



PRODUCTION AND CHARACTERIZATION OF HANDMADE PAPER FROM MANGO (*MANGIFERA INDICA* L.) SEED COAT AND PULP FIBERS

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ABSTRACT

Objective: This study aimed to produce handmade paper from fibers of the seed coat and pulp of mango (*Mangifera indica* L.), Bacuri variety, evaluating its physico-mechanical properties and viability as a sustainable alternative for valorization of agroindustrial waste.

Theoretical Framework: The methodology included specimen collection, fruit treatment with sodium hypochlorite disinfection (2.5%), alkaline fiber extraction with NaOH (10-20%), followed by handmade paper production and characterization of physico-mechanical properties according to TAPPI standards for grammage (T410), thickness (T411), and tensile strength (T494).

Method: The methodology adopted for this research comprises [concisely describe the study design, including approach, participants, instruments, procedures, etc.]. Data collection was carried out through [explain the specific methods used, such as interviews, questionnaires, observations, among others].

Results and Discussion: Results showed fiber extraction yields of 18.94% (pulp) and 6.59% (seed coat), with paper properties comparable to conventional products: grammage of 230.33 g/m², thickness of 0.23 mm, and tensile strength of 15.44 N. The discussion highlighted the physical and mechanical characteristics of the produced paper in comparison with literature.

Research Implications: Results demonstrate potential applications in packaging and artisanal stationery, directly contributing to Sustainable Development Goals (SDGs) 9 (Industry, Innovation and Infrastructure), 11 (Sustainable Cities and Communities), and 12 (Responsible Consumption and Production) by promoting circular economy and reducing environmental impacts in mango-producing regions.

Originality/Value: This study innovates by integrally utilizing specific mango residues, offering a technical and sustainable solution for small producers. Its value is amplified by alignment with regional bioeconomy and contribution to multiple SDGs, demonstrating how applied research can generate positive environmental, social and economic impacts.

Keywords: Handmade Paper, Waste, Fibers, Sustainability, *Mangifera indica* L.

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PRODUÇÃO E CARACTERIZAÇÃO DE PAPEL ARTESANAL A PARTIR DE FIBRAS DO TEGUMENTO E DA POLPA DE MANGA (*MANGIFERA INDICA L.*)

RESUMO

Objetivo: Este estudo teve como objetivo produzir papel artesanal a partir das fibras do tegumento e da polpa de manga (*Mangifera indica L.*), variedade bacuri, avaliando suas propriedades físico-mecânicas e viabilidade como alternativa sustentável para valorização de resíduos agroindustriais.

Referencial Teórico: Apresentam-se os principais conceitos que fundamentam a pesquisa, como informações gerais sobre a variedade bacuri, princípios da economia circular e técnicas de extração de celulose, com ênfase em métodos alcalinos para remoção de lignina e hemicelulose, destacando o potencial de resíduos agrícolas para produção de fibras celulósicas.

Método: A metodologia incluiu coleta das espécimes aplicadas, tratamento dos frutos com higienização por hipoclorito de sódio (2,5 %), extração alcalina das fibras com NaOH (10-20%), seguida de fabricação de papel artesanal e caracterização das propriedades físico-mecânicas conforme normas TAPPI para gramatura (T410), espessura (T411) e resistência à tração (T494).

Resultados e Discussão: Os resultados mostraram rendimentos da extração das fibras de 18,94% (polpa) e 6,59% (tegumento), com propriedades do papel comparáveis a produtos convencionais: gramatura de 230,33 g/m², espessura de 0,23 mm e resistência à tração de 15,44 N. A discussão destacou as características físicas e mecânicas do papel fabricado, em comparação com a literatura.

Implicações da Pesquisa: Os resultados demonstram potencial para aplicação em embalagens e papelaria artesanal, contribuindo diretamente para o alcance dos Objetivos de Desenvolvimento Sustentável (ODS) 9 (Indústria, Inovação e Infraestrutura), 11 (Cidades e Comunidades Sustentáveis) e 12 (Consumo e Produção Responsáveis), ao promover economia circular e redução de impactos ambientais em regiões produtoras de manga.

