

# Literature Review and Preliminary Analysis of Cassava By-products Potential Use in Particleboards

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Particle panels for construction are environmentally favorable, as they allow the combination of different components (as is the case with agro-industrial waste from the production and processing of food and products derived from agricultural activities). The objective of this article is to analyze studies focused on the use of cassava by-products in the production of panels for civil construction/furniture in the last 10 years through a bibliographical survey, as well as to present a preliminary analysis of the feasibility of using cassava by-products to manufacture particle panels in their natural state. As a result, the theoretical search detected the gap created by the scarcity of published studies on the topic. On the other hand, the experimental analysis indicated the promising potential of using the cassava by-product for panel production, provided that the weaknesses initially indicated in this research can be addressed.

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## INTRODUCTION

The United Nations Human Settlements Program, by means of its report called World Cities Report 2020 (UN-Habitat 2020), reports that the world will continue to urbanize during the next decade, increasing the current rate from 56.2% to 60.4% by the year 2030. The same document, which draws attention to this global urbanization, displays that 96% of urban growth will occur in less developed regions, making it difficult to respect and guarantee sustainable patterns of consumption and production described in The Sustainable Development Goals Report (UN 2022).

The construction of environmentally healthy buildings and the search for new materials (adaptable and productive) minimizing impacts on the environment reveal the importance of research involving sustainability in the built environment. If on the one hand urbanization combines population and economic growth, on the other hand, it exerts strong pressure for more resources such as raw materials, land, water, and energy, further highlighting the importance of discovering new technological alternatives capable of reducing environmental impacts.

According to the United Nations Environment Program (UNEP 2020), the construction sector is strongly associated with practices that result in high carbon emissions, excessive use of non-renewable materials, and, as a result, environmental degradation.

Although technological advances have been achieved in recent decades, practices with negative ecological consequences in the sector are still easily identified, such as excessive demand for raw materials, inadequate disposal of large volumes of waste that is harmful to the environment, high energy consumption during production, transportation, use and disposal of construction materials, among others (Asdrubali *et al.* 2015; Viel *et al.* 2019; Cintura *et al.* 2021).

According to Cintura *et al.* (2021), some strategies have been detected and adopted to mitigate the above mentioned problems. These strategies include the use of ecological materials, the use of raw materials from other sectors, and the adoption of local materials.

Agro-industrial waste, for example, comes from the production and processing of food and products derived from agricultural activities. Due to their chemical and physical constitution, they present themselves as a potential ecologically viable alternative for the construction industry, as they transform a discarded by-product into a material with added economic value (Caetano 2021).

Waste, when inappropriately disposed of in soil or water, is considered a source of environmental impact in the form of an overload of organic matter or a generator of polluting gases if burned inappropriately (Caetano 2021). Research regarding the disposal of cassava by-products, for example, indicates that this waste can represent serious environmental problems since its large-scale production is carried out in the most different geographic areas of the planet.

Coelho (2018) recalls that the amount of cassava bagasse produced in starch factories is high and that such residue, when untreated, can cause problems for industries. Among those is the large volume of by-products with no apparent commercial value that is sometimes donated to livestock farmers for animal feed or released into the environment, contributing to environmental problems due to the high organic load (Wosiacki and Cereda 2002; Marcon 2007).

In this sense, particle panels for use in civil construction and furniture have great potential from an environmental point of view, as they enable a different component combination, replacing conventional materials with others coming from waste or by-products from different industries, such as agro-industrial waste. This substitution, in addition to promoting waste materials as raw materials, also helps to reduce the market pressure exerted on wood production.

It is essential to note that in Brazil, the standard that establishes the requirements for a Medium-Density Particleboard (MDP) is NBR 14810 (ABNT 2018). In these standards, panels are classified into six different types, depending on the usage and environmental conditions, as shown in Table 01:

**Table 1.** Classification of MDP Panels According to NBR 14810 (ABNT 2018)

Type	Description
P2	non-structural panels for internal use in dry conditions
P3	non-structural panels for use in humid conditions
P4	structural panels for use in dry conditions
P5	structural panels for use in humid conditions
P6	structural panels for use in severe load conditions, in dry environments
P7	structural panels for use under severe load conditions in humid environments

When talking about wood production, for the Brazilian Forest Service (SFB 2020), in Brazil, the planted trees and forests sector present themselves in a contradictory way.

