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Brazilian Agro-Industrial Wastes for Potential Textile Materials: characterization and analysis of coconut (*Cocos nucifera*) fiber

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Dissertation presented at School of Arts, Science and Humanities from University of Sao Paulo to obtain the title of Masters of Science in Textile and Fashion from the Textile and Fashion Postgraduate Program.

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Dra. Júlia Baruque Ramos

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*"Never doubt that a small group of thoughtful, committed,
citizens can change the world. Indeed, it is the only thing
that ever has."*

- Margaret Mead

RESUMO

SIQUEIRA, Mylena U. **Resíduos Agroindustriais Brasileiros para Potenciais Materiais Têxteis: caracterização e análise da fibra de coco (*Cocos nucifera*)** 253. p. Dissertação (Mestrado em Têxtil e Moda) – Escola de Artes, Ciências e Humanidades, Universidade de São Paulo, São Paulo, 2023. Versão Corrigida.

A cadeia agroindustrial brasileira gera cerca de 291 milhões/tons/ano de resíduos. O coqueiro (*Cocos nucifera*) tem importante papel econômico e social na agroindústria do Brasil, sendo o 5º maior produtor da fruta do mundo. A atividade gera grande quantidade de cascas residuais, enquanto sua destinação final inadequada causa contaminação e riscos socioambientais. É crescente a necessidade do uso de matérias-primas alternativas em substituição às originadas de recursos fósseis na indústria brasileira. O assunto adquiriu importância à luz das recentes aplicações de agrofibra de base biológica, como a fibra de coco. O presente estudo tem como objetivo investigar os resíduos agroindustriais brasileiros como potenciais matérias-primas têxteis e realizar o processo de extração e caracterização físico-química da fibra de coco verde (*Cocos nucifera*). A metodologia foi realizada através de Revisão Sistemática de Literatura (RSL) e análise bibliométrica dos dados; e caracterização têxtil da fibra de coco verde (comprimento; título; caracterização tênsil - resistência e alongamento na ruptura, tenacidade e módulo de Young; regain; microscopia óptica transversal e longitudinal; MEV; densidade, conteúdo de lignina, celulose e hemicelulose; TGA; FTIR e DRX). A biomassa agrícola das principais culturas apresenta adequabilidade para aplicação em têxteis, como fibras naturais e polímeros; biossorventes para efluentes industriais; material de obtenção e reforço de celulose em compósitos. Estudos com a fibra de coco aplicam—se a biossorvente para efluentes têxteis; artesanato; compósitos e copolímeros verdes. Os valores encontrados das fibras de coco verde in natura foram: comp.: 11,7±1,5cm; regain: 10,1%; dens: 1.00 (g/cm^3) cristalinidade: 47,1%; ten.: 14,4 ± 3,4 cN/tex; along.: 45,6 ± 12,6 %; MY 0,865 ± 0,308 N/tex; 56,0% de celulose e 37,0% de lignina. Para fibras de coco verde maceradas: comp.: 12,3 ±1,6 cm; regain: 11,0%; dens: 1.10 (g/cm^3); cristalinidade: 47,5%; ten: 14,2 ± 3,9 cN/tex; alongamento: 52,8 ±11,7%; MY: 0,721± 0,280 N/tex.; 57,0% de celulose e 36,5% de lignina. Com esse estudo pretendeu-se ampliar possíveis alternativas sustentáveis às matérias-primas têxteis convencionais.

Palavras-chave: Resíduos Agro-industriais; Indústria Têxtil; Fibra do coco verde; *Cocos nucifera*; Sustentabilidade; Design biomateriais.

ABSTRACT

SIQUEIRA, Mylena U. **Brazilian Agro-Industrial Wastes for Potential Textile Materials: characterization and analysis of coconut (*Cocos nucifera*) fiber.** 253 f. Dissertation (Master of Textile and Fashion) – School of Arts, Sciences and Humanities, University of São Paulo, São Paulo, 2023. Revised version.

The Brazilian agro-industrial chain generates around 291 million/tons/year of waste. The coconut tree (*Cocos nucifera*) plays an important economic and social role in the agroindustry of Brazil, being the 5th largest producer of the fruit in the world. The activity generates a large amount of residual bark, while its inadequate final destination causes contamination and socio-environmental risks. The need for the use of alternative raw materials to replace those originating from fossil resources in Brazilian industry is growing. The subject has gained importance in light of recent applications of bio-based agrofiber, such as coir fiber. The present study aims to investigate Brazilian agro-industrial residues as potential textile raw materials and carry out the extraction process and physical-chemical characterization of green coconut fiber (*Cocos nucifera*). The methodology was performed through Systematic Literature Review (SLR) and bibliometric data analysis; and textile characterization of green coconut fiber (length; count number; tensile characterization - strength and elongation at break, tenacity and Young's modulus; regain; transverse and longitudinal optical microscopy; SEM; density; lignin, cellulose and hemicellulose content; TGA; FTIR and XRD). The agricultural biomass of the main crops is suitable for application in textiles, such as natural fibers and polymers; bio sorbents for industrial effluents; material for obtaining and reinforcing cellulose in composites. Studies with coconut fiber apply to bio sorbent for textile effluents; craftsmanship; green composites and copolymers. The values found for in natura green coconut fibers were: length: 11.7 ± 1.5 cm; regain: 10.1%; Crystallinity index: 47.1%; tenacity: 14.4 ± 3.4 cN/tex; elongation: 45.6 ± 12.6%; YM: 0.865±0.308 N/tex; 56.0% cellulose and 37.0% lignin. For green retted coconut fibers: length: 12.3 ± 1.6 cm; regain: 11.0%; Crystallinity index: 47.5%; tenacity: 14.2 ± 3.9 cN/tex; elongation: 52.8 ± 11.7%; YM: 0.721 ± 0.280 N/tex.; 57.0% cellulose and 36.5% lignin. This study intended to expand possible sustainable alternatives to conventional textile raw materials.

Keywords: Agro-industrial wastes; Textile industry; Green coconut fiber; *Cocos nucifera*; Sustainability; Biomaterials Design.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABAG	Congresso Brasileiro do Agronegócio
ABIT	Associação Brasileira da Industria de Têxtil e Confecção
ABNT	Associação Brasileira de Normas Técnicas
ABRAFAS	Associação Brasileira de Produtores de Fibras Artificiais e Sintéticos
CONMETRO	Conselho Nacional de Metrologia, Normalização e Qualidade Industrial
ABRELPE	Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais
ABTT	Associação Brasileira de Técnicos Têxteis
AGEITEC	Agência Embrapa de Informação Tecnológica
APROCOCO	Associação Nacional Dos Produtores De Coco
CAISAN	Câmara Interministerial de Segurança Alimentar e Nutricional
CAMEBA	Cama, mesa e banho
CFS	Committee on World Food Security
CMMD	Comissão Mundial Meio Ambiente e Desenvolvimento
CNA	Confederação de Agricultura e Pecuária do Brasil
CNI	Confederação Nacional da Industria
CONAMA	Conselho Nacional do Meio Ambiente
EI	Ecologia Industrial
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
FAO/ONU	Organização das Nações Unidas para Agricultura e Alimentação
FEFAF	Fundação de Estudos e Pesquisas Agrícolas e Florestais
FLW	Food Loss and Waste
GDP	Brazilian Gross Domestic Product
GHG	GreenHouse Gas Emissions
GVR	Grand View Research
IBAMA	Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis
IBGE	Instituto Brasileiro de Geografia e Estatística
IEMI	Instituto de Estudos e Marketing Industrial
IPEA	Instituto de Pesquisa Econômica Aplicada

LSPA	Levantamento Sistemático de Produção Agrícola
MMA	Ministério Meio Ambiente
ODS	Objetivos de Desenvolvimento Sustentável
PAM	Produção Agrícola Municipal
PGRS	Plano de Gerenciamento de Resíduos Sólidos
PNRS	Politica Nacional de Resíduos Sólidos
SENAI	Serviço Nacional de Aprendizagem Nacional
SINDCOCO	Sindicato Nacional dos Produtores de Coco
SINMETRO	Sistema Nacional de Metrologia, Normalização e Qualidade Industrial
SISNAMA	Sistema Nacional do Meio Ambiente
SNVS	Sistema Nacional de Vigilância Sanitária
SUASA	Sistema Unificado de Atenção à Sanidade Agropecuária

LIST OF EQUATIONS

SUMMARY

1. INTRODUCTION

Agribusiness plays an important role in the production, processing, and transformation of food. According to the Brazilian Institute of Geography and Statistics (IBGE, 2021), the crop of agricultural production forecasts a record 2.5% in 2021, and to meet food needs in 2050 it requires a 60% increase in the planted area, and in the consumption of water in the region amid water crises (BIASE, 2017). The abundance is the result of increased activity in the modern agricultural sector, which produces 291.1 million/tons of residues in its largest crops (SCHNEIDER et al., 2012). This system presents unexplored economic opportunities, pressuring conservation of resources, polluting and degrading natural ecosystems, causing environmental risks and contamination to society (BIASE, 2017; ELLEN MACARTHUR FOUNDATION, 2017).

Brazil participates in 4.5% of the coconut world produced, with annual growth of 0.8% of the harvested area, while the cultivated area grew by 13.2%, and productivity in 143.2 and 114.8% between 1990 and 2015 (BRAINER, 2018a; SIMONE; PEREIRA; DOUTOR, 2020a). Although, the accumulation of coconut post consumption represents a problem for the health management of rural and urban areas (MARTINS et al., 2016a). The husks, when deposited incorrectly, occupy large spaces with decomposition responsible for gases contribution to global warming and diseases (CASTILHOS, 2012). The industry processes a small portion of coconut by-products, which generates about 80% to 85% of the gross bulky weight (FERREIRA-LEITÃO et al., 2017; MARTINS et al., 2016a). With environmental awareness, there is interest in developing sustainable materials from renewable resources and agro-lignocellulosic materials for bioproducts (AGOPYAN et al., 2005a; ASHBY, 2016a).

The need for renewable manufactured products is a major challenge for the Brazilian industry dependent on petrochemical resources. For DUNGANI et al., (2015), agricultural waste is the most abundant form of natural fiber. The use, processing, and characterization of agro-industrial wastes is a great opportunity to generate value and develop by-products and co-products (BERTÉ, 2009; DAHIYA et al., 2020; EMBRAPA, 2018; SHAHID-UL-ISLAM; SHAHID; MOHAMMAD, 2013).

Renewable resources are aimed at the sustainability of ecosystems and for maintaining healthy and sustaining the textile industry. There is great interest in sustainability by industry professionals, including in materials with competitive mechanical properties, lightness, and biodegradability of low-cost natural fibers to replace petroleum-based fibers in composites (ALARCON et al., 2021b; ATIQAH et al., 2020; HOQUE; CHUAN; MENG, 2021; IZWAN et al., 2021). Indeed, markets for products based on the agro-fiber present great potential for application in absorbents, technical textiles, geotextiles, filters, bio composites, and other automotive and construction sectors (SHISHOO, 2007). Research efforts have been alternatives to different levels of control and management (CHAN et al., 2021; ONU; MBOHWA, 2021a). The high volumetric rate of agro-industrial residue in combination with increased environmental awareness makes research into appropriate textile technologies and treatments a priority (MADHAV et al., 2018a).

Thus, to cover the themes to be developed for this study, six chapters were structured: (i) introduction; (ii) objectives; (iii) bibliographic review, in which contexts of structural analysis of the textile industry and interaction of the value chain with the agricultural industrial segment, agro-industrial wastes fundaments and coconut fiber inputs; (iv) methodology; (v) results and discussions, which address the dynamics of sustainability as a guideline and fundamentals for restructuring cycles of agricultural residues, Brazilian scenario of productive insertion (marked by the data analysis network) and materials and related applications of green coconut fiber in Brazilian development researches.; (vi) conclusions obtained in this work and general considerations.