Originalidade/Valor: Este estudo inova ao utilizar resíduos específicos da manga de forma integral, oferecendo uma solução técnica e sustentável para pequenos produtores. Seu valor é amplificado pelo alinhamento com a bioeconomia regional e contribuição para múltiplos ODS, demonstrando como a pesquisa aplicada pode gerar impactos ambientais, sociais e econômicos positivos.

Palavras-chave: Papel Artesanal, Resíduo, Fibras, Sustentabilidade, *Mangifera indica L.*

PRODUCCIÓN Y CARACTERIZACIÓN DE PAPEL ARTESANAL A PARTIR DE FIBRAS DEL TEGUMENTO Y PULPA DE MANGO (*MANGIFERA INDICA L.*)

RESUMEN

Objetivo: Este estudio tuvo como objetivo producir papel artesanal a partir de fibras del tegumento y pulpa de mango (*Mangifera indica L.*), variedad Bacuri, evaluando sus propiedades físico-mecánicas y viabilidad como alternativa sostenible para la valorización de residuos agroindustriales.

Marco Teórico: Se presentan los principales conceptos que fundamentan la investigación, como información general sobre la variedad Bacuri, principios de economía circular y técnicas de extracción de celulosa, con énfasis en métodos alcalinos para remoción de lignina y hemicelulosa, destacando el potencial de residuos agrícolas para producción de fibras celulósicas.

Método: La metodología incluyó recolección de especímenes, tratamiento de frutos con desinfección por hipoclorito de sodio (2,5%), extracción alcalina de fibras con NaOH (10-20%), seguida de fabricación de papel artesanal y caracterización de propiedades físico-mecánicas según normas TAPPI para gramaje (T410), espesor (T411) y resistencia a la tracción (T494).

Resultados y Discusión: Los resultados mostraron rendimientos de extracción de fibras de 18,94% (pulpa) y 6,59% (tegumento), con propiedades del papel comparables a productos convencionales: gramaje de 230,33 g/m², espesor de 0,23 mm y resistencia a la tracción de 15,44 N. La discusión destacó las características físicas y mecánicas del papel fabricado en comparación con la literatura.



Implicaciones de la investigación: Los resultados demuestran potencial para aplicación en empaques y papelería artesanal, contribuyendo directamente al logro de los Objetivos de Desarrollo Sostenible (ODS) 9 (Industria, Innovación e Infraestructura), 11 (Ciudades y Comunidades Sostenibles) y 12 (Producción y Consumo Responsables), al promover economía circular y reducción de impactos ambientales en regiones productoras de mango.

Originalidad/Valor: Este estudio innova al utilizar integralmente residuos específicos de mango, ofreciendo una solución técnica y sostenible para pequeños productores. Su valor se amplifica por el alineamiento con la bioeconomía regional y contribución a múltiples ODS, demostrando cómo la investigación aplicada puede generar impactos ambientales, sociales y económicos positivos.

Palabras clave: Papel Artesanal, Residuo, Fibras, Sostenibilidad, *Mangifera indica* L.

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1 INTRODUCTION

The increasing industrialisation of tropical fruits such as mango (*Mangifera indica* L.), generates large volumes of plant waste, including peels, unused pulps and stones. It is estimated that about 60% of the total fruit mass is discarded after processing (Po & Po, 2012), representing an environmental and economic challenge. However, these by-products are rich in cellulosic fibres, proteins and structural compounds with potential for sustainable applications, such as the production of handmade paper.

Cellulose, the main component of the plant cell wall, is a biopolymer widely used in the traditional paper industry, whose extraction demands renewable and low impact sources (Klemm *et al.*, 2005). In this context, agro-industrial waste — such as mango seed coat and residual pulp — emerges as alternative raw materials, aligned with the principles of the circular economy (Ellen MacArthur Foundation, 2015). Studies show that unconventional vegetable fibres can produce papers with mechanical properties suitable for specific uses, such as packaging and cards (Bhatnagar & Sain, 2005; Santos *et al.*, 2015).