On the one hand, the country develops forestry in planted forests, with integrated production and a sophisticated and complex production structure. On the other hand, it still faces high rates of illegal deforestation of native forests. Furthermore, according to the same source, the sector is experiencing difficulties in expanding due to difficulties in obtaining raw materials.

According to the Brazilian Agricultural Research Corporation (Embrapa 2023), cassava is a plant from the Euphorbiaceae family with the scientific name *Manihot esculenta* Crantz. The reason for the choice of the plant for this study is that it is one of the most important energy foods for more than 1 billion people, mainly in developing countries. In total, there are more than 100 cassava-producing countries, with Brazil being the fifth largest global producer, behind Nigeria, the Democratic Republic of Congo, Thailand, and Ghana. Due to its adaptability, cassava is cultivated in all Brazilian states, and the state of Paraná is the second largest national producer (Embrapa 2023).

What draws attention to cassava is its high adaptive capacity in different agroecological conditions, good resistance to drought, and the absence of specific care for growth. It is a plant with a diverse cultural cycle (from planting to harvest) varying from 6 to 36 months, depending on the variety planted.

Marcon (2007) describes cassava as a shrubby plant, composed of an aerial part and an underground part formed by tuberous roots. This plant is generally classified as bitter since the concept of bitter depends on the hydrocyanic acid (HCN) levels. However, even in the case of wild cassava, free hydrocyanic acid is volatile at 27.5 °C, *i.e.*, this substance is quickly volatilized at room temperature in tropical regions.

Baharuddin *et al.* (2016) reported that the cassava's composition can vary depending on environmental conditions, variety, plant age, and geographic location. However, regardless of the type, the plant tuber is made up of starch and carbohydrates (carbon, oxygen, and hydrogen molecules), in addition to other small amounts of minerals, proteins, and vitamins.

Marcon (2007) and Coelho (2018) state that by-products originating from plant processing can be solid (brown peel, intermediate skin, discard, and bagasse or mass) and liquid (root washing water, press water or vegetable water from manufacturing of flour called manipueira). These by-products stand out for their concentration of fiber (such as the peel) and starch (such as cassava mass – a product resulting from the cassava starch extraction).

For the authors in question, when talking about starch, it is worth remembering that it not only plays the role of an energy reserve but also acts as a strategic reserve for the development of products that are more beneficial to human health and the environment. Known as “white gold due to its wide technological applications in the generation of products with high added value” (Marcon 2007, p.19), recent research has used cassava starch to produce bioadhesives, biocomposites, nanocellulose and biofuels (Fabrício and Mahlmann 2014; Calegari and Oliveira 2016; Monteiro *et al.* 2016; Travalini *et al.* 2016; Akinyemi *et al.* 2019; Kariuki *et al.* 2019; Monroy *et al.* 2019).

Marcon (2007) also highlights the diversity of applications of cassava, not limited to human and animal food. The plant is used in the production of various industrial products, covering sectors such as brewery, biodegradable plastics, paper industry (contributing to characteristics such as body, finish, gum, and paper firmness), textile industry (in processes such as sizing, stamping, thickening of dyes, finishing and firmness of fabrics), ceramic alloys, foundations, mining, adhesives, paints, cosmetics, medicines, explosives, the oil industry and alcohol production, as well as new polymers with diverse

applications.

Few studies have explored the production of constructive elements for civil construction based on cassava. However, it is believed that particleboard made from cassava by-products could be an ecologically viable alternative for use in construction or furniture. This alternative, in line with Chen and Ma (2023), promotes the use of new technologies that add alternative materials (such as the use and recycling of organic waste), avoids the emission of toxic gases, and promotes the decentralization of production by harnessing the endogenous potential of each region. These characteristics are in line with the precepts of decarbonizing the construction sector.

In this panorama, the work proposed here aims to analyze the studies focused on the use of the cassava by-product in the production of panels for civil construction in the last 10 years through a Bibliographic Synthesis (BS) as well as presenting the preliminary analysis of the feasibility of using of cassava by-product for the manufacture of particle boards in its natural state. Observing the behavior of by-products in their natural state was understood in this work as a way of simplifying processes to make the intended technology more accessible. To achieve this, BS is guided by the protocol presented by Mandola *et al.* (2020) and Gaffuri *et al.* (2023). The experimental part was carried out in the laboratory following the protocols described below.