2. OBJECTIVES

2.1 General objective

Investigate Brazilian agro-industrial residues as potential textile raw materials and carry out the extraction process and physical-chemical characterization of green coconut fiber (*Cocos nucifera*).

2.2 Specific objectives

- Carry out a data survey of Brazilian agro-industrial residues, identifying the main crops and their main applicability;
- Carry out a systematic review of the literature on: (i) Brazilian agro-industrial waste data, identifying the main crops and their main applicability; and (ii) green coconut fiber, including technical aspects, its current employability, economic and production data for the sector in Brazil;
- Determine the physicochemical characteristics of green coconut fiber textiles, based on length tests; count number; tensile characterization (breaking strength and elongation, toughness and Young's modulus); regain; density; transverse and longitudinal optical microscopy; MEV; TGA (with estimated lignin, cellulose and hemicellulose contents); FTIR; and XRD;
- Compare the results with those of other fibers with recognized textile employability and/or other palm tree species;
- Indicate alternatives for the use of coconut fiber with a focus on the application in the textile and design industry, considering the current market and its challenges.

3. JUSTIFICATION

The manufacture of textile fibers plays an important role in the world economy, being a complex and multilayer system (LOPES et al., 2021a). Although there is a wide variety of fibers currently used in textiles, research is focused on exploring alternative sources of natural fibers (GEORGE et al., 2006). According to data from the Food and Agriculture Organization of the United Nations, about a third of the food produced in the world is wasted or lost (FAO, 2013; FAO/ONU, 2013). The high volumetric rate of agro-industrial waste in combination with increased environmental awareness makes research into appropriate textile procurement and treatment technologies a priority (MADHAV et al., 2018a). Residues from the food supply chain are the most available biomass resources subject to circular processing (SIQUEIRA et al., 2022a). Residues such as bark, seeds, leaves, and other fruit and vegetable residues have been scientifically proven as viable and valuable raw materials for numerous products (SILLANPÄÄ; NCIBI, 2019a; WIESMETH, 2021a, 2021b, 2021c). For Laudes Foundation (2021), the valorization of these residues offers great potential to reduce the extensive harvest, fires, and their environmental and climatic impacts; generate new low-cost additive revenue streams for farming communities; and activate a new, scalable, and environmentally sustainable fiber source for the growing apparel and fashion industry. Among the sources, vegetable fibers have the main advantages in sustainable appeal (LOPES et al., 2021b). Sustainability has become an important aspect of the manufacturing industry and of research interest (KALITA; KUMAR; DAVIM, 2021). Coconut (*Cocos nucifera.*) is an important multifunctional crop in the tropics, cultivated in more than 90 countries, considered the most useful tree to man, each part of the palm during history has been put to active economic use by humanity (ADKINS; FOALE; HARRIES, 2010). However, on average in Brazil, about 7 million tons of green coconut are discarded per year, the husks, processing and consumption residues, when deposited incorrectly, occupy large spaces with decomposition responsible for causing socio-environmental risks to society (CASTILHOS, 2012). Green coconut fibers stand out due to their intense abundance of residues, and their physicochemical properties of high quality, low cost, low density and biodegradability (RAZERA, 2006). Therefore, there are alternatives for the reuse of these productive residues, such as their use in textile applications (MARTINS et al., 2016a).

4. LITERATURE REVIEW

4.1. Textile Industrial Scenario

4.1.1. Introduction to Textile Sector History: World and Brazilian Scenario

One of the advances of humanity was the act of weaving, being one of the oldest manual practices (HARRIES; HARRIES, 1976). The knowledge of basketry with flexible fibers such as cotton, linen and wool to develop garments was used (PEZZOLO, 2017).

New technologies have enhanced human ability, increasing their calculation and memory capacity, simplifying production processes and providing a large volume of information (KUASNE, 2008). Subsequent improvements made possible great combinations of physical and human resources and led to the factory system replacing the domestic production system (GAMA, 1985). In view of this, the British textile industry boosted the Industrial Revolution, causing advances and stimulating the coal and iron industries (LOBO, R.N.; LIMEIRA, T. N. P.; MARQUES, R, 2014).

The textile industry is considered a precursor to mechanized production processes in the Industrial Revolution, developed between the end of the 18th century and the beginning of the 19th century in Western Europe (KELLER, 2010). A major milestone was the creation of machines that allowed wider fabrics to be woven more quickly. Thus, the main technological advances associated with the Revolution were concerned with spinning, and the demand for fibers stimulated the production of synthetic fabrics that did not require special conditions and abundant labor forces (MONTEIRO, 2014). Synthetic fibers were developed in the late 1930s and production was boosted after World War II (DREW; SINCLAIR, 2015).

The invention and availability of the sewing machine in the 19th century popularized the industry, while the widespread use of nylon in the 20th century also innovated in material possibilities (CANAVAN, 2015). There was an industry transition from an extensive accumulation regime (1989-2008), in which free market economies focused on design and distribution while manufacturing was subcontracted to reduce costs, to an intensive accumulation regime (2009-2029), in the reduction of trade barriers with a growing discrepancy between supply and demand for fibers with a focus on two main fibers, cotton and polyester, with a 70% decrease in flax fibers (SCHEFFER, 2012a).

In the global competitive scenario, the advent of fashion and design for textile products indicated a new pattern of competition for advanced countries such as peripheral countries in East and Southeast Asia (KELLER, 2010). The manufacture of textile fibers has an important role in the world economy, being a complex and multilayer system (LOPES et al., 2021a). The textile industry can be credited for its continued innovation over 350 years of history, in particular, in recent decades the driving force involved (i) the impulse of technology; (ii) the development of materials in polymer science and fiber technologies, and (iii) market and consumer demands (SHISHOO, 2012a).

The current global textile industry has constantly evolved in international exchanges. Asia leads textile production with 2/3 of the total manufactured (BEZERRA, 2014). Considered a traditional industry, it has promoted a great increase in product technology and diversification in industrial applications, such as specialized fibers and polymers with additives with special properties (STEGMAIER, 2012a). Research platforms such as Grand View Research (GVR) report that the size of the global textile market is projected at USD 100.3 billion in 2020, with an expected expansion of 4.4% per year from 2021 to 2028. With dominance at 47 .6% of global revenue in Asia-Pacific countries in sales volume of apparel products (GRAND VIEW RESEARCH, 2021a)

The industrialization process in Brazil began with the textile industry, between 1844 and 1913, slowly (ARAGÃO; BEZERRA, 2002). The consolidation period takes place at the beginning of the First World War with an industrial park boosted by the rise in European tariffs in previous years. The sector accelerated with an emphasis on the dynamic sectors of apparel, in the second half of the 1950 century (LOBO, R.N.; LIMEIRA, T. N. P.; MARQUES, R, 2014; SENAI, 2016a). The industry was strengthened with the representation of the Associação Brasileira da Indústria Têxtil e de Confecção (Brazilian Association of the Textile and Clothing Industry - ABIT) in 1957 and the Associação Brasileira dos Técnicos Têxteis (Brazilian Association of Textile Technicians - ABTT) in 1962. Only in 1965, due to the active presence of representatives, was the textile sector included in the industrial groups on the agenda of the government's Strategic Action Plan (SILVA, 2012). In 1990, after the commercial opening, the links in the chain faced weaknesses due to competitive deficiencies in technology, inter-firm cooperation, and demand from the consumer market sensitive to income and financing conditions. Factors that led to its decline involve competition with Asian products (KELLER, 2010; VARTANIAN, PEDRO RAFFY; MACIEL, 2019a).

The Brazilian textile sector is traditional and of high growth, an industry present for almost 200 years in the country. Verticalization is one of the competitive potentials of the industrial manufacturing plant, which represents the realization of all processes in the chain (ABIT, 2020a; PETERS et al., 2015a). Brazil is currently the 5th largest textile industry in the world and the 4th in the clothing segment. In 2019, textile production reached an average of 2.04 billion tons, which represents a turnover of around US$ 36.5 in an entire chain, investments of around US$ 730 million, generating about 1.5 million direct jobs and 8 million indirect jobs, 75% of which are full labor, 2nd largest worker in the manufacturing industry, the most complete chain in the West, from fiber production to retail (ABIT, 2020b; CAVALCANTI; DOS SANTOS, 2021a; FILLETI; BOLDRIN, 2020). With an estimated expansion of 11.5% from 2017 to 2022 in apparel retail (MARIANO, 2018a) growth of 10.4% in apparel production in volume, reaching 5.5 billion pieces (IEMI, 2021).

The size of consumption of clothing in 2019 reached US$ 1.272 trillion, in 6.3 billion pieces, in 148 thousand physical points of sale (98.3%), and in e-commerce (1.7%). The consumption of clothing, bed, and bath (household) presented a 5.7% growth rate. The import of parts between 2015 and 2019 grew by 17.4%. In 2020, the industry faced a decrease of 8.5% in textile manufacturing, 5.4% in the evolution of the manufacturing industry, and 22.3% in the production of clothing in terms of the volume of items. However, estimates point to a growth of 8.3% in the production of textile manufacturers, 22.1% in the production of apparel, and 25% in the retail of apparel (IEMI, 2020).

Despite the economic importance and productive participation of the country as the 5th largest producer, Brazil presents a little significant contribution to world trade but is highlighted in South America, focused on domestic trade (JUNIOR, 2017a; VARTANIAN, PEDRO RAFFY; MACIEL, 2019b). Within industrial parameters, clothing items are more representative in factories and employment segments in Brazil, and the textile sector as a whole is growing (MACHADO et al., 2013). Among the regions, the Southeast and the South of the country stand out, with a concentration of

80.9% of the distribution of the textile industrial park, with a share of 16.2% in the Northeast, 2.5% in the Midwest, and 0.4 % in the North (JUNIOR, 2017b).

These numbers indicate, on the one hand, the large productive concentration of the textile industry, which became more capital intensive, and, on the other, the greater dispersion of garments, with a probable increase in informality.

4.1.2. Textile and Apparel Chain

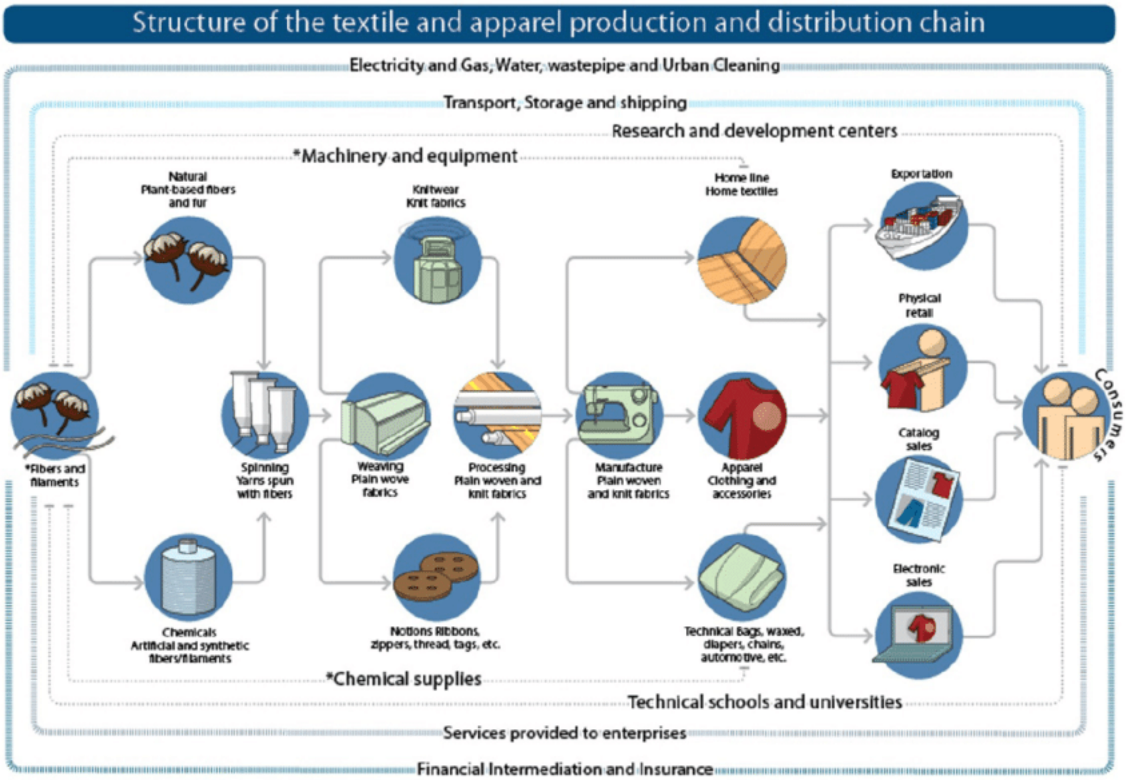
The textile chain is a traditional Brazilian manufacturing sector that began in the late nineteenth century. Given the restrictive policies on international trade in part of the 20th century, the country represents the only western country with the largest integrated production chain in the West, from raw materials to technical clothing, from fibers to garments (CAVALCANTI; DOS SANTOS, 2021b; MARIANO, 2018b; VARTANIAN, PEDRO RAFFY; MACIEL, 2019b).

