THE USE OF ORGANIC RESIDUES TO DEVELOP PACKAGING: TESTS IN MOLDED PULP

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ABSTRACT

At the end of its life the packaging may become a residue if it is not correctly discarded, becoming a visible component of the waste produced on the planet, with a defined shape and communicating with the world. In the same way, large-scale agricultural production generates organic residues that, although representing fiber-rich materials, are discarded, such as rice husk, coconut husk, wood fibers, among others. To contribute with solutions to minimize the environmental impact of packaging and organic residues, the present study aims at performing preliminary tests of molded pulp packaging manufacturing from organic residues, in a circular economy context. Action research was used as the method to guide the collective construction (project team and partner companies), and the direction of the preliminary tests of packaging to be manufactured. The tests performed on coconut fibers in transfer molding and thermoforming were promising, but they required the addition of binder substances like byproducts from starch, especially in the transfer molding method. Besides using fibers from alternative sources to cellulose, the proposed packaging is potentially compostable and may replace non-renewable material like oil-based polymers.

Keywords: Circular economy, Sustainability, Ecodesign

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1 INTRODUCTION

Every year, a great number of raw materials is destined for the manufacturing of single-use only disposable packaging. Several times, they are made from non-biodegradable and non-renewable materials, like plastic, glass, and metal (Debnath et al, 2022). Some countries like Canada, Costa Rica, and the European Union prohibited the use of this packaging. In Brazil, plastic drinking straws and bags were banned in some states. According to the Brazilian Packaging Association (ABRE, 2022). Brazil produced the equivalent of 20.5 billion USD in packaging in 2021, a 31.1% increase over 2020, due to the increase in online shopping and food delivery. Of this, the most used materials are plastic at 37.1%; paper packaging at 34.6%, and metallic packaging at 21.4%.

The packaging excess challenges the sustainable development of our society (Lu et al., 2020). What is to be done with the residues generated from packaging on the planet, and what are the solutions found to minimize the environmental impacts? The transition of the dominating linear economy for a model based on intentional circularity and design may construct a new base essential for the market economy and packaging use (Casarejos et al., 2018). According to Weetman (2019), it is a real sustainable economy, which works without residues, saves resources, and acts in synergy with the biosphere. Instead of dealing with emissions, the subproducts, and damaged or undesirable goods like “residues” or “waste”, these items, in the circular economy, become raw material and input for a new cycle of production.

In this sense, molded pulp packaging has been conquering space in the market for being noticed as a sustainable material (Wever and Twede, 2007), for being done from renewable and/or recycled material, besides being easily reused in successive cycles. Insofar as the wood cellulose global price is growing and the advance of electronic media is reducing the recycling of fibers from paper residues, the demand for alternative sources of raw material for the creation of molded pulp packaging is continually growing (Gouw et al., 2017; Johnston, 2016). The present study aims at performing preliminary tests of molded pulp packaging manufacturing from organic residues, in a circular economy context. Considering the extension of the exposed problem, the following research question is presented: what challenges do the fibrous organic residues bring to the development of packaging by means of molded pulp techniques?

This research aims at contributing to the utilization of organic residues that may be in a process of incorrect destination, generating expenses or environmental damage for the producer and/or community, like soil contamination, transportation expenses, or taxes for destination in sanitary landfills. Besides, it technically explores the development of compostable packaging that replace non-renewable source materials like plastic, with attractive and functional structural projects, which add value to the residue and contribute to local development.

In section 2, characteristics of the materials and manufacturing processes of molded pulp products are explained, and some examples of similar packaging that are already marketed in the national and international markets are reunited. In section 3, there is the detailing of two tests performed: the first, using coconut fibers and cellulose in a traditional process of molded pulp; the second, using coconut fibers, cassava starch, and Teca wood sawdust in a thermoforming process. Finally, the main aspects observed during the tests are commented on, with recommendations for future research.