## BIBLIOGRAPHIC SYNTHESIS AND ITS RESULTS

### Bibliographic Strategy

To understand the extent of prior research regarding use of cassava in the construction industry, this research carried out a literature exploration based on the protocols presented by Mandola *et al.* (2020) and Gaffuri *et al.* (2023). These protocols established the criteria for surveying, analyzing, and selecting articles. The searches were carried out in international and interdisciplinary bibliographic databases: *Scopus*, *Web of Science/ Scielo*, and *MDPI*.

The texts were collected by defining a search string in which the terms and concepts were defined in four fields, as listed in Table 2. The first field was defined focusing on the type of material (cassava). The second field defined how the material (particleboard) was used. The third field focused on the area (civil construction), and the last field focused on the origin of the material (agro-industrial waste). For the final formatting of the search string, Boolean operators **AND** were used between the search fields and **OR** between terms in the same field.

**Table 2.** Definition of Fields for the Search String

	Field 1	Field 2	Field 3	Field 4
Term used in the search (title, abstract or keyword)	cassava	Particle Board	Civil Construction	Agroindustrial Waste
		Particle Panel	Construction	Agroindustrial Residues
		Particleboard	Building	Agro-industrial Waste
			Construction	Agro-industrial Residues

The search for articles also stipulated the inclusion and exclusion criteria. As an inclusion criterion, it was defined that the academic articles should directly address the topic in the title, keywords, or summary and necessarily include the area of civil construction. The exclusion criteria would be presenting concepts outside the stipulated

area, incomplete articles, and without bibliographic data. In the exclusion criteria, just one satisfied condition mentioned was sufficient to exclude the article.

After applying the above criteria, eight articles were selected that partially met the requirements as shown in the graph in Fig. 1.

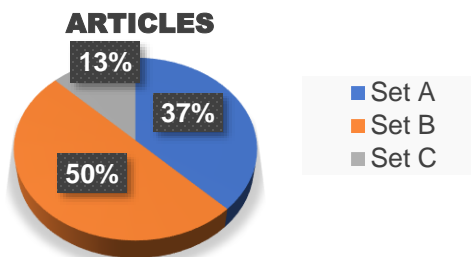


Fig. 1. Graph of articles selected from the search string

### Bibliographic Results

Following the strategy described above, the literature search found 8 articles that met the search requirements stipulated for this work. Among the searched articles, Set A shows 3 studies of panels made from cassava particles. The research by Aisien *et al.* (2015), who investigated the potential of cassava for composing a particleboard panel, stands out. In this study, cassava stalks were used mixed with urea-formaldehyde resin. In this process, they obtained particle panels that met the ANSI/A208.1 (1999) standard for general use with commercially used resin addition in wooden panels (phenolic type). A similar study was presented at the National Meeting of Built Environment Technology in 2020, the objective of which was to create a Medium Density Fiberboard - MDF panel from cassava stems mixed with urea-formaldehyde resin (Santos *et al.* 2020).

The Baharuddin *et al.* (2016) study presented a particleboard panel made from cassava root mixed with a polyester-type binder. In this case, the panel did not meet the minimum standards required by ANSI/A208.1 (1999).

There are 4 studies in Set B that investigated the use of cassava components in the form of binder or bioadhesive, these being the use of cassava starch as glue in the plywood industry, the study of ecological agglomerate using a mixture of agro-industrial waste with wood and cassava stalks, the use of modified cassava starch and sour starch as a binder (Monteiro *et al.* 2016; Akinyemi *et al.* 2019; Monroy *et al.* 2019; Hidayat *et al.* 2022). The studies cited concluded that the cassava component usage proved to be favorable, fulfilling the function for which it was designed.

In Set C only one study used cassava components as a way to improve the physical or chemical characteristics of other elements that do not refer to particle boards, among which is the use of cassava flour as a mixture to improve the physical, mechanical and durability of high-strength concrete (Adam *et al.* 2022). In this case, the use of cassava also had a favorable response.

The studies cited used cassava taken from the food sector and, from there, followed the process of peeling, grinding, and obtaining the material to form particles. In none of the cases was the cassava waste used as a by-product – taken directly from the starch factories. It was also noted that none of the studies found used the cassava product in its natural state, *i.e.* in all cases it was pre-treated before use.

With this in mind, this study aims to achieve a preliminary characterization analysis of particleboards made from cassava by-products in order to understand how the material behaves in its natural state before any applied treatment.

