hz; medium frequencies, from 200 Hz to 2,000 Hz; and high frequencies, from 2,000 Hz to 20,000 Hz. When sound waves reach a surface, part of their energy is absorbed, part reflected and part transmitted by it. In a reverberant place, it is difficult to understand a speech, hence the importance of acoustic conditioning of the environment to understand the sound in a place.

The objective of this work is the development of acoustic panels produced with butiá waste obtained from the processing of the fruit from agro-industries. The topic on materials describes the method for obtaining butiá waste and the production process for molds and acoustic panels. In the characterization methods, the stages of apparent density and acoustic absorption tests are described, using the impedance tube test. Finally, the results obtained in these tests are presented, compared with the characterization of the acoustic properties of panels made from other materials.

II. MATERIALS AND METHODS

The butiá fruits used to obtain the waste and, later, to produce the acoustic panels, were obtained in Gravataí, Rio Grande do Sul, Brazil. The preparation and production of the samples were hand-made, enabling reproduction by local communities in the butiazais. It is important to highlight that no binders are used in the production of panels, only water.

2.1. Process of obtaining residues from butiá fruits

To separate the pulp from the fruits, a Braesi DES-60 Fruit Pulper was used, located in the Food Laboratory of the Instituto Federal Farroupilha, Campus Santa Rosa, RS. Initially, the fruits were washed and left to soak for cleaning. They were then placed in the fruit pulper (Figure 2a). After obtaining the pulp (Figure 2b), it is possible to observe that the fibers remain, along with the peel and coconuts (Figure 2c).

Figure 2: a) Pulp machine used in the process: place where the fruits are inserted (red arrow), place where the waste comes out (orange arrow), place where the pulp comes out (yellow arrow) and place where the pulp is being deposited (arrow blue); b) Pulp obtained in the process; c) Waste obtained in the process.
Source: Authors.

The butiá pulp is used in the production of various foods and drinks, while the fibers, shells and nuts are, in most cases, discarded. To produce the acoustic panels, butiá fibers and bark were used, whilst the nuts were separated and discarded.

2.2. Production of acoustic panels

To make the panels, perforated rectangular molds with heights of 30mm and 40mm (external measurements) were produced in 3mm thick acrylic (Figure 3). The molds were produced with the aid of a 1000x600 laser cutting machine - MC1060 at the Innovation and Digital Manufacturing Laboratory of the School of Engineering (LIFEELAB) of the Federal University of Rio Grande do Sul (UFRGS).

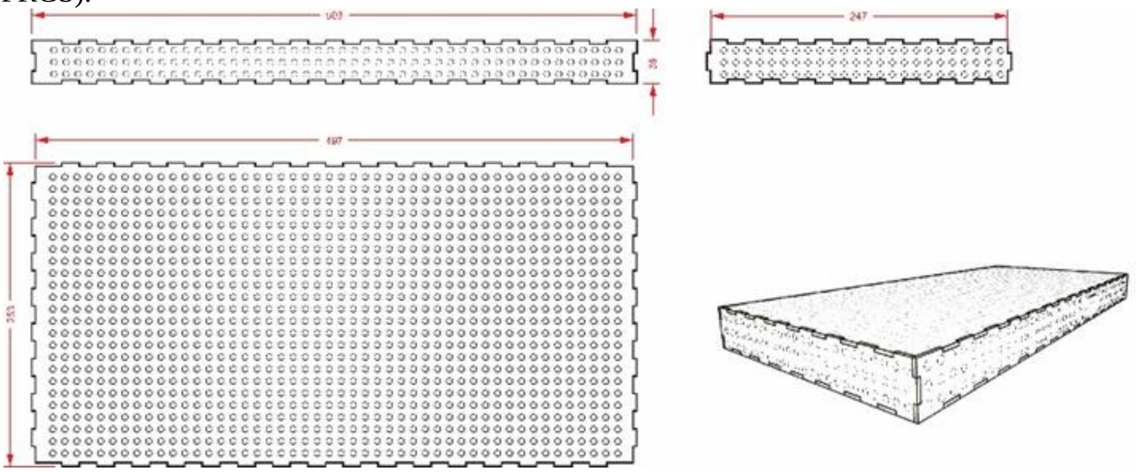

Figure 3: Technical drawing of the molds developed from 3mm thick acrylic sheets, used to produce the samples, in rectangular shape - 503x 253x 40mm. Source: Authors.