2 THEORETICAL REVIEW

Molded pulp products are currently used in the handling and packaging of thousands of manufactured products, providing protection to the products, and convenience to the clients in addition to economic and environmental benefits (IMFA, 2022). According to the International Molded Fiber Association (IMFA, 2022), molded pulp products may be categorized into four groups based on the manufacturing process and the quality of the materials:

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1. Thick wall: it uses a simple mold and achieves wall thickness between 5 and 10 mm. One surface is relatively smooth, with the other side very rough. The drying may be natural or in ovens. Used for packaging heavy items (vehicles pieces, furniture, motors, etc.);

2. Transfer Molding: it uses a shape mold and a transferring mold, and the wall thickness achieves around 3mm to 5mm. Surfaces are relatively smooth on both sides, with one side rougher. The drying may be natural or in ovens. The most common use is for eggs boxes and packaging electronic or household appliances products.

3. Thermoforming: it uses warm molds, where the product is pressed, densified, and dried - no need for oven cure. It achieves a wall thickness of around 1mm to 4mm. The surfaces are smooth and the shapes well-detailed. These products may be used as replacements for transformed plastic items.

4. Processed: this kind relates to products that require secondary or special treatment, like post-pressing, cut or drill, printing, special formulations and additives, and relief, among others.

For the purposes of this study, the emphasis will be given to the processes of transfer molding and thermoforming, considering that their finish results are adequate for a higher variety of packaging applications. In the transfer molding process, the result is a product with better dimensional precision in relation to the thick wall products, once not only the finish becomes much smoother, but also there is an opportunity of squeezing more water from the material (Didone et al., 2017). In this way, the improvements in precision and dimensional stability may expand the range of applications of these products. In the thermoforming process, the objective is to dry at least partially the molded pulp while it is still being pressed. As a rule, such a process may achieve a higher resistance, higher taxes on production, and a more detailed finish (Didone et al., 2017).

Debnath et al. (2022) observe that, as the result of a higher solids content (consistency) of the cellulosic fibers pulp, with all-directions-oriented fibers instead of being oriented mainly in one plan, it is possible to achieve very different results in comparison to the plane paper manufacturing. In addition, the fibers employed in the production of the molded pulp are possibly harder (less refined), in comparison to the manufacturing of products like printing papers or cardboard, besides suffering hornification (structural changes in fibers originated from dehydration or recycling of the fibrous pulp), which results in a greater rigidity of the wet fibers, leading to a thicker mantle structure (Zhang et al., 2022).

In pulp manufacturing, virgin (primary) fibers derived from woody or non-woody plants may be used, likewise recycled (secondary) fibers, derived from residues from paper and cardboard (Debnath et al, 2022). Natural fibers may be stemming from several resources, like wood (chemical and mechanical processes of pulping), recycled fibers, and agricultural biomass residues, for instance, wheat straw (Zhang et al., 2022), sugarcane bagasse, bamboo (Liu et al., 2021), banana stem, pineapple leaves (Rattanawongkun et al., 2020), sisal, abaca, dendê palm, and coconut (Westman et al., 2010). In general, relatively long fibers provide resistance, tenacity, and structure, while shorter fibers generally may provide high volume (low density), quite enclosed texture, and surface smoothness. The fiber length distribution also influences a series of properties. For instance, a short fiber length distribution will form a thinner structure in comparison to long fibers distribution (Debnath et al, 2022).

The non-academic literature reveals which raw materials of vegetal origin are currently being used in molded pulp packaging manufacturing in national and international companies. Secondary research from information available in Google Explorer® and Scholar® platforms allowed to highlight 15 companies from different countries that manufacture such products, and the data were obtained, mainly, from their respective websites and news platforms. In relation to the selected companies, Growpack, Já fui mandioca, Ankur, Pulpac, Lifepack, and Be green packaging stand out. The website links are available in the references list at the end of this paper.

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Among the eight Brazilian companies of the group, it was possible to observe that they use, in higher proportion, maize or wheat straw, cassava starch, or sugarcane bagasse in their packaging manufacturing. In some cases, it is not used only a single input in the composition, being possible to mix bamboo fibers, wood sawdust, or rice husk. In the other countries, besides the material already used in Brazil, companies that use less-conventional raw materials, like banana stems, coconut fibers (Figure 1), hemp straws, and vine blocks, among others, were found. Besides, less than half produce from subproducts' inputs, that is, agricultural residues that are not treated or reused in the production chain.