Also, 2 out of 3 of the studies involving the manufacture of particle panels using cassava followed the protocol established for conventional wood panels using phenolic resins as binders in the mixture. This type of thermosetting adhesive is traditionally used in the production of wooden panels, and due to its chemical composition, it is a product with proven toxicity for humans. Hussin *et al.* (2022, p.3910) states that although these commercial resins (urea-formaldehyde (UF), phenol-formaldehyde (PF), melamine-formaldehyde (MF), phenol-resorcinol-formaldehyde (PRF), and resorcinol-formaldehyde (RF)) have good workability and bonding performance they still “consist of harmful or toxic chemical agents derived from fossil resources, which makes their application severely limited”.

Ferro *et al.* (2015) affirms that when dealing with these resins, two negative points can be highlighted: the high energy consumption for their curing (with temperatures on average above 160 °C) and the emission of formaldehyde (a component considered toxic to both humans and the environment). The same author explains that manufactured panels with this type of adhesive emit formaldehyde both during the production process and during their useful life and after consumption, becoming a problem when transformed into waste discarded in the environment.

The literature review revealed that there is a publication scarcity on the subject and that none of the studies presented the behavior of cassava in its natural state, and in all cases, the product was pre-treated before use. Therefore, the experimental analysis, which is still preliminary, presented below aimed to evaluate the behavior of cassava by-products in their natural state and taken directly from starch industry waste. The focus was on reducing the processes involved in preparing materials for particleboard production, making the technology simpler and more accessible in the various regions where the materials studied here are found.

## EXPERIMENTAL

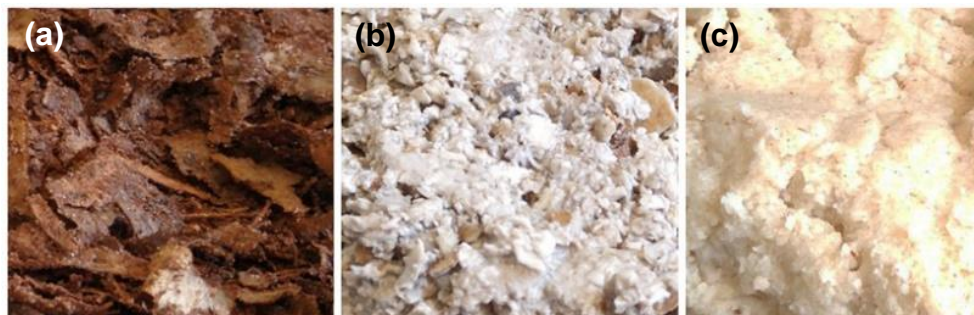
### Methods and Approach

The experimental research took place in the laboratory involving the material collection and selection phases. Preliminary tests were performed called protocols 1 and 2: observation of the product’s behavior and analysis of the results. In order to fulfill the objective established for the work, the collection of materials combined the factors of environmental preservation, utilization of agro-industrial waste, and transformation of discarded products into products with added economic value.

Thus, the cassava by-product used in this research was collected during a technical visit to the Bankhardt Starch industry in the District of Graciosa - municipality of Paranavaí (Northwest of Paraná - Brazil). Among the main cassava producers in the state of Paraná, 27 municipalities are located around Paranavaí within a radius of less than 200 km away, this being a prominent region in the Brazilian cassava production scenario.

During the technical visit, it was possible to learn about the entire process of manufacturing starch, involving the cassava receiving stages, peeling, washing and grating, separating the starch, drying, and packaging.

From this industrial process, the three by-products that would be used in the research were selected: the brown skin (a) resulting from the first peeling, the intermediate skin (b) resulting from washing and grating, and the cassava mass (c) resulting from starch extraction (Fig. 2). Starch is extracted from the cassava roots.



**Fig. 2.** Cassava by-products: (a) the brown skin; (b) the intermediate skin; (c) the cassava mass

To understand the collected material, mainly regarding the initial characteristics of particle adhesion without the use of any type of adhesive and resistance to the Growth of Microorganisms (GrM), the samples were taken to the analysis laboratories of the Federal Institute of Paraná - Paranavaí Campus to start preliminary tests called protocol 1.

In this protocol, the first measurement obtained was the moisture content taken on the infrared moisture analyzer model IV 2000 GEHAKA at a temperature of 103 °C for an average time of 20 min. The pH of the samples was then measured using the PHmeter model mPA 210. Three samples were taken from each by-product.