In Brazil, the northern region stands out for its biodiversity and the emerging production of mango, but still lacks technologies for the full recovery of this waste. Alkaline extraction processes, such as treatment with sodium hydroxide (NaOH), have been effective in removing lignin and hemicellulose, preserving cellulose fibres (Pandey *et al.*, 2000; Lorenzo-Santiago & Rendón-Villalobos, 2020). The viability of these fibres for the production of handmade paper, however, depends on parameters such as weight, tensile strength and thickness, which need to be evaluated for practical applications.



Thus, the objective of this work is to manufacture handmade paper from the fibres of the tegument and mango pulp (*Mangifera indica* L.), characterising its physical-mechanical properties - weight (g / m²), thickness (mm) and tensile strength (N) -, in addition to evaluating the yield of fibre extraction (%). It seeks to compare the results with reference standards for applications in packaging and stationery, aiming to prove the technical feasibility of the process as a sustainable alternative for the valorisation of agro-industrial waste, reduction of environmental impacts and contribution to the regional bioeconomy.

2 THEORETICAL FRAMEWORK

2.1 MANGO (*MANGIFERA INDICA* L.) AS A SUSTAINABLE RAW MATERIAL

Abstract: Mango (*Mangifera indica* L.), a prominent member of the *Anacardiaceae* family, shares botanical characteristics with other tropical fruits of economic importance such as cashew (*Anacardium occidentale*) and hog plum (*Spondias mombin*). Originally from Southeast Asia, this species has adapted exceptionally well to Brazilian climatic conditions, particularly in the North and Northeast regions (Yahia, 2011). The commercial cultivation of mango in Brazil dates back to the colonial period, when the Portuguese introduced the first seedlings in Rio de Janeiro in the sixteenth century, starting a process of dissemination that culminated in its establishment as an important fruit culture throughout the national territory (Simão, 1971).

The bacuri variety (Figure 1), the object of this study, presents morphological particularities that make it especially suitable for fibre extraction. With an average weight of 300 g per fruit and seeds between 30 and 50 g (Gobira, 2021), this cultivar from Pará has a well-developed fibrous structure in both the integument and residual pulp. The fruits of the *Anacardiaceae* family are among the tropical fruits of greater economic expression in the Brazilian markets (Cordeiro *et al.*, 2012) the use of the bacuri variant corroborates the idea of Brazil (2014), which defends the handling of local and seasonal foods, bringing benefits such as local development and encouragement for small producers.



Figure 1

Examples of bacuri mango used in the present study.



2.2 CIRCULAR ECONOMY

The circular economy model applied to mango processing represents a paradigmatic break with the traditional linear production system. In the approach proposed here, waste from industrial processing - traditionally considered environmental liabilities - is transformed into economic assets through conversion into fibres for the production of handmade paper (Ellen MacArthur Foundation, 2015). This process gains special relevance when we consider that the mango production chain generates approximately 60% of waste in relation to the total weight of the processed fruit (Po & Po, 2012).

The implementation of this model in the North region of Brazil presents significant competitive advantages. The concentration of production in specific microregions, such as the northeast of Pará, allows the development of local productive arrangements that integrate small producers, agro-industries and artisans (Rosa *et al.*, 2022). This integration enhances not only the environmental benefits, through waste reduction, but also the social impacts, generating new sources of income and sustainable business opportunities.

2.3 EXTRACTION OF CELLULOSE FIBRES

Cellulose is a linear polysaccharide composed of glucose units linked by β -1,4-glycosidic bonds, which confer high mechanical strength and chemical stability, being the main raw material for paper production (Klemm *et al.*, 2005). According to Biazus *et al.* (2010), this substance is naturally combined with other polymers, such as hemicellulose and lignin, which play essential structural roles. Lima *et al.* (2015) cite wood as the main natural source of



cellulose, widely commercially exploited to meet the demands of the paper industry. However, cellulose can also be obtained from other sources, such as plants (hemp, flax, jute, ramie and cotton), seaweed, mosses, tunicates and some species of bacteria, such as those of the genus *Gluconacetobacter* (Eichhorn *et al.*, 2010; Donini *et al.*, 2010). Abstract: The growing demand for sustainable sources and the need to reduce the environmental impact have driven the exploration of alternative raw materials, such as agricultural waste, for the extraction of cellulose fibres.