Figure 1. Coconut-fiber-based packaging example

The main manufacturing process used by these companies is thermoforming. The result is products with a well-detailed finish that have a similar appearance to plastic material (IMFA, 2022). Because they have a nice finish, these packaging are mainly destined for the food sector, mainly fast food. In a few cases, when the molding process is by transference, they are produced with the aim of protecting other kinds of products, like electronics, household appliances, and furniture (IMFA, 2022).

3 METHODOLOGY

The research is the applied type, and it is characterized by its practical interest. The nature is exploratory, because its purpose is to provide greater familiarity with the problem, to make it more explicit, or to build a hypothesis (Gil, 2010). To understand the state of the art on molded pulp, a search was carried out in the Web of Science database in the period of September 1st to 15th, 2022, using the string: pulp molding, molded pulp, and packaging. In this search, 17 articles on the topic were extracted. To carry out the preliminary tests, the action-research method was used. Action research has an empirical basis that is conceived and carried out in association with an action or with the resolution of a collective problem, and comprises repeated cycles of analysis, fact-finding, conceptualization, planning, action implementation, and evaluation (Gil, 2010). A participant survey was carried out, the researchers carried out the practical tests, observations, analyses, and the design of the final report, as well as the bibliographical research that helped in the design of this study.

In this context, the research is used for the collective construction (project team and partner companies) of preliminary tests of packaging to be produced from waste. To assist in the collection of data on packaging, the Packaging Radar was used, a reference model developed by Sastre et al., (2020), which considers the theoretical framework specific to each stage of the packaging life cycle, it offers a perspective on the simple and systemic at the same time and serves as a guideline for the design of sustainable packaging. Based on the partner companies, the parameters for preliminary tests were defined.

4 RESULTS AND DISCUSSION

In the present section, the results of the preliminary tests of pulp molding from discarded coconut fibers, cellulose, cassava starch, and Teca wood sawdust (Tecnona grandis) are presented. Coconut fiber and sawdust were selected by the team due to the availability of waste that is currently sent to landfills by partner companies in the study. Cassava starch and cellulose were selected because they are the inputs most used by the converting industries that collaborated with the tests described below and because they are abundant residues of Brazilian agriculture. The team decided to test transfer molding and thermoforming.

4.1 Transfer molding

The transfer molding tests were carried out in a molded pulp packaging converter industry located in São Bento do Sul, a city in the state of Santa Catarina, Brazil on September 29th, 2022. To develop this study, dehydrated coconut residues in long fibers and powder mixed with water were used. The tests were carried out on a manual machine with an angle die for forming (Figure 2.a), resulting in the following scenarios: a) long fibers and pure coconut powder were not suitable for this process, because even if there were mixers at the bottom of the tank, the material settled and did not stick to the mold; b) as cellulosic fibers were added to the mixture (pre-consumer cardboard scraps, supplied by packaging companies), better results were observed in the agglutination of the fibers among themselves and in the molding; c) the best result observed contained a mixture of 50/50 cellulose pulp and coconut powder. In this composition, it was possible to shape the piece and dry it with little deformation (Figure 2.c).