According to the Serviço Nacional de Aprendizagem Industrial (National Service of Industrial Apprenticeship - SENAI), a productive chain is understood to be:

> [...] the conglomerate of productive activities, interconnected among themselves, that make up a certain productive process, contemplating from the obtaining of the raw material to the commercialization of the finished product and the agents responsible for the good functioning of this interconnection.[...] The textile productive chain /clothing comprises the processes for obtaining fibers (initial raw material), the processes for obtaining yarn, the processes for obtaining fabrics, the processes for ennobling textile substrates, the processes for making up to the sale of the finished product to agents facilitators of these operations (SENAI, 2016a).

Bezerra (2014) points out that each of the stages has its own characteristics, presenting discontinuity, in which the results of each stage are the main inputs for the next. With several connected operations, but independent from each other (BEZERRA, 2014). The high degree of verticalization present in the spinning and weaving, spinning and knitting and knitting and clothing links are relevant to the context of the industry in the country (JUNIOR, 2017a) (**Figure 1**).

Figure 1. Structure of the textile and apparel production and distribution chain



Source: (AMARAL et al., 2018; SENAI, 2016a)

There is a tendency for the textile chain to have larger companies and market concentration in the stages of raw material production and spinning and processing, while the finished products have a smaller size and characteristics of greater dispersion and competitiveness (VARTANIAN, PEDRO RAFFY; MACIEL, 2019b).

4.1.2.1.Textile Fibers

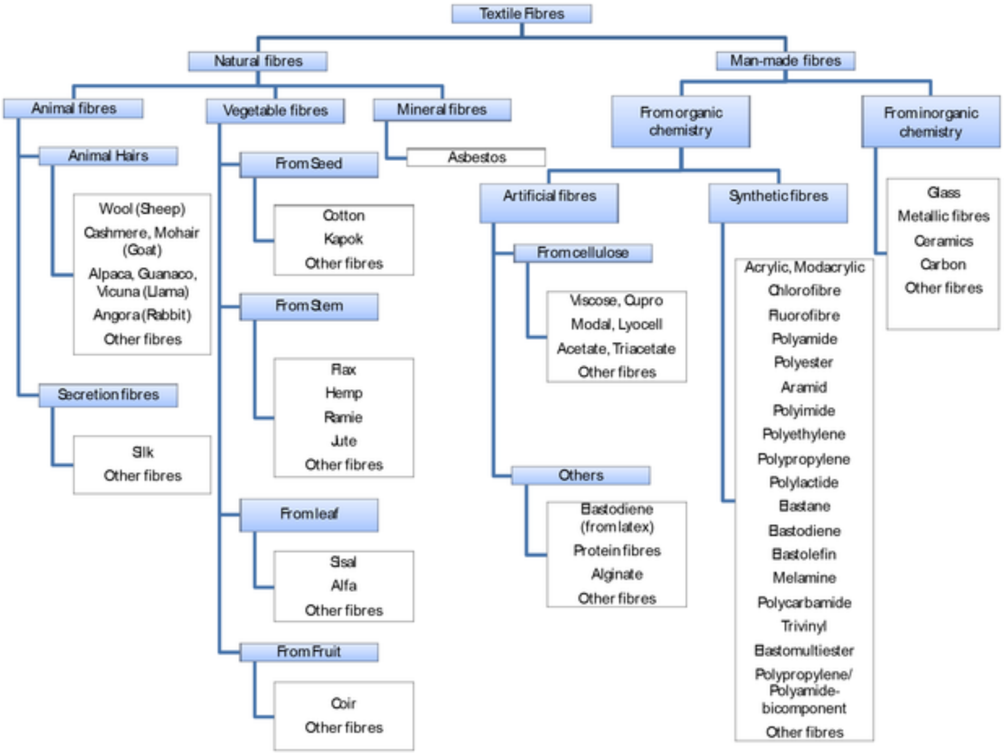
According to Resolução Conselho Nacional de Metrologia, Normalização e Qualidade Industrial (Resolution National Council of Metrology, Standardization and Industrial Quality - CONMETRO), textile fiber is understood to mean any element of chemical or natural origin, consisting of linear macromolecules, which presents a high proportion between its length and diameter and whose characteristics of flexibility, softness and comfort to use, make this element suitable for textile applications (CONMETRO, 2008).

Considering their origin, textile fibers can be divided into natural and chemical (PEZZOLO, 2017; SENAI, 2016a).

Natural fibers are obtained from material originating from natural sources, three main groups can be identified: cellulosic fibers (plant), protein fibers (animal origin) and also mineral fiber. The dimensional structure of natural fibers allows for its own unique demands and final characteristics (LOBO, R.N.; LIMEIRA, T. N. P.; MARQUES, R, 2014). Mineral fibers are extracted from rocks and are commonly suitable for insulation (ERHARDT, 1976a). Animal fibers are divided into the majority, wool, fine hairs and types of silk (GRIES; VEIT; WULFHORST, 2015b)

Chemical fibers are industrially produced materials through artifices or chemical syntheses and divided into categories: natural, synthetic and inorganic polymers. Synthetic bases refer to processes using substances from the petrochemical industry entirely by man, while artificial or regenerated bases are obtained from natural sources of cellulose, such as wood pulp, and undergo processes to form a new fiber (ERHARDT, 1976b; LOBO, R.N.; LIMEIRA, T. N. P.; MARQUES, R, 2014) (**Figure 2**).

Figure 2. Textile fibers classification.



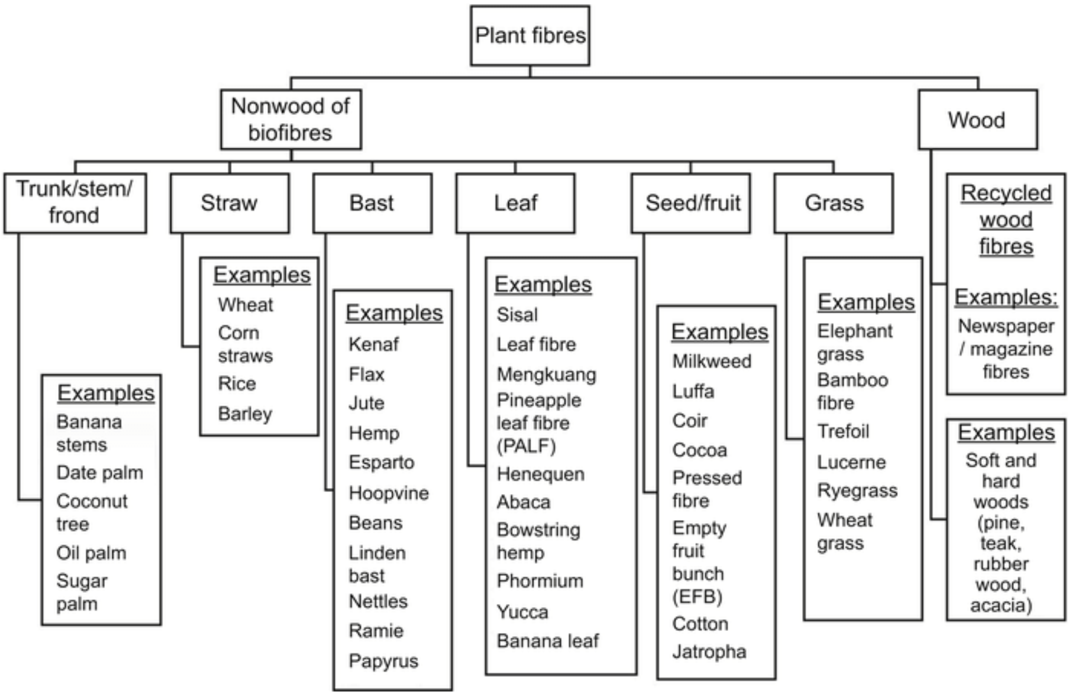
Source: (ISO/TR, 2012).

Among these groups there are filaments, fibers of indefinite length (very large), and discontinuous fibers, fibers of short length (SINCLAIR, 2015). Fibers have a range of physical and mechanical properties, including: (i) length, shape and diameter; (ii) color and brightness; (iii) strength and flexibility; (iv) abrasion resistance; (v) sensory to touch; (vi) moisture absorption; (vii) electrical properties. And chemical properties such as: (i) fire resistance; (ii) chemical reactivity and resistance; and (iii) antimicrobial properties (DREW; SINCLAIR, 2015; SINCLAIR, 2015). For Lobo et al., (2014), other important properties include touch, uniformity, durability and shine.

4.1.2.2. Vegetable Fibers

Plant fibers are composed of natural cellulose, which is why they are called cellulosic fibers. (LOBO et al., 2014). Plant fibers are classified into different categories based on their origin: leaf fibers (sisal, pineapple, abaca, etc.), stem fibers (flax, ramie, jute, kenaf, hemp, etc.), seed fibers (cotton, kapok, milkweed, etc.) and other sources such as fruit fibers and bark (YU, 2015) (**Figure 3**).

Figure 3. Vegetable fibers classification.



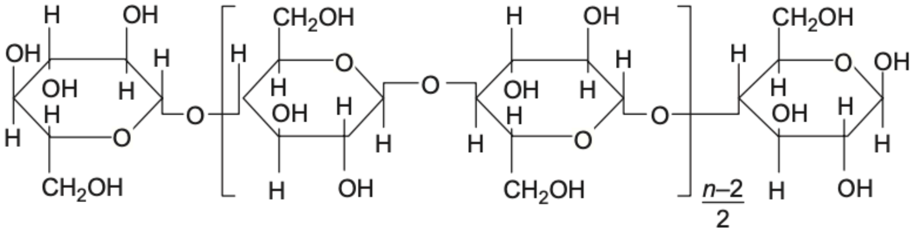
Source: (GRIES; VEIT; WULFHORST, 2015b; RAMESH; PALANIKUMAR; REDDY, 2017).

Plant fibers are cellulosic in nature, but have other components in their heterogeneous polymeric complex such as lignin and hemicellulose, which is why they are also called lignocellulosic fibers (DEBNATH, 2017a). In addition to these, it is possible to find inorganic and organic compounds (pectins, simple carbohydrates, terpenes, alkaloids, saponins, polyphenolics, gums, resins, fats and greases, among others) (EMBRAPA PANTANAL, 2017).

Cellulose is the most abundant and almost inexhaustible naturally occurring organic macromolecule on Earth, an important component found in renewable resources in the cell wall of green plants and algae, bacteria and fungi (SALLEH et al., 2021).