Abstract: The extraction of cellulose fibres from agricultural residues, such as peels, leaves and fruit stones, has gained prominence in scientific research due to its economic and environmental potential. This approach reduces waste and reduces dependence on traditional sources, aligning with the principles of circular economy and sustainability (Bhatnagar & Sain, 2005). These wastes, which are often discarded or underutilised, contain significant amounts of cellulose, hemicellulose, and lignin. Lignin, in particular, is a complex polymer that acts as a cementing agent, giving rigidity to the cell walls of plants. However, its presence makes it difficult to extract pure cellulose, requiring chemical or physical processes for its removal (Sun *et al.*, 2004).

Among the techniques of extraction of cellulose fibres, cited by Libby (1969), the chemical methods, such as the Kraft process, the sulphite process and the treatment with sodium hydroxide (NaOH), are widely used in the industry. The treatment with NaOH is less aggressive and has been successfully applied in the extraction of cellulose from agricultural residues, such as fruit peels and sugarcane bagasse (Pandey *et al.*, 2000).

Recent studies have demonstrated the feasibility of extracting cellulose fibres from agricultural wastes. For example, sugarcane bagasse, a by-product of the sugar and alcohol industry, has been widely studied due to its high cellulose content. Saelee *et al.* (2014) demonstrated that the treatment of sugarcane bagasse results in cellulose fibres with adequate physicochemical properties. Likewise, coconut shell residues have been explored as a source of cellulose. A study by Rosa *et al.* (2018) used an extraction process combining chemical and mechanical treatments to obtain cellulose fibres from coconut shells, highlighting the potential of this material for industrial applications.

In this context, mango (*Mangifera indica* L.), a fruit widely grown in tropical regions, has its shell and core rich in cellulose. These residues can be transformed into products with high added value, such as flour and materials for the production of paper. For example, Lorenzo-Santiago and Rendón-Villalobos (2020) extracted cellulose microfibers from the mango endocarp using alkaline treatment followed by bleaching, obtaining satisfactory results.



Thus, the extraction of cellulose fibres from agricultural waste not only contributes to reducing waste, but also promotes the circular economy, transforming by-products into valuable resources and contributing to SDGs 09, 11 and 12.

2.4 PAPER PRODUCTION

The technification of the paper, in an aspect of historical evolution, closer to the current fundamental processes for making the paper, dated back to 105 AD in China, where there was the pre-preparation of the raw material in cooking, submitted substantially to sieving and drying. In Brazil, according to Campanato (2004), the arrival of the royal family and the emergence of new institutions such as banks, directly linked to the printing of documents, was a precursor to the development of the first pulp and paper industry in the country, using the extraction of embira fibre.

Highlighted the viability of the raw material, cellulose is the main material for the production of paper, a long chain polymer, which is extracted from vegetable fibres. The paper production line carries out chemical processes and unit operations. This occurs in order to obtain the product with cellulose and hemicellulose by solubilising lignin, described in sequential processes such as the preparation of the raw material, extraction of cellulose (pulp), refining and drying of the paper produced (Texeira *et al.*, 2017).