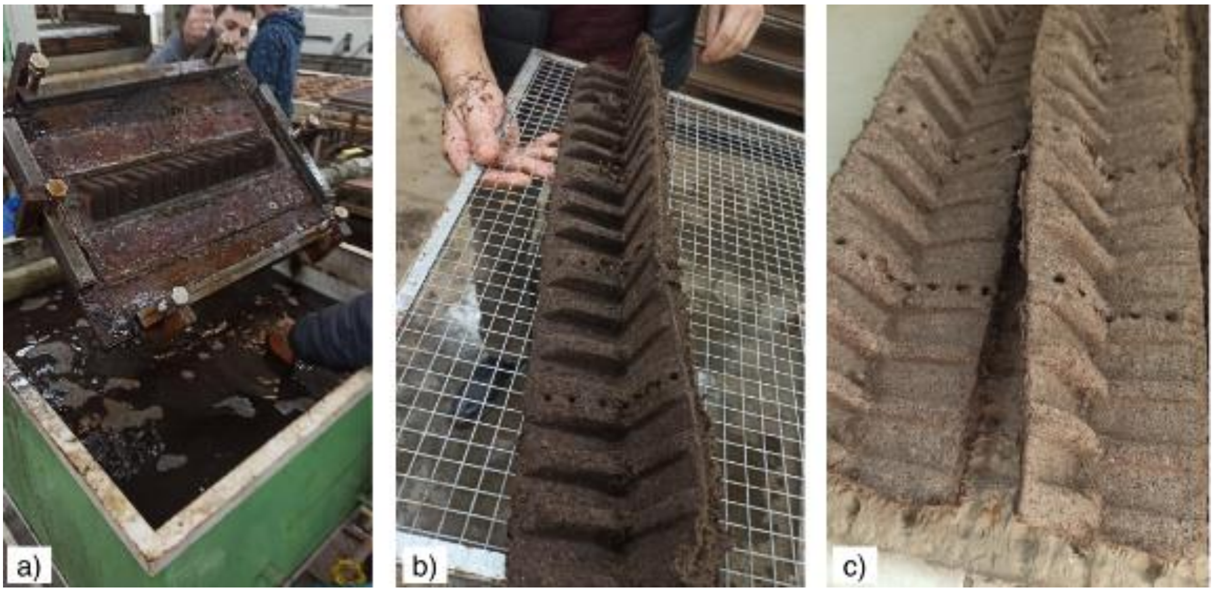

Figure 2. a) a) Manual transfer molding machine; b) Molded piece with cellulose and coconut powder before drying; c) Dry molded piece.

In this process, around 90% to 92% of water is used in the composition for mixing in the tanks and passing through the pipes, however, a large part of the water is removed during molding and returns to the process. According to the converting industry, damaged parts and residual material are returned to the tanks for reprocessing, with no generation of pre-consumer waste.

As it is a company specializing in packaging manufacture and components made from molded cellulose pulp (unprinted cardboard scraps acquired from shipping box industries), the tests became feasible and quick. The green coconuts were dehydrated and sent in long and short fiber formats to the company. The internal material analysis laboratory, after several tests such as fiber strength, agglutination, and expansion in water, found that the short coconut fiber could continue with the tests in the machine, as they presented characteristics like cellulosic fiber. The practical tests determined the percentage of viable coconut fiber for the formation of the piece. This preliminary study aimed to explore the behavior of the material. It is intended in future studies to deepen the tests through experimental designs (Design of Experiments) to extract knowledge about the variables of the process of making the short coconut fiber and the parameters of the productive equipment. The objective of this study is to use organic waste in the manufacture of packaging. Although cellulosic fiber is compostable, the goal of the preliminary tests is to be able to use the highest percentage of coconut fiber in its composition.

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4.2 Thermoforming

In the second stage of tests, thermoforming was used to analyze differences in fiber behavior between processes. The tests were carried out in a compostable packaging factory in the city of Novo Hamburgo, state of Rio Grande do Sul, Brazil, on August 10th, 2022. This industry uses cassava starch as a base raw material in the composition of its products. Four different compositions were tested with the cassava starch, long coconut fiber, coconut powder, Teca sawdust (Tecnona grandis), and water, in a food tray matrix, as described below (proportions in relation to the weight of each item): a) 59.7% water, 38.3% cassava starch and 1.9% long coconut fiber; b) 40.74% water, 43.82% cassava starch, 3.08% long coconut fiber and 12.34% coconut powder; c) 25.16% water, 38.7% cassava starch and 36.13% coconut powder; d) 37.82% water, 35.23% cassava starch and 26.94% sawdust, (Figure 3).