To produce the panels, initially the butiá waste was hydrated with drinking water and a blender was used to obtain a more homogeneous material. From this procedure, a paste was obtained, which can be seen in Figure 5a.

In the next step, the molds were filled with small amounts of waste paste, until they were completely covered (Figure 5b,c). The molds were then placed on a smooth surface to begin the paste drying process. They were exposed to solar radiation in the morning for approximately 3 hours, and even without sun, they remained outdoors until 5 pm (Figure 5d). This process was repeated for 3 consecutive days. After this period, the panels were removed from the molds to facilitate drying (Figure 5e) and after 15 days they were completely dried.

The panels were produced between the months of January and February of 2022, and the environment temperature varied between 20° and 36° C. The drying time (days) also varies, as the more heat and sun received, the faster the drying process occurs. The thickness of the panel also affects drying time, as the thicker it is, the longer the process takes.

It was possible to observe linear retraction of the panel, as well as the total volume (Figure 5f). In thickness, this reduction was approximately 1 cm in height. The panels produced in the 40mm mold were reduced to 30mm and the sample produced in the 35mm mold were reduced to 25mm. This difference can be attributed to the amount of water contained in the paste and also to the way in which the material is deposited. Despite the attempt to maintain the production standard, this is an artisanal process.

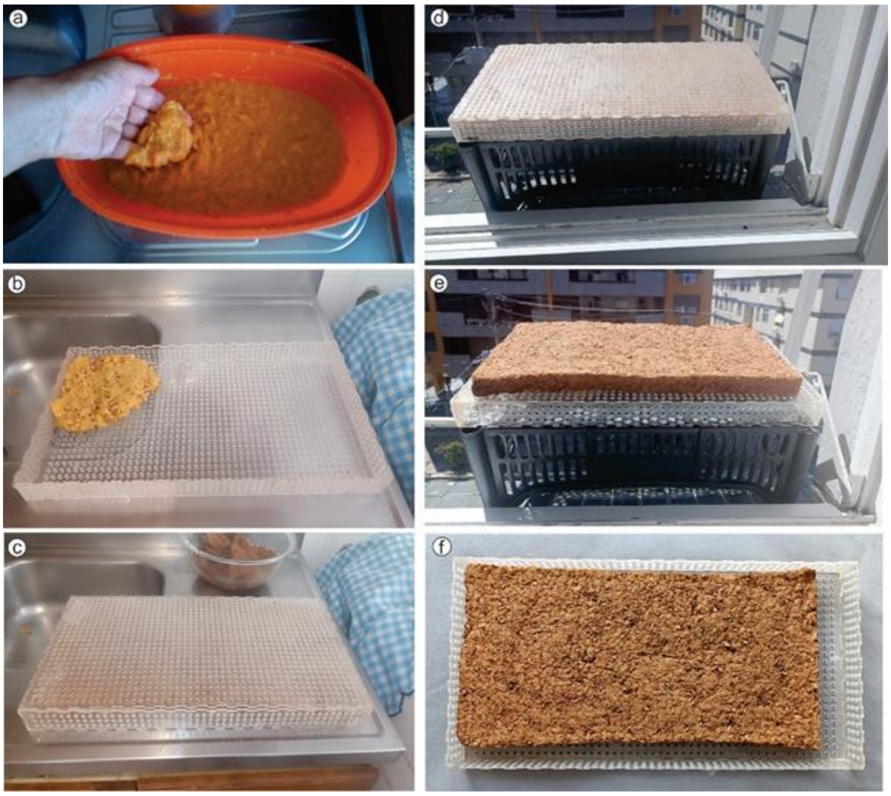

Figure 5: Waste diluted in water; b) Mold being filled with waste; c) Mold completely filled with waste; d) Panel drying in the sun; e) Panel removed from the mold, drying in the sun; f) Panel completely dry. Source: Authors.

To produce the specimens (Figure 6), a hand saw and an electric sander (Figure 6c) were used. Small squares were removed from different parts of the panels (Figure 6b) and sanded until they reached the necessary dimensions of the samples to carry out the tests on the impedance test (Figure 6d). The test specimens showed small differences in height, which was due to the artisanal process in the artisanal production of the panels (Figure 6e).