According to Yu (2015), cellulose is a linear polymer, long-chain molecule and carbohydrate composed of carbon (44%), hydrogen (6.2%) and oxygen (49.4%) (**Figure 4**).

Figure 4. Cellulose molecule diagram.



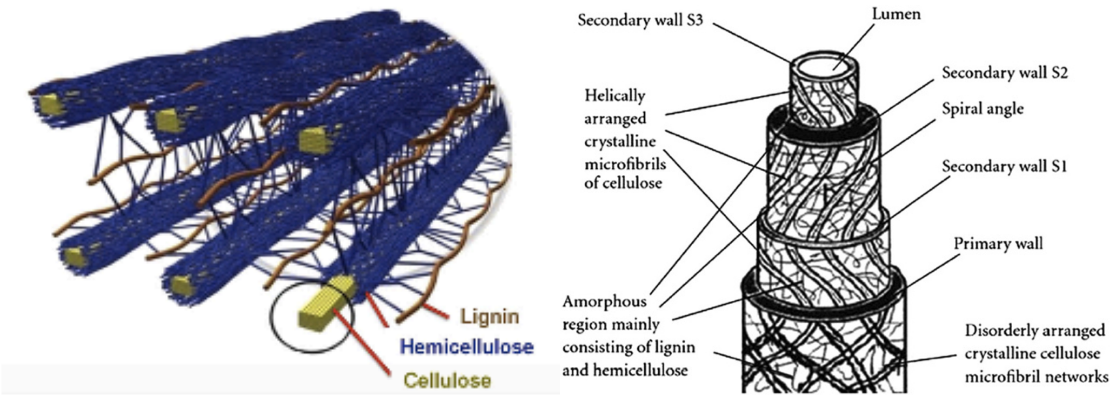
Source: (YU, 2015).

Cellulose molecules are formed into fibrils or bundles of molecular chains, which combine to form cellulose fibers. Cellulose has properties common to plant fibers due to its high molecular orientation and crystallinity, which imply strength, rigidity, low elongation and low flexibility (ERHARDT, 1975; SENTHIL KUMAR; SUGANYA, 2017)

Cellulose is a microcrystalline biopolymer with ordered crystalline and disordered amorphous regions, which can crystallize in different polymorph points (LIITIÄ; MAUNU; HORTLING, 2000). The mechanisms are complex, due to the structural molecular organization of amorphous and crystalline regions in different types of fibers (TOKURA et al., 2000; VIIKARI et al., 2000). The OH groups in cellulose lead to a large number of hydrogen bonds, some of the cellulose molecules line up, forming a highly ordered region (crystalline) and a less ordered region (amorphous) (TAUFIQ; MANSOR;

MUSTAFA, 2021). Geometric conditions determine mechanical properties, such as its microfibrillar angle. Fiber types and orientation influence which type of fabrication method is suitable (BAHTIYARI; EKMEKÇI KÖRLÜ; BILISIK, 2021) (**Figure 5a** and **5b**).

Figure 5. The structure of natural fiber.



(a) **(b)**

Source: (TAUFIQ; MANSOR; MUSTAFA, 2021).

Cellulose hollow fibril structures are held together by hemicellulosic matrix and lignin. Stiffness is increased by the hydrophobic lignin network acting on the coupling (TAUFIQ; MANSOR; MUSTAFA, 2021). According to Lopes (2017), the combination of good performance, versatility and simple and low-cost processing has reinforced the advantages of plant fibers in polymeric composites (LOPES, 2017). The main advantages are: (i) it comes from renewable sources; (ii) continuous availability; (iii) biodegradability; (iv) low cost; (v) low density; (vi) specific properties; (vii) less abrasive nature (SANTOS et al., 2015). The special visibility directed to the fibers is due to its content as a promising material for sustainability (GUIMARÃES et al., 2009).

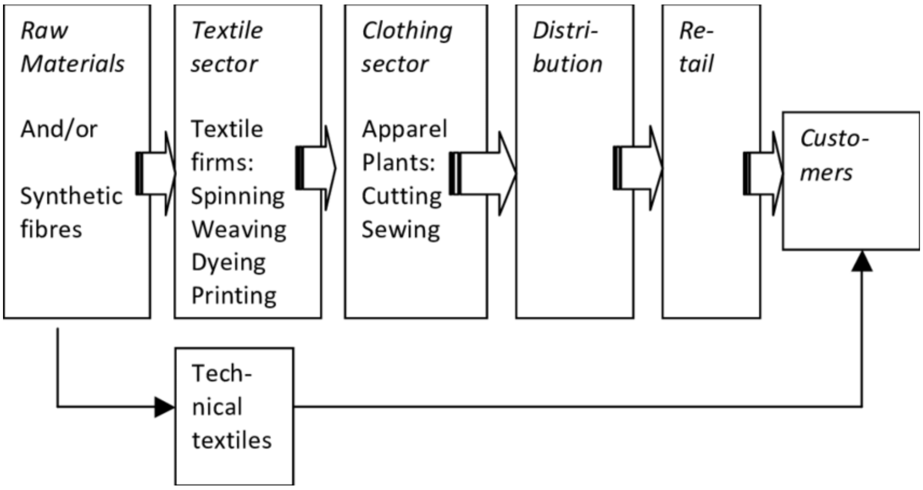
However, it is noteworthy that the physical-chemical properties are directly linked to crops and soil characteristics, weather conditions, and other contexts of production and extraction (ARANGUREN; MARCOVICH; REBOREDO, 2016; KICIŃSKA-JAKUBOWSKA; BOGACZ; ZIMNIEWSKA, 2012a). Due to their biological origin and renewability, plant fibers are targeted for sustainability, provided that ecological processes are also adopted in cultivation, processing and production (DEBNATH, 2017a, 2017b; THOMPSON, 2015).

In Brazil, there is a wide variety of lignocellulosic fibers, with different chemical, physical and mechanical properties, which are intertwined with the country's biodiversity. These fibers come from sisal, coconut, jute, ramie, curaua, sugar cane bagasse fiber and soy (MARINELLI et al., 2008).

4.1.2.3.Textile Fibers Use

According to Mordor Intelligence (2021), the global textile industry presents segmentations by type of application, (clothing application, industrial/technical application, and domestic application), by material (cotton, jute, silk, synthetics, and wool), by process (Woven and Nonwoven) and by geography (North America, Europe, Asia-Pacific, Latin America and the Middle East and Africa). The main segments are fashion and apparel (clothing, ties, and accessories for apparel, bags), followed by technical textiles (construction, transport, medical, protective) household (bed linen, kitchen, upholstery, towel), and other textiles (GRAND VIEW RESEARCH, 2021b; SLATER, 2003a). (**Figure 6**).

Figure 6. Textile fiber applicability set.



Source: (ECKHARDT, [s.d.]).

The increased demand for natural fibers is pointed out as part of the main trends and forecasts of the textile market in the period 2021-2026, due to its lightness, strength, and wide application (MORDOR INTELLIGENCE, 2021). Reports from Grand View Research (2021) reveal the use of 44% of natural fibers in the 2020 global revenue in diversified applications in fashion and apparel, and as a trend in market leadership and share due to consumer environmental concerns from 2021 to 2028 (GRAND VIEW RESEARCH, 2021b).

Vegetable fibers have wide employability in textile, cellulose, and paper, cosmetics, automobile, aerospace, food (seeds and oil), civil construction, bio compounds, polymeric matrices, absorbent materials, packaging, upholstery, and renewable energy industries, among others (EMBRAPA PANTANAL, 2017; KICIŃSKA-JAKUBOWSKA; BOGACZ; ZIMNIEWSKA, 2012b; SATYANARAYANA; GUIMARÃES; WYPYCH, 2007a; THOMPSON, 2015).

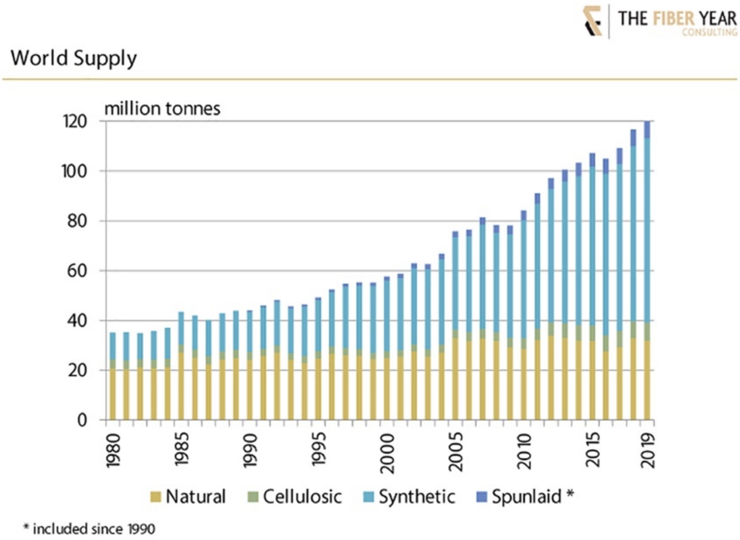
Humans are increasingly dependent on textiles for household use, clothing, appliances, and medicine (ASHBY, 2016b). Given the continuous improvements of textiles, such as long-lasting properties and protection (antibacterial), they are increasingly covering more diverse applications because of adapting to the needs of users, such as military, defense, astronomy, medicine, and daily use among others (SALLEH et al., 2021).

4.1.3. Fiber Consumption

Globalization has made the textile industry one of the largest consumer industries (ISLAM; AHMED; AZADY, 2021a). Until 1990, the consumption of natural fibers was higher than that of composites. However, between 1990 and 2000, the consumption of natural fibers increased 81% and natural fibers only 20%, exceeding the number and consumption of chemicals in the years following that of natural fibers (GRIES; VEIT; WULFHORST, 2015b).

According to the International Fiber Journal (IFJ), the annual report The Fiber Year 2020 reveals a slowdown along the global textile chain, due to the Covid-19 pandemic, in supply, processing and consumption. However, when analyzing the production of fibers over the years until 2019 (**Figure 7**), the scope of natural fibers dropped by 3%, while man-made cellulosic fibers showed a growth of 6%, and synthetic ones, predominantly polyester, by 5%. The total volume represents 120 million tons (with Spunlaid, fake fabrics), at an average consumption of 16 kg per capita (ENGELHARDT, 2020a, 2021).

Figure 7. World Suply of fibers.

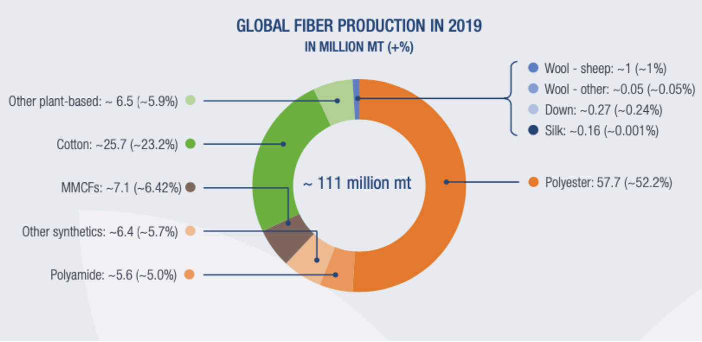


Source: (ENGELHARDT, 2020a).

The report highlights the increased consumption and contribution of the Americas and growing investment in synthetic and regenerated fiber raw materials such as polyester, nylon and viscose (ENGELHARDT, 2020b).

However, Textile Exchange's Preferred Fibers and Materials Market Report 2020 shows that global fiber production has increased by about 107 million tons in 2018 to 111 million tons in 2019, which has doubled in recent years. There is evidence of an increase in fiber by more than 30%, to 146 million tons in 2030 if consumption remains the same. Synthetic fibers accounted for 63% (70 million/tons) of global fiber production, with emphasis on polyester and polyamide (TEXTILE EXCHANGE, 2019a; TEXTILE EXCHANGES, 2020) (**Figure 8**).