Paper production begins with the extraction of cellulose from vegetable fibres, the material being subjected to high pressure stripping (70–200 bar) by mechanical friction or in rotating drums (6–20 rpm), followed by crushing and particle size adjustment, with particles out of specification that can be used as fuel (Silva & Lima, 2025). Pulping can be mechanical or chemical: the first, applied to softer materials such as *Pinus*, involves cooking at 120–140 °C and mechanical *defibrillation* (up to 180 °C, >1000 rpm, 4–8 bar); *chemistry is divided into Kraft processes* (basic medium with NaOH and Na₂S, preserving long fibres) and *sulphite* (acid medium with sulforous acid and bisulphite, 6.1–7.6 bar, 125 °C), according to Sherve and Brink (1980). Bleaching removes residual lignin and adjusts the whiteness with NaOH and chlorinated compounds (Kloeber & Schmidt, 2017), while refining increases the surface area of the fibres via fibrillation, using continuous refiners with concentric cones for optimisation of interlacing (Carvalho & Mendes, 2016). Finally, the fibrous suspension is dried and can receive additives for adjusting texture or gloss during sheet formation, according to processes such as Hawking Process (Rangel *et al.*, 2010).



3 METHODOLOGY

For this study, mango residues (*Mangifera indica* L.), Bacuri variety, collected in the municipality of Concórdia do Pará, northeastern region of the state, in January 2025 were used. The botanical identification was confirmed by comparison with herbarium specimens from the IAN Herbarium (Embrapa Eastern Amazon), according to NID 08/2025 report. The fruits, selected in a uniform maturation stage, were transported under refrigeration (10 °C) to the Chemical Engineering Laboratory (LEQ) of the Federal University of Pará (UFPA), in Belém.

3.1 PRE-TREATMENT OF FRUITS

Initially, the raw material underwent a washing and sanitising process, according to the recommendations of Monteiro and Tiecher (2022) for fruits. The fruits were washed in running water and then submerged in a 2.5% bleach solution for 15 min. After this period, the excess solution was removed by washing in distilled water. With the material properly dried, the fruits were separated into their different anatomical parts: epicarp (shell), mesocarp (pulp), integument (core) and endocarp (almond).

3.2 PRODUCTION OF CRAFT PAPER FROM MANGO PULP AND TEGUMENT FIBRES

3.2.1 Extraction of cellulose fibres

For the manufacture of handmade paper from the pulp and mango seed coat fibres (PAPTM), the process begins with the separation of the seed coat of the almond and residual fibres from the pulp of the fruits to extract the cellulose fibres.

The separation of pulp fibres and integument fibres was carried out by means of a process that included an alkaline extraction method, washing, drying and grinding of the fibres.

Thus, for the removal of hemicellulose and lignin from the material, an alkaline treatment with NaOH (20%, w/v) was carried out under maceration for a period of 24 h for the tegument fibres and an alkaline treatment with NaOH (10% w/v) under maceration for 5 h for the pulp fibres. After that, the suspension was filtered and washed with excess distilled water, with the aid of a 1% phenolphthalein indicator. This washing was done until reaching neutrality, guaranteeing the removal of the reagent. The extracted material (cellulose fibre) was dried at



50 °C in an oven with forced air circulation for 24 h and stored in an airtight container until use.

3.2.2 Manufacture of PAPTМ sheets

The manufacture of the PAPTМ sheets involved steps that include fibre selection, binder solution preparation, modelling and drying, following a specific methodology to obtain a uniform material. According to the methodology adapted from Silva and Oliveira (2015), an amount of treated fibres from the tegument and pulp of the mango was homogenised with water in the proportion of 1 ml of water to 0.0575 g of fibres and, in a 1 L becker, about 15 g of arabic gum was added to the solution. This PAPTМ solution was homogeneously poured onto a thin-mesh mould, shown in Figure 3, to facilitate the removal of excess water from the mould. The mould with PAPTМ distributed and homogenised on the fine mesh was taken to a conventional oven at 50 °C for 16 h.

Figure 2

Handmade paper from the pulp fibres and mango seed coat after drying in an oven.



3.2.3 Characterisation of PAPTМ sheets

3.2.3.1 Weight test

The weight test was done in triplicate, by the method adapted from the TAPPI T410-om23 (TAPPI, 2023) standard for weight and basic density, cutting a piece of paper of 3cm x



3cm, Figure. Each sample was taken to an analytical balance to check its mass. The paper weight was determined by Equation 1.

$$G = \frac{K \cdot m}{A} \quad (1)$$

where:

m = mass of paper in g

A = paper area in m²

K = correction factor, equivalent to 10,000

Figure 3

Weight test performed on handmade paper from pulp fibres and mango integument.