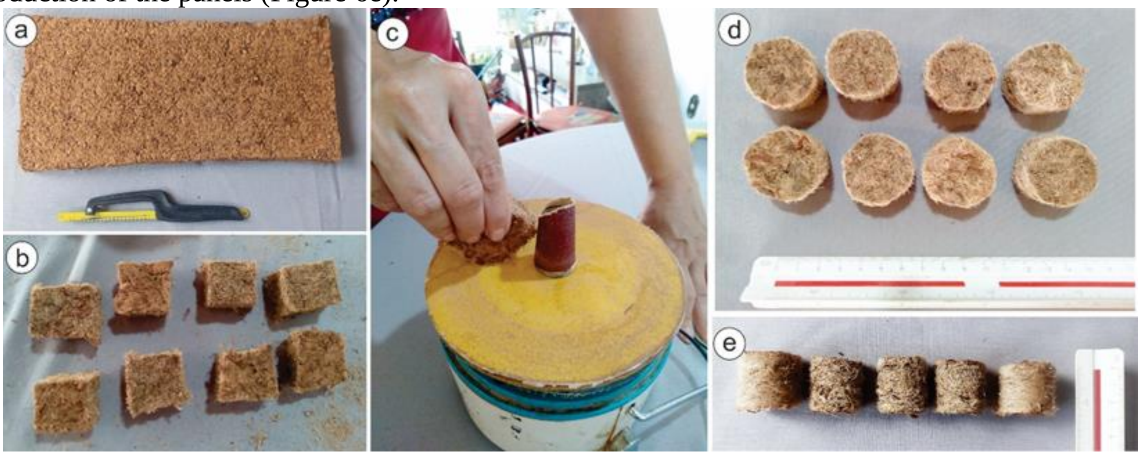

Figure 6: a) Panel; b) Squares taken from different parts of the panel; c) Sanding of the test pieces; d,e) Ready test pieces. Source: Authors.

In total, seventeen samples were produced. Five samples were produced for the apparent density test, measuring 50 mm in diameter and 30 mm in thickness. For the acoustic absorption test, six samples measuring 50 mm in diameter and 25 mm thick were produced, and six with dimensions of 50 mm in diameter and 30 mm thick.

2.3. Characterization methods

To characterize the butiá waste panels, apparent density and acoustic absorption tests were carried out. The tests to determine the apparent density of the panels were carried out based on ABNT NBR

7190/1997: Design of Wooden Structures, with some necessary adaptations depending on the peculiarities of the material.

For the test, five specimens of the material measuring 50 mm in diameter and 30 mm thick, on average, were used. The specimens were stabilized in a climatic chamber until reaching a stabled humidity, under conditions (65 ± 5) % of relative humidity and temperature of (20 ± 3) ºC. A caliper was used to size the samples and a scale with a minimum resolution of 0.1g. The tests were carried out at the Wood Engineering Laboratory at UFPel, in Pelotas, RS.

The acoustic absorption analysis was carried out in partnership with the Federal University of Santa Maria – UFSM, and an impedance tube was used that covers the range from 100 Hz to 6.4 kHz. Six specimens of each thickness, 25 mm and 30 mm, and a 25 mm sample of melamine acoustic foam were tested to compare the results. The tests the acoustic absorption was carried out based on ISO 10534-2:2023: Acoustics - Determination of acoustic properties in impedance tubes.

III. RESULTS AND DISCUSSIONS

3.1 Density

According to the method adopted to calculate the density, the results obtained were entered into a spreadsheet, crossing these data, resulting in an average density of 0.178 g/cm3. The resulting values indicate that butiá fruit waste panels have an extremely low average density, similar to the density of some polymeric foams, such as PVC foam (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 values most similar (≈ 0.2 g/cm³) [10]. Compared to industrialized fibrous materials such as glass wool sheets and blankets (0.3 g/cm³). When it comes to sound absorption, the density of the material is a significant factor, as the materials used to improve the level of reverberation in environments are light, low density, fibrous or porous [11].

3.2 Acoustic absorption

The results of some frequency points measured in the acoustic absorption tests are shown in Table 1 and are graphically illustrated in Figure 7. Points ranging from 50 Hz to 6,300 Hz were measured.

Table 1: Results of acoustic absorption tests.