Figure 8. Global Fiber Production 2019



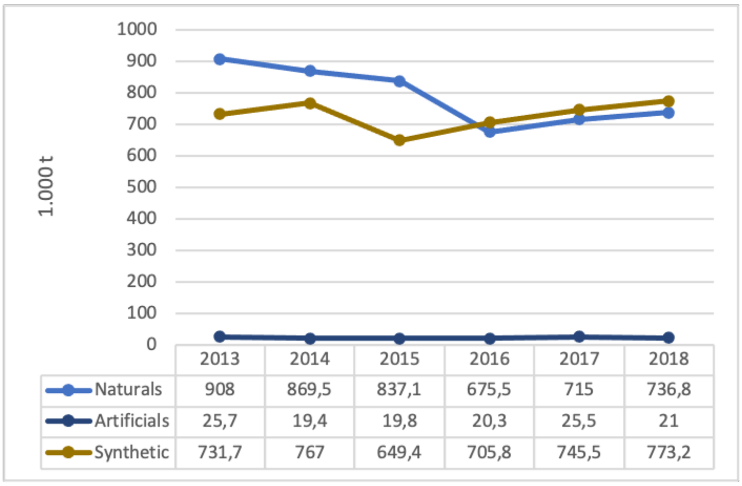
Source: Textile Exchange (2020).

The preferred fibers respectively are polyester, with 52% (58 million/tons) of market share, followed by cotton, with around 26 million tons, and man-made cellulosic fibers growing with 7 million tons. Other vegetable fibers such as jute, kenaf, coconut, flax, sisal, ramie, kapok, abaca and hemp have a small share of 5.8% of the total in 2019 (6.5 million/tons). However, less than 20% of the fibers have some sustainability criteria (NAYAK et al., 2021a; TEXTILE EXCHANGES, 2020).

According to the Associação Brasileira de Produtores de Fibras Artificiais e Sintéticas (Brazilian Association of Artificial and Synthetic Fiber Producers - ABRAFAS), the Brazilian petrochemical-textile complex works on a large scale and is responsible for productivity above 380 thousand tons/year, between synthetic and artificial fibers and multifilaments (ABRAFAS, 2020).

The rise in consumption and use of synthetic fibers represents a major change in the country's textile chain, which until then remained largely with the production of cotton and natural fibers (ZEFERINO, 2019). In contrast to the exponential growth of 42.7% synthetic textile fibers over the period 2010-2017, while natural fibers did not show significant growth worldwide (CAVALCANTI; DOS SANTOS, 2021a) (**Figure 9**).

Figure 9. Consumption of natural, artificial, and synthetic fibers and filaments in Brazil, 2013-2018.



	2013	2014	2015	2016	2017	2018
Naturals	908	869,5	837,1	675,5	715	736,8
Artificials	25,7	19,4	19,8	20,3	25,5	21
Synthetic	731,7	767	649,4	705,8	745,5	773,2

Source: Adapted from (ABIT, 2018).

In reason to the expansion of activities in the clothing textile industry to meet the growing demand in the clothing supply chain, there is a significant and abusive increase in the use of inputs such as energy, water, and soil (BARBOSA et al., 2016).

In the textile sector, with the growing and large consumption demand of natural textile fibers, the production and market of synthetic fibers found a great space for expansion due to their characteristics of low cost, strength, shine, and mainly, the absence of large agricultural spaces, a special type of climate and intensive work (LOBO, R.N.; LIMEIRA, T. N. P.; MARQUES, R, 2014)

4.1.4. Impacts on Procurement, Treatment and Production of Textile Raw Material

Today's fashion industry is characterized by mass production, high turnover, and products designed for a short, linear lifecycle (ELLEN MACARTHUR FOUNDATION, 2017; PATNAIK; TSHIFULARO, 2021). During the period of industrialization, raw materials were seen as abundant, available, and cheap, with increasing material production, current supply disturbances were caused (RATHINAMOORTHY, 2018a). The simplistic approach treated resources as an infinite supply without harmful consequences (MIRAFTAB; HORROCKS, 2007a). According the authors, this system is responsible for putting pressure on all parts of the textile supply chain, creating a negative dynamic in the search for lower prices in materials and labor (FLETCHER; GROSE, 2011a).

Examples of imbalance and environmental disturbance of great magnitude can be identified in the textile industry and its activities. To achieve better growing conditions and optimal fiber quality, contamination from chemicals and artificial fertilizers is carried into the soil, air, and water. Bringing consequences such as genetic changes, loss of soil fertility, and terrestrial risks to communities that live and feed on them (SLATER, 2003b, 2003c, 2003d, 2003e, 2003f). The sources of stress take different forms, originating from the production of natural fiber, agricultural problems (pesticides, fertilizers, and excessive irrigation), or the extraction and conversion of oil to synthetic fibers (ISLAM; AHMED; AZADY, 2021a; NAYAK; PANWAR; NGUYEN, 2020). Heavy equipment for yarn production and the environmental effects of chemicals used in washing, cleaning, bleaching, or carbonization, together with the emission of gases from devices in baling, opening, and carding and chemical residues used for better spinning, such as the process of fabric treatment, in dyeing and printing, are some of its adverse effects (SLATER, 2003g, 2003h, 2003i). Considering the use phase and analysis of the life cycle of products as major environmental harm due to consumer handling and disposal, which generates waste as they complete their usefulness (CUNLIFFE, 1995; FERNANDES et al., 2021a; HAZEL, 1996; MUTHU, 2015; PASQUINI, 1995).

At a global level, textiles are in the last position in terms of recycling, while there is 80% recycling of steel, followed by paper and plastics. Highlighting the need for indirect inputs such as water, energy, and land, it is estimated that an American needs $600m^2$ to meet their annual fiber needs while 60 million tons of textiles are sent to landfills or burned (SCHEFFER, 2012a). The expansion and development of industrialization and production processes in virtually all Western countries inaugurate a culture of mass consumerism (FILHO, 2008; LIPOVETSKY, 2009).

The fragmentation of supply and disposal chains makes concentration and organization difficult to control, while there is a shortage of material (SCHEFFER, 2012b). The sum of factors highlights the selection of fibers as a variable intervention, carbon footprint, and global climate change (NAYAK et al., 2021a; PETERS et al., 2015b). The impact of the industry turns to geographic stability in which a large part of the industries is remaining in countries with non-compliance in the safety of specific supplies and management of low-income workers (PATTERSON, 2012; SCHEFFER, 2012b).

Koszewska (2015) argues that globally extended supplies and manufacturing processes are not as transparent when compared to other industries such as food (KOSZEWSKA, 2015).Thus, there is a contemporary preferential trend in many industries to minimize the production of pollution and depletion of resources, however, environmental efforts may not be as effective due to the public inability to measure pollution, which leads to systems of justice to lenient and/or non-existent sentences (IVANOV, 2017). Therefore, understanding biogeochemical cycles is an important tool for identifying the environmental impacts generated (SENAI, 2016b).

4.2. Textile and Agricultural Sector: Relationships and Challenges

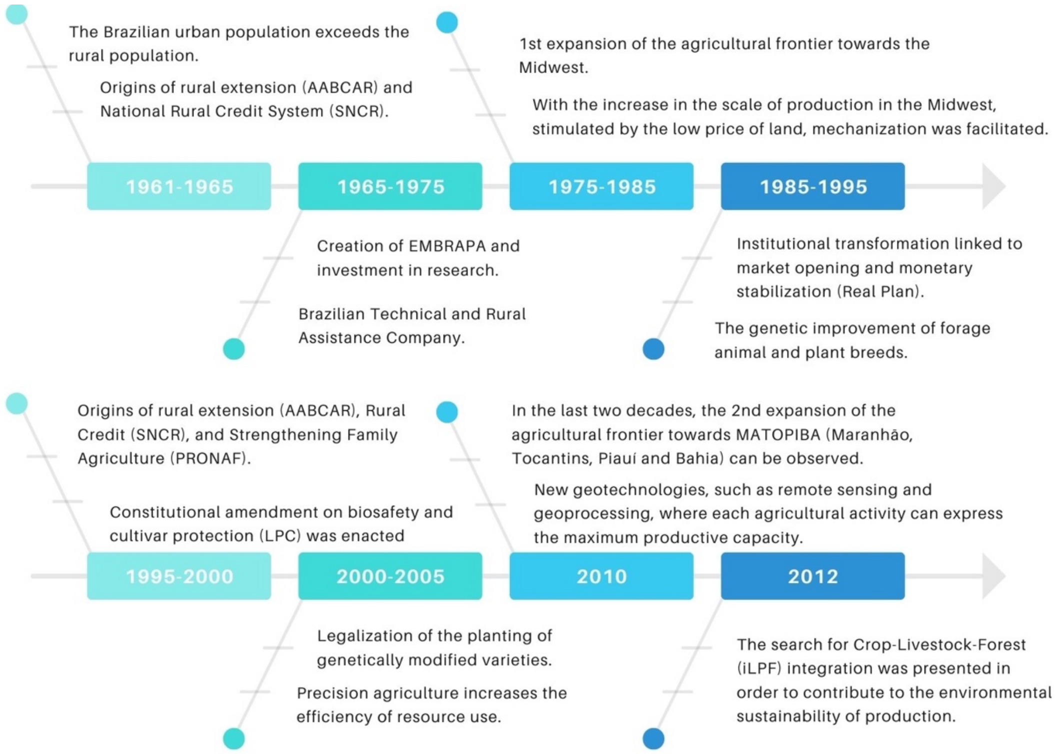
4.2.1. Conventional Agriculture

The agricultural revolution transformed human beings into producers of their own food, during periods of hunting and gathering. The practice of agriculture led to the creation of the first institutions and the rise of great civilizations in antiquity (BAPTISTA, 2010; LIMA, 2017).

The main technological transformations in the sector began 200 years ago. Meeting the consumption of a population in constant exponential growth was an important factor in the technological interventions that supported the Industrial Revolution (CARVALHO; DA COSTA, 2017; MIRANDA, 2018). Until 1900, Brazilian production employed rudimentary and manual techniques, and in 1920, refined techniques were introduced (ALBUQUERQUE; NICOL, 1987; REIFSCHNEIDER et al., 2017). Around 1940, advances related to the growth of the petrochemical industry as an energy matrix began, in 1950, advances in the pharmaceutical industry provided the emergence of biotechnology and subsequent improvements in the use of hybrid seeds (ALVES; CONTINI; GASQUES, 2008). The growth until this moment was associated with the expansion of the cultivated area (ABRA, 2013; PARIZOTTO SEIDLER; FRITZ FILHO, 2016). In 1960 the use of chemical pesticides and machines began to increase productivity. The growth of modern industry took place in 1970, when there was a 1000% increase in tractors used with previous decades and with an increase in molecular biology (MOTTIN; SILVA, 1973; WAGNER et al., 2010). In 1990, with genetic manipulations and living organisms. Studies highlight the year 1990 as a milestone in the process of globalization and transnationalization of agriculture (AGRA; DOS SANTOS, 2014). The content moves from traditional agriculture to intense use of technology.

The Brazilian agricultural sector, through the trajectory of technological innovation, since the 1960s, ceases to be an importer of food and becomes one of the largest exporters in the world (CIB, 2015). Establishing itself as a leader in the export of grains and fruits, integrated production of fibers and energy (MAFRA, 2010; VIEIRA FILHO, 2017) (**Figure 10**).

Figure 10. Timeline of important facts that transformed Brazilian agriculture and increased its productivity 1961-2012.