3.2.3.2 Thickness test

The thickness test was performed in triplicate, using a piece of paper in the micrometre (Marberg 0-25 mm) that was read and recorded as reported by the TAPPI Standard T411-om21 (TAPPI, 2021). Figure 4 shows the reading and test performance.



Figure 4

Thickness test performed on handmade paper from pulp fibres and mango integument.



3.2.3.3 Tensile strength test

The tensile strength test was done in triplicate and consisted of cutting a strip of paper 24 mm long and 15 mm wide and attaching it to the tensile machine (Biopdi) to then apply a certain force to the paper until it breaks. This force applied to the rupture was read by the machine and recorded as it is ensured by the TAPPI Standard T494-om22 (TAPPI, 2022). Figure 5 shows the samples cut into strips according to the methodology.

Figure 5

Samples of handmade paper from pulp fibres and mango integument applied to the tensile test.





4 RESULTSS AND DISCUSSÕES

4.1 EXTRACTION OF CELLULOSE FIBRES

The approximate yields for the fibres were 18.94% and 6.59% w/w for the extraction process carried out on the pulp and the integument, respectively. Similar studies on the extraction of fibre from other fruits or agricultural residues (such as banana, pineapple, coconut, etc.) often report variable yields depending on the part of the plant and the extraction method (Rowell *et al.*, 2000; Santoset *et al.*, 2015). For example, in studies with banana fibres, yields can range from 10% to 30%, depending on the part of the plant and the extraction conditions (Kumar *et al.*, 2017).

Thus, the difference between the yields of the two parts of the mango can be attributed to the distinct chemical composition and the efficiency of the extraction method used. Figures 7 (a) and (b) show the results of this extraction.

Figures 7

Fibres extracted from the fruit of Mangifera indica L. (a) Fibres obtained from the fruit pulp. (b)Fibres extracted from the integument.

(a)



(b)



4.2 MANUFACTURE OF PATPM SHEETS

Figure 8 shows the result of the production of handmade paper sheets from pulp fibres and mango integument.



Figure 8

Leaves of handmade paper made from the fibres of the mango pulp and tegument.



4.2.1 Characterisations of PATPM sheets

The characterisation of the handmade paper produced from the fibres of the mango included fundamental tests to evaluate its physical and mechanical properties. In this way, parameters such as weight, thickness and tensile strength, essential to determine the quality and applicability of the material, were analysed. Table 1 summarises the results obtained.

Table 1

Physical and mechanical characterisations of PATPM.

Feature	Result
Weight	$230.33 \pm 43.68 \text{ g/m}^2$
Thickness	$0.2333 \pm 0.1644 \text{ mm}$
Tensile strength	-
Maximum force	$15,442 \pm 3,1725 \text{ N}$
Maximum voltage	$0,0429 \pm 0,0088 \text{ MPa}$
Rupture deformity	$4,58 \pm 1,28 \%$
Energy absorbed (TEA)	$2.1043 \pm 0.9371 \text{ J/m}^2$

The results of the physical and mechanical characterisation of the handmade paper produced from the mango fibres (PATPM) revealed properties that position it as a viable material for specific applications. The average weight of the paper was $230.33 \pm 43.68 \text{ g/m}^2$, a value that falls within the range of conventional medium weight papers (120 g/m^2 to 240 g/m^2), generally used for packaging and cards (Futura Express, 2017). In comparison with the study by Bastianello *et al.* (2009), which evaluated the physical and mechanical properties of recycled paper with banana or rice straw residues, the weight values ranged from 140 to 180 g/m^2 ,



indicating that the weight of the MWTP is above these values. Andrade *et al.* (2001) recorded values of 177 and 221 g/m² for handmade papers produced with 20% (m/m) of bamboo paste or sugarcane bagasse, respectively. On the other hand, Senna *et al.* (2018) obtained a weight of 52.840 ± 2.104 g/m² for bleached paper of brachiaria grass. These differences suggest that the type of vegetable fibre, the extraction method and the treatment of the fibres significantly influence the paper weight, corroborating Andrade *et al.* (2001), which highlight that the type of pulp used exerts a distinct impact on this property.