Step 2 of this same protocol consisted of observing the adhesion behavior of the by-products in the *in natura* test panel condition (without the addition of binder) with four different treatments, as shown in Table 3.

**Table 3.** Making Panels with *in natura* By-products

Types of cassava by-products	Brown skin (%)	Intermediate skin (%)	Cassava mass (%)	Resin (%)
<b>T1 - brown skin</b>	100	0	0	0
<b>T2 - intermediate skin</b>	0	100	0	0
<b>T3 - cassava mass</b>	0	0	100	0
<b>T4 – Cassava by-products 1,2, &amp; 3</b>	33.33	33.33	33.33	0

To manufacture these initial panels, an aluminum mold with closed side walls and a bottom made of a fine sieve (less than 1 mm) measuring 150x150x5 mm was used, facilitating ventilation of the material in the greenhouse. The by-products, still in their natural state, were manually packaged in the mold and taken for 24 h in the sterilization and drying oven with forced air circulation, brand Lucadema model 82/480, at a temperature of 103 °C. This temperature was set by analogy with studies by Yano and Silva (2020).

The panels resulting from Treatments T1, T2, T3, and T4 were stored at room temperature and observed for 7 days to verify Growth of Microorganisms (GrM) such as molds and fungi.

After this period, the material was exposed to the sun for 5 days under direct radiation and then exposed to humidity to determine the degree of swelling as determined by the Brazilian standard. The swelling determination of the specimens followed the protocol defined by Brazilian Standard NBR 14810 (ABNT 2018). The swelling calculation was limited by Eq.1,

$$I = (E1 - E0) / E0 \times 100 \quad (1)$$

where  $I$  is the swelling in thickness of the specimen (%),  $EI$  is the thickness of the specimen after the immersion period (mm),  $E0$  is the thickness of the specimen before immersion (mm).

To complete protocol 1, the treatments were dried in a ventilated oven for 24 hours.

Therefore, the next stage, called protocol 2, began with the proposal to produce experimental panels with fresh material placed in a cold press.

For this, a steel mold measuring 150x150x50 mm was designed. The greater height of the form was designed so that the particles (larger volume) were packed and pressed at 3.5 MPa. After pressing, the plate should have approximate dimensions of 150x150x10 mm. For this stage, 3 samples were manufactured for the T4 treatment called T4\_1, T4\_2, and T4\_3. This treatment was chosen due to its better behavior in the previous stage, as will be discussed in the results section.

Using the Brazilian Standard NBR 14810 (ABNT 2018) as a reference, the calculation of the mass of particles for making the panels was carried out using Eq. 2,

$$D = m / v \quad (2)$$

where  $D$  is the nominal density of the panels, equal to 0.75 g/cm<sup>3</sup> (ABNT 2018),  $m$  is the mass (g) of particles, to be determined for making the panels, and  $v$  is the volume (cm<sup>3</sup>) of the panels, defined according to the desired panel size 150x150x10 mm.

The three by-products were manually mixed in a 1:1:1 ratio, placed in the mold, and taken to the Bovenau hydraulic press. During the process, it was observed that as the by-products were being pressed, the release of present water in the material was intense due to the high percentage of moisture contained in the material. The material remained for 20 minutes at a constant pressure of 3.5 MPa.

After pressing, the material was taken for drying in a ventilated oven. As the material had natural moisture content, it remained inside the mold for the drying process at a temperature of 103 °C for the time indicated in Table 4.

**Table 4.** Greenhouse Time

	Time (h)
T4_1	12
T4_2	24
T4_3	36

After this drying time, the samples were stored at room temperature and observed for 7 days in order to observe GrM. To conclude protocol 2, the same swelling test presented in protocol 1 was applied.

## Experimental Results

The experimental stage of this research began with protocol 1, the aim of which was to get to know the material collected, particularly about the initial adhesion characteristics of the particles without the use of any adhesive type, and to understand their resistance to the growth of microorganisms (GrM). The first measurement obtained was the moisture content using an infrared moisture analyzer and the samples' pH using the PHmeter device. From this first analysis, it was detected that the cassava mass (by-product C) was the material with the highest average moisture percentage and the intermediate peel (by-product B) was the material with the lowest average pH, as shown in Table 5. These averages are in line with the studies presented by Coelho (2018).