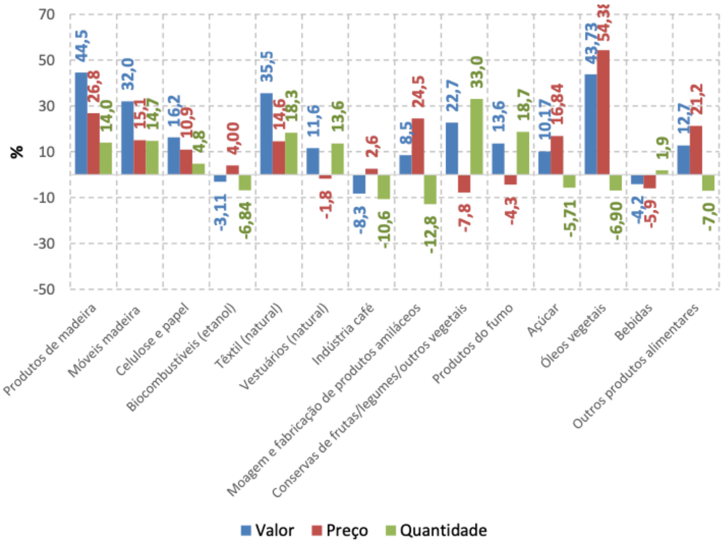
Source: Adapted from VIEIRA (2017).

The period comprising the years 1975 to 2016 was important in the many transformations that occurred, from economic opening to stabilization plans, with the participation of the government and the participation of the private sector, these brought an increase in production and competitiveness of the country with the international market (GASQUES; BACCHI; BASTOS, 2018). However, to analyze agricultural modernization in developing countries, it is important to understand the context of technological adoption of techniques at high and low levels by farmers, which highlights family farming in Brazil (CARVALHO; DA COSTA, 2017; DELGADO, G. & BERGAMASCO, 2017; ELI DA VEIGA, 2002; LIMA, 2017).

The Brazilian model of agricultural growth follows a type of expanded technological trajectory, regional contexts are united in 4 groups: family, employer, rural company and large property (ALVES et al., 2013; WAGNER et al., 2010). The centralization of capital, in the last decade, was accentuated above all in the technological research of inputs (COHEN; AGRICULTURE, 2019; MEDEIROS, 2000). The current agricultural industry operates in a competitive manner, increasingly relevant in terms of exports. Productivity growth provoked a lengthening of the supply and processing chain with increasing research, experimentation and diffusion (BUAINAIN et al., 2014; NAVARRO STOTZ et al., 2012).

Agribusiness currently accounts for 24.31% of the Brazilian GDP, according to data from ESALQ/USP. The agricultural branch corresponds to 68% of the value, which accumulated R$ 1.06 trillion reais in 2019. The data are expressive in the primary segment (CNA, 2021) (**Figure 11**).

Figure 11. Agricultural-based agro-industries: annual variation in volume, prices and billing from wood products, textile and clothing sector to food and crops. Value (blue) price (red) and quantity (green).



Source: CNA (2021).

However, agribusiness is at the heart of socio-environmental impacts. In the name of agricultural expansion, monocultures and new pastures are responsible for clearing, burning, soil exploitation models and lags in fauna and flora (HENRIQUES, 2011; SOUZA DE ROCHA; SCHNEIDER PEREIRA; TEIXEIRA MEIRA, 2014; ZAMBERLAN et al., 2014). Soil degradation and water erosion are some of the problems pointed out. Incorrect handling and water contamination resulted in significant environmental risks, associated with the generation of effluents and toxicity from the use of pesticides (DE DEUS; BAKONYI, 2012; PELLEGRINO; ASSAD; MARIN, 2007).

(BITTENCOURT, 2010) points out that the emphasis on physical degradation does not include the economic costs to the country's agricultural GDP.

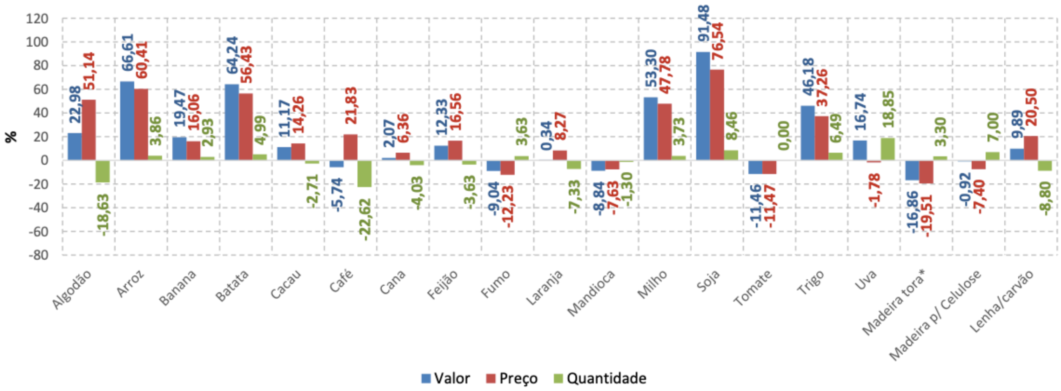
Specific analyzes reveal that the increase in temperature in Brazil can cause the reduction of regions suitable for cultivation (BOLFE et al., 2018). In view of this, Teixeira et al (2015) assess that the hitherto economic protection extends to biological safety and plant biodiversity (TEIXEIRA et al., 2015). The future of agriculture, therefore, must encompass sustainable agricultural systems, understood as the management and conservation of the natural resource base and the orientation of technological changes to ensure the achievement and satisfaction of the human needs of the present and future generations (BEZERRA; VEIGA, 2000; BOLFE et al., 2018; FAO, 2021a; PINAZZA; ARAUJO, 1993; SOGLIO; KUBO, 2016; VIEIRA; VIEIRA, 2019).

4.2.2. Productive Sectorial Survey of the Agricultural Industry

The development of Brazilian agriculture is based on productivity growth (ALVES; CONTINI; GASQUES, 2008). From 1961 to 2012, food production increased by more than 8 times, with population growth in the same period of 2.5 times. According to the Confederação da Agricultura e Pecuária do Brasil (Confederation of Agriculture and Livestock - CNA), agribusiness is recognized as a great vector of expansion and Brazilian economic growth (CNA, 2020). The agricultural productive harvest forecasts a record increase of 2.5% for Brazil in 2021 (IBGE, 2021). Its abundance is the result of increased activity in the modern agricultural sector (FAO, 2013; VASTOLA, 2015; ZARO, 2018). Agroindustry accounts for approximately 5.9% of the Brazilian Gross Domestic Product (GDP), promoting integration with the economy (EMBRAPA, 2020; TORREZAN, R.; CASCELLI, S. M. F.; DINIZ, 2017).

In the Brazilian scenario, agribusiness has gained great notoriety in the context of studies and political-economic-institutional focus (TEIXEIRA et al., 2015). Between 1975 and 2016, Gasques (2018) highlights that the agricultural product grew more than four times, the production of grains went from 40.6 to 187 million tons. According to the most recent report by the CNA (May 2021), Brazilian grain production is estimated at 271.7 million tons, a record and represents a growth of 14.6 million tons compared to the previous harvest. The Systematic Survey of Agricultural Production (LSPA) highlights that the average yield per year of crop and product shows crops such as sugarcane, corn, rice, soybeans and coffee (IBGE, 2020) (**Figure 12**).

Figure 12. Volume, prices and sales of the main crops in Brazil. Value (blue) price (red) and quantity (green).



Source: CNA (2021)

The country has become one of the leaders in the world agricultural economy, stimulated by the rapid growth in demand for food, fiber and energy (FRIES; CORONEL, 2014). The global prominence for the agroindustry, with extensive arable area in grains, cereals, fruits and especially with the sugarcane culture, therefore, generates a large number of by-products such as lignocellulosic residues (RESENDE; SOCCOL; FRANÇA, 2016).

4.2.3. Analysis of Land Use and Distribution

The textile and agricultural industries share challenges within the current Brazilian economic system, concerning global demand consumption, land use, greenhouse gas emissions, pollution, effluent generation, generation and disposal of waste and recycling (CIRCULAR SYSTEMS, 2020). The present intensity of agricultural sector growth in a primary-export model associated with the country's economic and demographic growth contributed to an extensive and intensive industrial sector in the 1930s (LIMA, 2006; VARTANIAN, PEDRO RAFFY; MACIEL, 2019a). Albuquerque (1982) shows commercial capital of agricultural land in the textile and food industry when reporting that, in the period of 1870, the high cotton price and the rapid return on investment induced possible changes in crops from coffee to cotton. Textile production increased by 83% in the period 1931-1935, supported by the supply of cheap labor and the cotton expansion that replaced coffee (ALBUQUERQUE, 1982). Fletcher (2011) exemplifies that cotton growing watercourses can affect access for other purposes (drinking and irrigating food crops), and contamination with fertilizers and pesticides makes them unsuitable for other uses (FLETCHER; GROSE, 2011a). Patterson (2012) highlights that population growth of advanced per capita consumption, rising temperatures, world food, clean water and fuel supplies are at constant risk, putting pressure on declining amounts of farmland and mineral and mineral reserves, fresh water (PATTERSON, 2012). Salleh (2021) raises the issue that natural fiber production is expected to decline due to the need for more land for food production. Fibrous material is cultivated in agriculture (animals and plants) (TOBLER-ROHR, 2011).

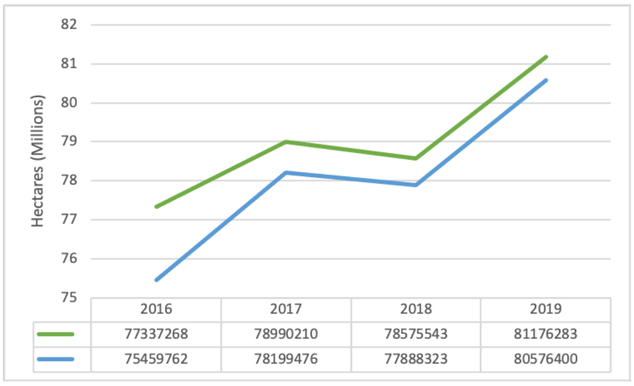
Agriculture and food processing plants represent point and diffuse sources of agricultural waste that are difficult to control (HANSON, 2014). The deficiencies of the agricultural system attract the interest of effective management, which consider the inadequate disposal of material in landfills and the distribution of space, facing the challenges of greenhouse gases and the toxic runoff of water in useful fertile land (GOMIERO, 2018; ONU; MBOHWA, 2021b; WARNER, 1980; WOJTKOWSKI, 2008a; YUSUF et al., 2019) . In addition to discarded nutritional and economic values, environmental, social, and cultural values are wasted. Soil, water, energy, land, logistics, labor is heavily used up in the service of wasted food production (BIASE, 2017; SAATH; FACHINELLO, 2018; SANTOS et al., 2020a). The deterioration of these systems imposes a time limit, and their regenerative properties are slow and cannot be boosted healthily. For KAPOOR; PANWAR; KAIRA, (2016), since the generation of waste and by-products are consequences of all industrial sectors, just like their inadequate disposal, the study of recovery and reuse of these by-products must be disseminated.

The current degradation reveals an inadequate technology, as industrial progress must be more concerned with increasing its efficiency more than production, and the consumption scale assumes limitations to the carrying capacity (GOODLAND, 1995). In the case of agro-industrial residues, due to their abundance, renewability, and use, they are economically and environmentally advantageous for their low density, low CO_2 emission, and biodegradability characteristics, when compared to thermoplastic polymer composites. The technology applied for conversion of agricultural biomass in products is not being realized in scale-up due to competitiveness with synthetic products (DUNGANI et al., 2015; LIMA, 2006; PRITHIVIRAJAN, R. & JAYABAL, S. & BHARATHIRAJA, 2015; ZEFERINO, 2019).