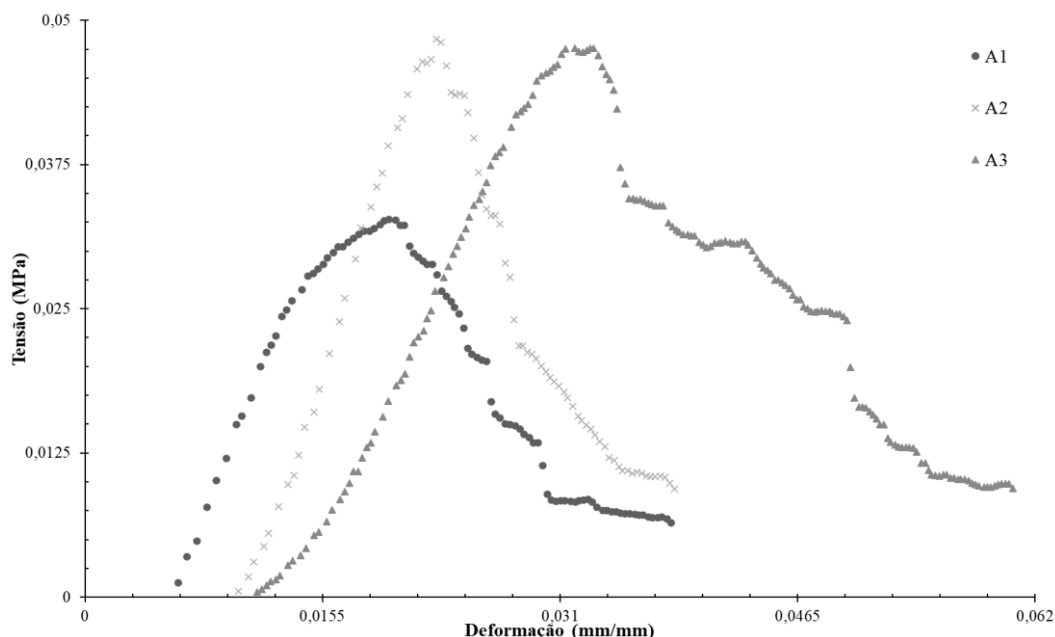
The average thickness of the MWTP was 0.2333 ± 0.1644 mm, indicating a relatively compact structure, comparable to recycled paper, which generally have thicknesses between 0.15 and 0.25 mm (Gonçalves *et al.*, 2018). In relation to the study by Bastianello *et al.* (2009), which reported thickness values ranging from 0.33 to 0.44 mm, the PMWR presented a lower thickness. Catunda *et al.* (2012) verified thicknesses of different types of paper, obtaining results of 0.088 mm (Kraft paper), 0.081 mm (recycled paper), 0.190 mm (handmade paper) and 0.100 mm (industrial paper). The variation in thickness is in accordance with Coraiola and Mariotto (2009), who demonstrated that factors such as plant species, variety, soil and climate conditions, fibre cutting method, paper shade used and amount of water added to the process can influence characteristics of ecological paper, such as colour, texture, malleability and thickness.

The graph in Figure 9 shows that samples A₂ and A₃ are more suitable for applications that require greater strength and ductility, while sample A₁ may be less suitable for these applications. The variation between the samples can be attributed to the lack of uniformity of the fibres in the paper or failures in the test. To ensure greater reliability of the results, it would be necessary to test a larger number of samples and review the product characterisation process.



Figures 9

Results of the tensile tests applied to the PATPM samples.