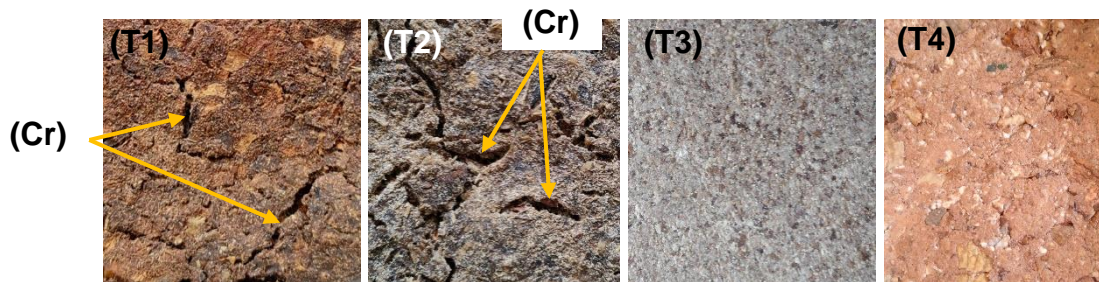
**Table 5.** 1st Stage of Protocol 1

	Average of Moisture	Average pH
<b>Cassava By- product 1 (brown skin)</b>	41.3%	6.21
<b>Cassava By- product 2 (intermediate skin)</b>	64.7%	4.32
<b>Cassava By- product 3 (cassava mass)</b>	85.6%	6.09

The second stage of the same protocol consisted of observing the by-product in its natural state to make panels without adding resin and without applying pressure to understand the material behavior in the adhesion process between the parts.

During this process, adhesion occurred between the parts, resulting in a dry and homogeneous material. At high temperatures, the starch present in the material promoted adhesion. This observation confirms the studies by Marcon (2007): the starch granule in excessive water, upon heating, gains viscosity and forms a paste, giving it viscoelastic characteristics that indicate the potential use of starch.

After the panels had been manufactured and dried, they were stored at room temperature and observed for 7 days to check for the growth of microorganisms (GrM), such as molds and fungi. During the established period, the material did not suffer any change in color, smell, detachment, or growth of microorganisms. However, for treatments T1 (100% brown skin) and T2 (100% intermediate skin), it was observed that the plates showed Cracks (Cr), indicating fragility in the connection of the materials. For treatments T3 (100% cassava mass) and T4 (by-products in a 1:1:1 ratio) there was no change (Fig.3).



**Fig. 3.** Cassava by-products: (T1) brown skin; (T2) intermediate skin; (T3) cassava mass; (T4) by-products in a 1:1:1 ratio

The treatments were exposed to direct solar radiation for 5 days in the next stage. Under these conditions, the treatments only suffered color variation, making the materials darker. In treatments T1 and T2, there was an increase in surface cracks, indicating that the drier material had more fragile adhesion. It was decided to continue the subsequent tests only with treatments T3 and T4.

The chosen samples were subjected to the swelling test according to NBR14180 (ABNT 2018). In this process, the samples were submerged in water for 24 h.

In both treatments, the specimens showed swelling greater than 35%. The wet samples were placed again for drying (24 h in a ventilated oven at 103 °C), typically returning to their initial state but maintaining a thickness variation above 30%, exceeding the limits established by the Brazilian Standard.

After drying, the treatments were stored for 48 h in the dark to evaluate the appearance of GrM. No growth of any microorganism type was observed in any of the treatments.

In this stage, known as protocol 1, it was observed that the material adhered without the presence of any adhesive type due to the presence of starch and did not show the growth

of undesirable microorganisms when dried under suitable temperature and ventilation conditions. Treatment T4 made up of equal proportions of each by-product, performed best, proving to be more homogeneous and maintaining its initial characteristics better after the tests applied. However, the resulting product did not have the necessary strength for panel production.

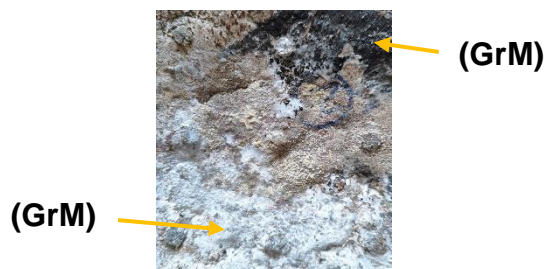
Therefore, the next stage, called protocol 2, began with the proposal to produce experimental panels with the fresh material placed in a cold press. In order to continue testing the material in its natural form, protocol 2 was executed without any prior treatment for the use of the by-product. Only pressure was applied, as explained in the methods section, to observe the change (or not) in the panel's strength.