Goodland (1995) emphasizes that human's dependence on agriculture will always exist, so land and other renewable sources are essential (GOODLAND, 1995). This reflects the concerns of the Malthusian theory, addressed by Lambin, (2012), that the finite stock of land and its inadequate distribution are insufficient to meet growing demand, causing a decline in welfare (LAMBIN, 2012). Based on the work of Malthus, Moran (2011) argues that, since demographic pressure has brought about a rapid agricultural technological innovation, resulting in extensive and harmful agriculture, one should expect from its expansion to increase the level of deforestation as well (MORAN, 2011). In global studies, about 12% of the global surface is used for cultivation; it is estimated that 15% of the global surface of land without ice could be converted to agricultural land, and more than 40% of the available lands were used (FOLEY, 2005; ROCKSTRÖM, J., W. STEFFEN, K. NOONE, Å. PERSSON, F. S. CHAPIN, III, E. LAMBIN, T. M. LENTON, M. SCHEFFER, C. FOLKE, H. SCHELLNHUBER, B. NYKVIST, C. A. DE WIT, T. HUGHES, S. VAN DER LEEUW, H. RODHE, S. SÖRLIN, P. K. SNYDER, R. COSTANZA, U. SVEDIN, M. FALKE, 2009)

Over time, there was an increase in the percentage of cultivated areas. From 1960 to 1980, the size of the harvested area doubled. Between 1975 and 2016, the expansion of temporary crops increased from 36.8 million to 69.5 million hectares (ABRA, 2013; GASQUES; BACCHI; BASTOS, 2018; VIEIRA FILHO, 2017). The 2017 Agricultural Census recorded an area of 351.3 million hectares (41.3% of the national territory). The area occupied with crops, 63.5 million hectares, represents 7.5% of the territory with annual, semi-perennial and perennial agriculture (grains, horticulture, fruit and forestry)(EMBRAPA, 2018; MINISTÉRIO DA AGRICULTURA, 2019a, 2019b). The search for more land is a threat to afforestation and increases the impacts of the climate crisis (CAMPBELL et al., 2018; ONU; MBOHWA, 2021c). Brazil faces a growth curve in planted area and harvested area in all temporary and permanent crops grown in the country (**Figure 13**).

Figure 13. Planted area or destined for harvesting (green line) and harvested area (blue line) from temporary and permanent crops



Source: Adapted from IBGE - Municipal Agricultural Production (PAM-PRODUÇÃO AGRÍCOLA MUNICIPAL, 2021).

Waste from these activities is an example of an expensive and inevitable result of human activity that poses a threat to the environment, while the decrease in the supply of raw materials is also a cause for concern (DUNGANI et al., 2015; SUNDARRAJ, A. A., & RANGANATHAN, 2018). The threat linked to agricultural exploration activities and the production of materials attracts the attention of both industries, in an attempt to balance habitats, protect the ecosystem, and dispose of useful land in reversing the loss of biodiversity (MACAULAY, 2007; ONU; MBOHWA, 2021c, 2021d).

Recent reports by Laudes Foundations reveal that turning innovations to the responsible use of agro-waste to generate raw materials based on cellulose textis would not require increasing cultivated land or increasing the volume of crops. Studies show that there is sufficient residue for fiber relocation and emphasize the importance of collaborative interventions in textile and agrifood systems to enable scaling of materials (LAUDES FOUNDATION, 2021a).

4.3. Agroindustrial Waste

4.3.1. Introduction to Residue Concepts

Solid waste is a response to several factors and is among the main concerns of modern society (EL-HAGGAR, 2007a; MAZZER; CAVALCANTI, 2013). However, the discoveries of practices, origins and final dispositions have manifestations and realizations through historical periods. Waste production has been part of human life since antiquity, fixation to the soil and life in villages and communities, intensified by major agricultural transformations that enable the emergence of cities, which leads to the first look at garbage as precariousness (DEUS; BATTISTELLE; SILVA, 2015; EIGENHEER, 2009). According to Velloso (2008) in the Middle Ages, most waste came from human activity related to their own physical body, such as pathogenic microorganisms in body fluids and decomposition, and their food, such as animal carcasses, fruit peels and vegetables. For the author, during this historical period, the representativeness of the waste was built by the social imaginary of epidemic and pandemic infections, generating fear and contempt for the material by man, also, the stigma of the workers responsible for the final destination as “marginal and disqualified” (VELLOSO, 2008). In this context, waste, seen as a threat and associated with misery, dirt and disease, was sent to distant physical spaces of coexistence, considering the bonfire as the ideal method to eliminate possibilities of transmission of infectious diseases (KELLER; CARDOSO, 2014; VELLOSO, 2008). In terms of the current pandemic situation, the cause of the Covid-19 pandemic and all other pandemics are linked, directly or indirectly, to changes in production and land use in capital-intensive monoculture agriculture (WALLACE, 2020).

In the 20th century, the risks associated with waste were for many years limited to public hygiene, the medical area and the sanitary conditions of society, in addition to the 40s and 50s, in which there was an intense change in society's behavior towards the consumption of goods and services. , to factors such as population growth, industrial development, accelerated urbanization, and increased use of natural resources, introducing synthetic and nuclear waste (MAZZER; CAVALCANTI, 2013; SOBARZO; MARIN, 2010). The growth and industrialization model implemented in this period favored the appearance of “dumps” throughout Brazil (ANDREOLI, 2001).

It was only from the 1970s onwards that there was an environmental burden and waste is considered an issue related to environmental preservation that takes on a global character, when addressed at conferences in Stockholm, in 1972, ECO92, in Rio de Janeiro and Tbilisi, in 1997 (DEUS; BATTISTELLE; SILVA, 2015; WILSON, 2007). According to Campos (2017), as a result of the history of the 21st century, the high generation of waste and inadequate disposal generate socioeconomic and environmental problems in all countries of the world. In Brazil, solid waste is one of the main environmental problems, being a prerequisite for the implementation of environmental management and treatment policies (BARBOSA, 2014; FREIRIA, 2011).

4.3.2. Residue Classification: definition, origins and types

Different authors attribute different definitions to the meaning of solid waste. Berté (2009) categorizes waste as “Material or rest of material whose owner or producer no longer considers it of sufficient value to conserve it” (BERTÉ, 2009) However, in Brazil, the definitions are standardized by environmental institutions and legislation. The Associação Brasileira de Normas Técnicas – (Brazilian Association of Technical Standards ABNT), defines solid waste as:

> Solid and semi-solid waste resulting from industrial, domestic, hospital, commercial, agricultural, services and sweeping activities. Included in this definition are sludges from water treatment systems, those generated in pollution control equipment and installations, as well as certain liquids whose particularities make it unviable to be released into the public sewage system or bodies of water, or require technically and economically unviable solutions in the face of the best available technology (ABNT NBR 10004, 2004).

For the most recent classification, in addition to the tax in the Política Nacional dos Resíduos Sólidos (National Solid Waste Policy- PNRS), Brazilian Law No. 12.305, of August 2, 2010, regulated by Decree No. 11,445, of January 5, 2007, 9,974, of June 6, 2000, and 9,966, of April 28, 2000, of norms established by the institutes of the Sistema Nacional do Meio Ambiente (National Environmental System- Sisnama), Sistema Nacional de Vigilância Sanitária (National Health Surveillance System - SNVS), Sistema Unificado de Atenção à Sanidade Agropecuária (Unified System of Attention to Agricultural Health - Suasa) and Sistema Nacional de Metrologia, Normalização e Qualidade Industrial (National Metrology, Standardization and Industrial Quality System - Sinmetro), which deals with solid waste such as:

> [...] material, substance, object or good discarded resulting from human activities in society, whose final destination is proceeded, proposed to

> proceed or is obliged to proceed, in solid or semi-solid states, as well as gases contained in containers and liquids whose particularities make it unfeasible to release them into the public sewage system or into bodies of water, or require technically or economically unfeasible solutions for this in view of the best available technology (PLANALTO/GOV, 2010).

It is worth highlighting the differentiation of the concept to that of waste, which according to the PNRS are "solid waste that, after exhausting all possibilities of treatment and recovery by available and economically viable technological processes, do not present any other possibility than the final environmentally friendly disposal proper" (PLANALTO/GOV, 2010).

According to Barbosa (2014), the main criteria involving the classification of waste relate its origin and dangerousness. The importance of analysis and knowledge of the characteristics of the materials is highlighted, for mapping the determinations and possible consequences of the residues, aiming at the operational stages and safety measures (BARBOSA, 2014). For the author, the origin of the waste can be classified into: Residential; commercial; institutional; construction and demolition; municipal services; treatment centers; industrial; and agricultural. However, according to Brazilian norms NBR 10.004, the classification report must include the origin of the waste, description of the segregation process and description of the criteria adopted in the choice of analyzed parameters (TCHOBANOGLOUS; KREITH, 2002).

For the purposes of this Standard, waste is classified as:

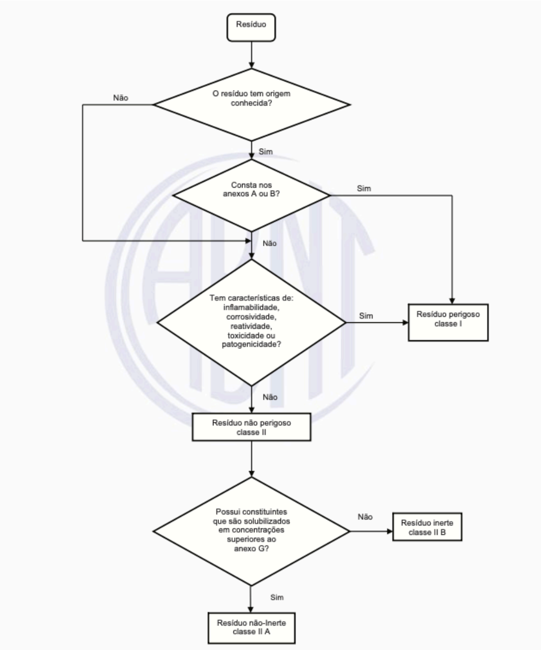
a) class I waste - Hazardous; which falls under flammability; corrosivity; reactivity; toxicity and pathogenicity.

b) class II waste – Non-hazardous; as food waste; ferrous metal scrap; non-ferrous metal scrap; paper and cardboard; polymerized plastic and rubber.

– Class II A waste – Not inert. properties, such as: biodegradability, combustibility or solubility in water.

– Class II B waste – Inert. Waste that, when sampled in a representative way, in dynamic and static contact with distilled or deionized water, does not have any of its constituents solubilized (ABNT NBR 10004, 2004; BARBOSA, 2014) (**Figure 14**).

Figure 14. Waste classification flowchart from official ABNT.



Source: (ABNT NBR 10004, 2004) .

This standard is complemented by the classification through the PNRS, as to origin: household waste, divided into dry and wet waste; urban cleaning waste; urban solid waste; waste from commercial establishments and service providers; waste from public basic sanitation services; industrial waste; health care waste; construction waste; agrosilvopastoral residues, divided into organic and inorganic; waste from transport services; mining waste. Also regarding dangerousness: hazardous waste and non-hazardous waste (BARBOSA, 2014; DE CAMPOS; GOULART, 2017; PLANALTO/GOV, 2010) (**Chart 1**).

Chart 1. Waste classification in terms of origin and form.