Material	Frequency (Hz)					
	1000	**2000**	**3000**	**4000**	**5000**	**6000**
Butiá Thickness 30mm	0.55 – 0.82	0.90 – 0,98	0.75 – 0.87	0.79 – 0.97	0.95 – 0.98	0.86 – 0.97
Butiá Thickness 25mm	0.44 – 0.71	0.92 – 1.00	0.77 – 0.90	0.70 – 0.82	0,80 – 0.94	0.86 – 0.97
Melamine 25mm	0.37	0.73	0.88	0.93	0.90	0.89

Figure 7 graphically illustrates the data shown in Table 1. According to the results, it is possible to observe that the 25 mm butiá fruit residue test specimens, compared to the 25 mm melamine, showed a higher variation at most frequencies with the exception of the 4000 Hz frequency, where melamine was superior.

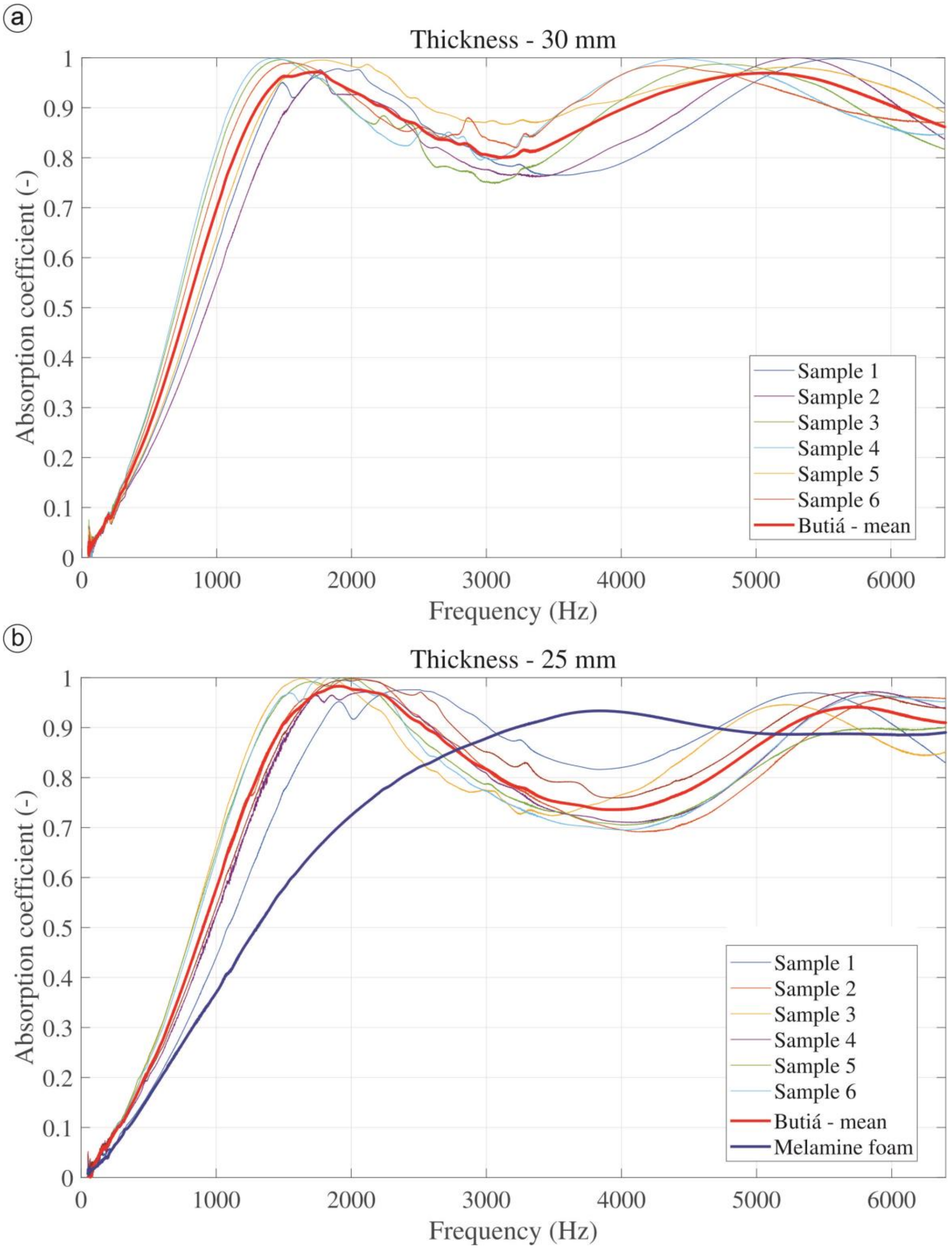

Figure 7: Acoustic absorption graphs of panels produced with butiá fruit waste. a) Acoustic absorption graphs with thicknesses of 30 mm b) Acoustic absorption graphs with thicknesses 25mm and 25 mm melamine sample. Source: Authors.