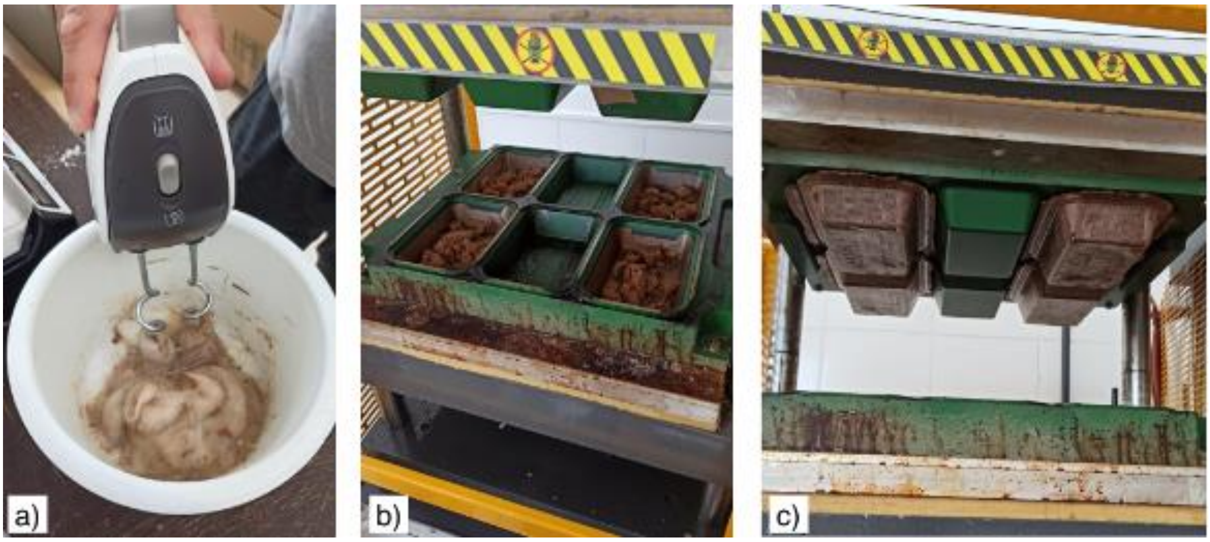

Figure 3. a) Composition mix I; b) Composition taken to thermoforming matrix; c) Thermoformed trays

The mixtures were made manually (Figure 3.a) and thermoformed at the same time (3'3”) and at the same pressure (20 bar). The addition of water in the compositions varied according to the texture and volume they presented during mixing. All compositions had satisfactory conformation results, however, due to their composition and water evaporation, they revealed very different final weights (14g, 26g, 28g, and 40g, respectively), as shown in Figure 4.