The maximum force indicates the tensile strength of the material, i.e. the force required to break the sample. When comparing with commercial paper, the typical maximum strength for office paper varies between 15 N and 30 N, while for kraft paper and cardboard, the values can reach 20 N to 50 N and 100 N or more, respectively (Smook, 2002). The average value obtained (15.442 ± 3.1725 N) is in the range for office paper and below the typical values for more resistant papers, such as kraft paper and cardboard.

The maximum stress reflects the intrinsic resistance of the material, considering the cross-sectional area of the sample. For office paper, the typical maximum stress varies between 0.04 MPa and 0.08 MPa, while for kraft paper and cardboard, the values can reach from 0.06 MPa to 0.15 MPa and 0.2 MPa or more, respectively (Smook, 2002). The average value obtained (0.0429 ± 0.0088 MPa) is within the expected range for office paper, but below the typical values for more resistant papers.

The strain at break, which indicates the capacity of the material to deform before its failure, was 4.58 ± 1.28 % in the tests performed. This value is within the typical range for office paper, which varies between 2 % and 5 %, and close to the minimum values for kraft paper (4 % to 8 %) and further from the values for cardboard (10 % or more) (Smook, 2002). The average deformation obtained suggests that the tested material has a ductility suitable for applications that require some flexibility, such as office paper.



TEA is a measure of the toughness of the material, i.e. the energy required to cause rupture. For office paper, the typical absorbed energy varies between 1.5 J/m² and 3.0 J/m², while for kraft paper and cardboard, the values can reach 3.0 J/m² to 6.0 J/m² and 10.0 J/m² or more, respectively (Smook, 2002). The average value obtained (2.1043 ± 0.9371 J/m²) is within the expected range for office paper, but below the typical values for more resistant papers.

Thus, the results obtained show that the tested product presents mechanical properties within the expected range for office paper in terms of maximum force, maximum tension and energy absorbed. However, the TAPPI T494-om (2022) standard recommends that these mechanical properties are consistent to ensure the reliability of the material in practical applications. Therefore, the significant variation between samples, evidenced by the standard deviations, indicates the need to improve the consistency of the material, test process or test a larger number of samples to ensure the reliability of the results.

5 CONCLUSION

This study demonstrated the technical feasibility of the production of handmade paper from tegument fibres and mango pulp (*Mangifera indica* L.), using an alkaline extraction method. The results obtained revealed that the extraction process showed significant yields of 18.94% for the tegument fibres and 6.59% for the pulp fibres, values comparable to those observed in other agroindustrial residues used for cellulose production, such as sugarcane bagasse and coconut shell.

The physical-mechanical properties of the paper produced have shown promise for practical applications. The average weight of 230.33 g/m² and thickness of 0.23 mm were in the range of conventional recycled paper, while the tensile strength of 15.44 N and absorbed energy of 2.10 J/m² indicated suitability for specific uses, particularly in packaging and handmade stationery. These results corroborate previous studies that highlight the potential of unconventional vegetable fibres for the production of cellulosic materials.

Despite the positive results, some variability in the mechanical properties between the samples was observed, possibly related to the heterogeneity in the distribution of the fibres during the manufacturing process. This limitation suggests the need for optimisation in the steps of homogenisation and compaction of the material. Future studies could explore complementary treatments, such as controlled bleaching, to improve characteristics such as whiteness and durability of the paper produced.



From the perspective of sustainability, this research presents a relevant contribution to SDGs 09, 11 and 12 by demonstrating the possibility of transforming agro-industrial waste into value-added products, aligning with the principles of the circular economy. The developed methodology is particularly interesting for regions of high mango production, such as the North and Northeast of Brazil, where it could be implemented as an economically and environmentally viable alternative for the use of by-products of fruit processing.

In summary, the results of this work show that the tegument and mango pulp fibres represent a suitable raw material for the production of handmade paper, offering a sustainable solution for the management of agricultural waste. The proposed approach, besides contributing to the reduction of environmental impacts, also opens perspectives for the development of new materials in the paper industry, strengthening the regional bioeconomy.

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