The 30 mm thick butiá waste panel samples achieved the best performance in relation to acoustic absorption when compared to the other samples, with the exception of frequencies of 2000 Hz and 3000 Hz, where samples from 25 mm panels were superior to those from 30 mm thickness.

Variations in acoustic absorption rates in samples with the same thickness may be related to a greater or lesser concentration of waste in the panels, due to the artisanal production process. According to Bistafa [11] the frequency increases according to the thickness and density of porous/fibrous materials,

Positive results in relation to sound absorption panels using plant fibers can be seen in the study carried out by Silva [12] with banana pseudostem, in which tests to determine sound absorption were carried out using an impedance tube. The work concluded that the thickness of the board is one of the most significant factors regarding its performance as a material for acoustic absorption, and presented satisfactory results in boards with a thickness of 5 cm.
Sakamoto et al. [13] investigated the sound absorption characteristics of rice straw, rice husk and buckwheat husk, with the aid of the impedance tube. They concluded the effectiveness of these materials as sound absorbers and reported the good performance of rice straw compared to the sound absorption of commercially available glass wool.
Acoustic panels produced with vegetable fibers were also the subject of study by Bastos [14], who developed and characterized panels made from various vegetable fiber residues and various binders, such as coconut, palm oil, sisal and açaí panels and panels mixed with two or more types of fibers. For comparison purposes, we used the results obtained by Bastos [14] with materials used as industrially produced acoustic absorbers, as can be seen in Table 2.

Table 2: Sound absorption coefficient of porous/fibrous materials commercially produced and artisanal panels made from vegetable fibers.

Material	Frequency (Hz)			
	1000	**2000**	**4000**	**6000**
Espumex 40mm (11)	0.52	0.48	0.65	--
Sonex 35mm (11)	0.71	0.95	0.89	--
Açaí artisanal (14)	0.80	0.80	0.88	0.88
Palm oil artisanal (14)	0.30	0.70	0.80	0.70
Sisal artisanal (14)	0.40	0.80	0.92	0.88
Coco *in natura* (14)	0.40	0.68	0.70	0.70
Mix of coconut and sisal (14)	0.43	0.93	0.92	0.90
Butiá 30mm waste	0.55 – 0.82	0.9 – 0.98	0.79 - 0.97	0.86 – 0.97
Butiá 25mm waste	0.44 – 0.71	0.92 - 1.00	0.70 - 0.82	0.86 – 0.97
Melamine 25mm	0.37	0.73	0.93	0.89

In absorbent materials, absorption is normally controlled by selecting thickness, density, porosity, among other factors. It should be noted that the thicknesses of the materials tested by Bastos [14] were not analyzed, but it is possible to observe that the butiá fruit waste panels presents good results in relation to industrially produced absorbent materials.
The production of acoustic panels with natural resources, specifically from vegetable fibers, is an opportunity to add value to waste and an alternative with a sustainable bias. In the case of butiá fruit waste panels, in addition to the ease in their manufacturing process, it is also an option for generating income combined with the conservation of biodiversity on small rural properties. The panels can be produced by local communities, strengthening the identity of local products and encouraging the circular economy and the territorial enhancement.

IV. FINAL CONSIDERATIONS

In the present study, the acoustic absorption coefficient of panels produced with butiá fruit waste was analyzed. The material was produced by hand to serve as an alternative for reusing waste and generating income for small producers, through the development of a product that strengthens local identity and the appreciation of the territory.
The molds for producing the panels are easy to make and assemble and make it possible to test other shapes. The production of the panels does not require binder, just water, which is a positive point in

the preparation process. It was found that, depending on the thickness, the drying time of the panels varies and the more heat and sun, the faster the process happens. Density, which is an important factor in absorbent materials, is extremely low compared to materials used in industry.
The results of the acoustic absorption tests were satisfactory in comparison to industrially produced acoustic absorbing materials, being superior in most of the ranges analyzed and also when compared to other vegetable fiber panels, such as coconut and sisal. The use of panels, overlapping thicknesses, is also an alternative to achieve satisfactory results in relation to sound absorption in the environment.

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