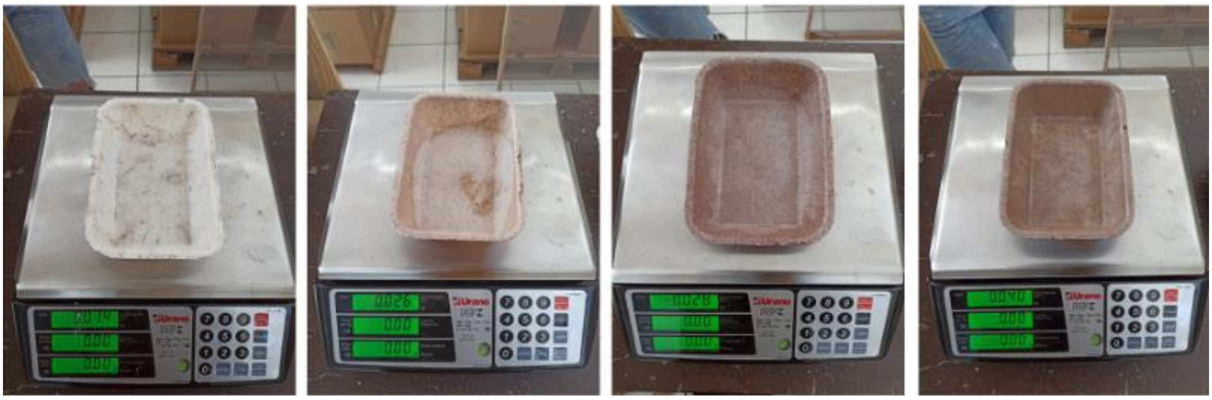

Figure 4. a) Visual result and the weight (in grams) of each composition test

This process also uses water in its composition, and it is an essential element for the materials mixing, expansion, and agglutination of starch in the heat. In contrast to transfer molding, this process loses water through evaporation, and pre-consumer waste cannot be reprocessed but is compostable.
The company is making initial investments in the production process and has adapted an electric press used in the manufacture of shoe soles. They currently produce compostable packaging on a small

scale, but they want to increase their production capacity and dispose of other residues in addition to cassava starch. The tests with coconut fiber and sawdust from Tecnona grandis became feasible due to the company's factory configuration. A good part of the information about the feasibility of the tests was previously provided by the company's professionals, reducing the number of attempts until reaching the minimum viable product.

Transfer molding allows large-scale production, making it possible to serve larger markets, such as food. This process has the advantage of causing less environmental impact, with reduced energy consumption and reuse of water in the manufacturing process, as well as the reinsertion of packaging as raw material. The thermoforming process consumes a lot of electricity in its press and water evaporates in the manufacturing process. The packages cannot be reinserted in the process; however, they are compostable. What positively differentiates it is the sophisticated finish and the greater possibility of packaging food, due to its high temperature pressing process, which potentially eliminates contamination by bacteria and fungi. Future studies should be carried out for analysis of these contaminants and compliance with legislation pertaining to the packaging of this nature.

5 FINAL CONSIDERATIONS

Concerning the growing demand for disposable packaging, molded pulp models have gained space in the market as they are perceived as a sustainable material, despite their aesthetic and geometric limitations (Wever and Twede, 2007). When testing new raw material alternatives for molded pulp processes, this study presented that there is an opportunity to use agricultural waste to replace packaging that is produced from polymers, such as food trays, and parts for protecting electronic products and home appliances, among others.

The preliminary tests carried out with coconut fibers were promising but required the addition of binding substances such as starch derivatives (in thermoforming) and cellulose (in transfer molding). Thermoforming tests with coconut fiber obtained satisfactory results, but its residues cannot be reprocessed, unlike transfer molding. The parameters studied will be the basis for proposing experimental designs and impact analysis of manufacturing processes. Variables related to the composition of the raw materials and adjustments in the process parameters will allow inferences about the technical feasibility of producing molded pulp packaging on a large scale. Follow-up indicators for future tests should be proposed, both from the physical point of view of the packaging and from the microbiological point of view. In addition, it is intended to search more on molded pulp, existing production models in other countries, and organic adjuvants with binding, brightness, and other properties. In relation to the research question, the challenges experienced in the preliminary tests showed difficulties in adapting conventional molded pulp manufacturing processes from cellulose. In the transfer molding process, the long coconut fiber did not pass through the equipment piping, due to its elongated characteristic. The short fiber behaved well, but with a low level of agglutination. The thermoforming process is a more flexible process for accepting new materials, but the challenge is to be able to produce on an industrial scale, compatible with market demands.

This study sought to initiate a discussion on the replacement of raw materials of fossil origin by renewable materials, which have no commercial value and are difficult to send to landfills. It is understood that this research is at an early stage. New tests need to be carried out in search of the technical and financial feasibility of producing molded cellulose packaging. Other challenges will be faced with the implementation of large-scale production of molded cellulose packaging from fibrous waste and are related to scalability, approval for use by government agencies and the total production cost of the chain. It is recommended the implementation of the packaging industry, close to the waste generator to avoid transport costs and CO2 emissions. The marketing of packaging must supply local communities. Finally, a life cycle analysis (LCA) between plastic packaging and molded pulp packaging is recommended as a study to verify the strengths and weaknesses of the proposed packaging, based on organic waste.

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