For this stage, 3 samples were manufactured for the T4 treatment (called T4\_1, T4\_2, and T4\_3) due to the better behavior observed in the pre-tests presented in the previous protocol.

The first observation during this process was that, as the by-products were pressed, the relatively high proportion of water present in the material led to its intense release in liquid form, thus causing difficulty for the production of the panel.

After pressing, the material was dried in a ventilated oven, and the samples were subjected to different times, as indicated in Table 4 (shown above). Considering the material's natural moisture content, it remained inside the mold during the drying process. After this time, the samples were removed from the mold and stored at room temperature for 7 days to observe the GrM.

Under these conditions, the presence of GrM was observed in treatments T4\_1 and T4\_2 (Fig. 4). Treatment T4\_3 showed no appearance of microorganisms, indicating that the longer drying time was favorable to preserving the by-product in conditions where the steel mold prevented better air circulation between the panel and the walls of the mold itself.



**Fig. 4.** Growth of microorganisms on the type panels T4\_1 and T4\_2

From this stage onwards, it was observed that the particles adhered, even without the presence of any adhesive type, but the test panel did not gain the necessary strength to allow the production of larger panels. In addition, it was realized that this protocol was unfeasible, as the difficulty of pressing the material in natura, the release of excess water present in the material at the time of pressing, and the drying time in an oven with the material still inside the mould made the process excessively time-consuming. Keeping the material inside the mold during drying meant that the board did not dry evenly internally, favoring the appearance of microorganisms.

When applying the swelling test as specified in the methods section, it was noticed that due to the absence of any type of binder or water-repellent resin, the material behaved in the same way in both protocols 1 and 2, showing a thickness variation of more than 30%, which is considered to be above the value stipulated by the Brazilian standard for

requirements and test methods for medium-density particleboard (ABNT 2018).

As a result, new studies will be carried out to use the particle with previous drying and stipulated particle size (and no longer in the natural state as found in the industry). Furthermore, to improve the resistance characteristics (to stress, humidity, and growth of microorganisms, among others), the subsequent steps will be carried out using bioadhesive-type binders, that is, vegetable polyurethane-based resins.

Finally, the research that will follow up this study will keep the same focus as this preliminary analysis, using agro-industrial waste, avoiding phenolic glue usage, and transforming waste products into products with added economic value.

Considering the availability of material added to the favorable physical and chemical constitution, this research will continue seeking new protocols for manufacturing the panel in order to mitigate the weaknesses observed in this preliminary analysis.

## CONCLUSIONS

Within the field of the study of new materials, with sustainability in civil construction as a research objective, this work aimed to present a bibliographical overview and a preliminary analysis of the characterization of particleboards made from cassava by-products.

The objective set for this stage was to understand the state of the art regarding the use of cassava by-products in construction/furniture and the behavior of these by-products in their natural state. This behavior mainly concerned the adherence of the material without the use of any binder type, as well as its behavior to the growth of microorganisms under various conditions.

In experimental research, due to the lack of specific standards, this research used, by analogy, references from works that used other materials. To establish the experimental flowchart, two types of protocols were stipulated. Protocol 1 consisted of observing the material in natura without using pressing. Protocol 2 observed the material still in natura using cold pressing. At the end of the study, the following conclusions were reached:

1. Based on the bibliographic synthesis, it was possible to identify that studies regarding the use of cassava in components in civil construction/furniture are scarce. However, research addressing the intended material indicates the potential for using cassava in the particleboards production. In all the studies that used cassava in some way, the product's response to the proposed research was favorable.
2. After applying both protocols in the experimental section, it was noted that the material was cohesive and no microorganisms appeared (when dried under suitable conditions), even without any resin type usage. It was also found that the mixture of the 3 by-products (brown skin, intermediate skin, and cassava mass) performed better than the treatments consisting of a single by-product in isolation.
3. From the triangulation of the data found in the literature review and the observation of the experimental analysis, it was found that the cassava by-product is a material with the potential to be used in particleboards for use in construction and furniture, as long as, its most apparent fragility problems found during this study can be remedied: low mechanical strength and high swelling index. To this end, the study will continue with new protocols in an attempt to remedy these weaknesses.

## ACKNOWLEDGMENTS

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