About Origin			
Household waste	Commercial Establishments And Service	Health Services	Transport Service
Urban cleaning waste	Providers Basic Sanitation Public Services	Construction	Mining
Urban solid waste	Industrial Waste	Agrosilvopastoral	-
About Dangerousness			
Dangerous		Not dangerous	

Source: Adapted from (PROTEGEER, 2017)

4.3.2.1. Industrial Waste

Since its inception, the industry has been an open material flow system (EL-HAGGAR, 2007b, 2007c). In its Article 13, the Política Nacional de Resíduos Sólidos – (National Solid Waste Policy- PNRS) defines "industrial waste" as those that are generated in production processes and industrial facilities (PLANALTO/GOV, 2010). According to CONAMA Resolution No. 313/2002, Industrial Solid Waste is all waste from industrial activity found in solid, semi-solid, gaseous (primary and atmospheric), and liquid (when contained) states (MMA, 2012). Waste from various industrial production chains, belonging to complex areas and requiring specific evaluation for the adoption of technical and economic management solutions are included (IPEA, 2012; PMA, 2013)

Waste is classified according to its physical-chemical or infectious-contagious properties, identifying the contaminants present in its mass, hazardous (40% of the waste) or non-hazardous, category of origin and subdivision based on quality condition, packaging, use or intended negotiation (GARCIA et al., 2016; IPEA, 2012; ROCCA, 1993). Studies reclassify industrial waste as by-products or secondary raw materials, such as metals, paper and cardboard, glass, plastics and biodegradable waste (CNI, 2014). These can also be composed of slag (incineration residues), sludge, oily residues, acid residues, alkaline residues, metallurgical, petrochemical, mining, wood, fibers, residues related to plants and animals (food, pharmaceutical or spice industries) , rubber, glass and ceramics (BENCIVENGA, 2007; MARCO; CASTRO; CÓRDOBA, 2019).

The diversities present in industrial activities cause waste throughout the production process, subject to environmental disorders and contamination (ALMIR; PEREIRA, 2016).

4.3.2.2. Agrosilvopastoral and Agroindustrial Residues

Among the various industrial segments, the agribusiness segment occupies a prominent position in Brazil and is in continuous growth. Agroforestry residues are generated in agricultural and silvicultural activities, including those related to inputs used in these activities (PLANALTO/GOV, 2010). Among the residues that originate, it can be divided into two sources: inorganic, composed of pesticide, seed and fertilizer packaging, veterinary product bottles, sacks, and household waste, among others, occupy large spaces and are not biodegradable. Organics are generated mostly from the processing of plant biomass (crop tailings) and animal farms (DE CAMPOS; GOULART, 2017; RODRIGUES et al., 2013; SANTOS; GUARNIERI; BRISOLA, 2018; SCHNEIDER et al., 2012). Agricultural residues still have an international division as: (i) primary biomass that remains after the main part of the crop is harvested, such as straw, stems, and leaves; (ii) secondary – post-harvest biomass, such as bagasse and molasses, found in mills (LAUDES FOUNDATION, 2021a).

Biomass as organic compounds from agricultural waste is a by-product of agricultural activities, found in abundance throughout the world (BARBOSA, 2014; LAUDES FOUNDATION, 2021b) Brazil stands out as a major generator of biomass. As shown in **Table 1**, it is estimated that the mass supply of biomass in 2005 was 558 million tons (including wood, surplus wood, forest residues, harvest residues, industrial residues, etc.), with a growth projection of 1,402 million tons in 2030.

Table 1. Brazilian Mass supply of biomass per agro-industrial and agricultural waste (million tons).

	2005	2010	2015	2020	2030
Total (woods, forests, crops)	558	731	898	1058	1402
Agricultural waste	478	633	768	904	1196
Agro-industrial waste (agricultural and forestry)	80	98	130	154	207

Source: Adapted from (MORAES et al., 2017).

The union of the concepts of industrial and agroforestry (agricultural) residues characterizes the biomass of agroindustrial residues addressed in this study. Agroindustrial residues are important abundant sources of organic compounds for the production of new materials and use as raw material in industrial processes and various consumer goods (PELIZER; PONTIERI; MORAES, 2007; RODRIGUES SAMPAIO; SILVANA HADDAD; VANIA BATTESTIN WIENDL, 2018). However, biomass residues generated in agroindustrial activities are still underutilized and destined for natural decomposition [121]. Waste is a concern for the increasing depletion of natural resources, and also for environmental policy and health problems (EL-HAGGAR, 2007a).

Lignocellulosic materials represent 60% of the plant biomass of the biosphere. The total supply of lignocellulosic residues corresponds to approximately 2.9 × 103 million tons of cereal crops, 3 × 103 of seed production, and 5.4 × 102 of other crops, in addition to 40 million tons of inedible materials, such as wheat stalks, corn straw (the stalks and leaves) and wood chips from logging, discarded as waste (RESENDE; SOCCOL; FRANÇA, 2016).

Concerning the residues generated by agroindustries associated with agriculture, the following processing industries stand out: beverages; fabrics from wool, cotton, and natural fibers; dehydrated and freeze-dried foods; candy industry; alcohol industry; sugar industry; frozen food industry; flour industry; canning and canning industry; juice industry; dairy industry; agricultural inputs industry and countless others (SCHENINI, 2011).

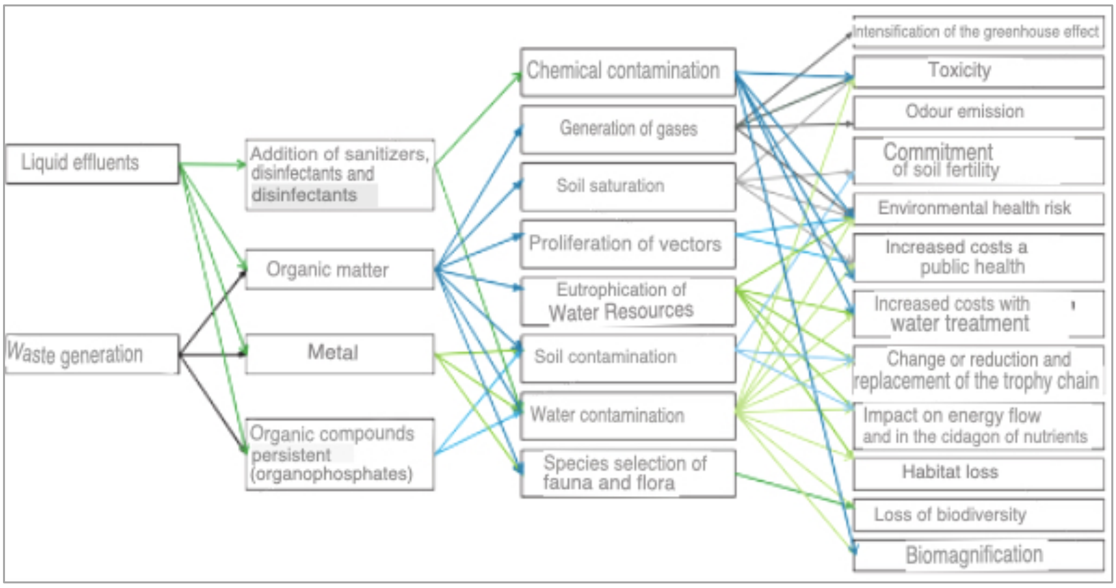
4.3.3. Ecological and Socioeconomic Impacts

Currently, agriculture seeks to secure food while minimizing adverse impacts on the environment. Global losses of fertile soils caused by erosion continue at an annual rate of 10 million hectares due to unsustainable agricultural practices. Sustainable practices guide the agroecological system. Transdisciplinary research in the agricultural area has been the basis over the years for achieving ecological results and technology transfers (FORSTER et al., 2013).

Scientific issues relevant to agriculture and sustainability are the depletion of water resources, overuse and misuse of chemicals, generating expected impacts on climate change and crop productivity (BHULLAR, 2013). In addition, the effects of climate and environmental externalities on crops, including disasters and disease, the consequences of different cultivation practices (such as monoculture) turn to tillage and residue burning, and the use of pesticides (AHMED et al., 2013; SILLANPÄÄ; NCIBI, 2019a).

The character of the market makes it difficult to prevent the effects of overproduction and pollution. (GOEDMAKERS, 1989). According to Bhullar (2013), there is no alternative to modern agricultural practices with increasing population. (**Figure 15**).

Figure 15. Negative impacts of agro-industrial residues from agriculture.



Source: (SCHNEIDER et al., 2012).

However, such abrupt climate changes, and variations in rainfall patterns, droughts, and intermittent floods, threaten agricultural production and may result in reduced yields. Therefore, market infrastructure and new production methods are needed to address yield gaps and optimize potential (AHMED et al., 2013). The definition of agro-biodiversity involves the diversity of cultural systems and practices, the relationship between land used for agriculture and other areas, and interactions with nearby ecosystems. These concepts do not provide standardized solutions, but developing approaches for instrumentation in the solution of agro-environmental problems (BÀRBERI, 2013), For the ecological dynamics of these complex agro-ecosystems, more parameters involved in biodiversity must be considered (WOJTKOWSKI, 2008b).

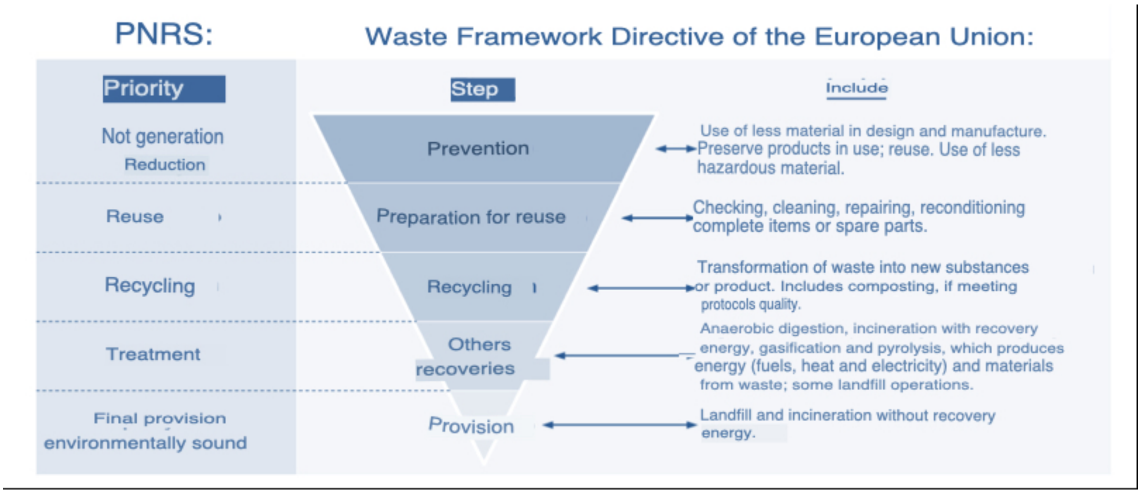
4.3.4. Legal Obligations and Sanctions: Law 12.305 on Solid Waste Management and Agroindustry

In view of the high generation of waste, it is reported that underdeveloped and developing countries such as Brazil have been investing in the management and treatment of their waste (DE CAMPOS; GOULART, 2017). In 1989, Bill 354/89 was presented to the Senate, on packaging and treatment of waste from the health sector, being a milestone for the elaboration of reverse logistics assumptions, with high resistance from the industrial sector (BERTÉ, 2009; FREIRIA, 2011).

To regulate the management of solid waste, on August 2, 2010, Law 12,305, called Politica Nacional de Resíduos Sólidos (National Solid Waste Policy - PNRS), regarding the different segments and waste generated, which was a national regulatory framework of great importance for waste. This involved federal institutional articulation (Union, State and Municipalities), productive sector and society in general (MMA, 2012). The established guidelines cover the integrated management of waste such as the shared responsibility of generators, public authorities and consumers (PLANALTO/GOV, 2010).

The PNRS in Brazilian legislation guides bases for the safe management of industrial waste on fronts such as: (i) non-generation, reduction, reuse and recycling, environmentally appropriate treatment and final disposal; but also, (ii) encourage the adoption of sustainable patterns of consumption of goods and services; (iii) adoption of the development and improvement of clean technologies; (iv) reduction of dangerousness of hazardous waste; and (v) encouraging the recycling industry, in order to encourage inputs of recyclable and recycled materials (PLANALTO/GOV, 2010). Identifying the potential for reuse and/or recycling of these wastes in the industry would promote the so-called "industrial symbiosis" (FERNANDA; CCSA, 2009; PINHEIRO; RICARDO; NUNES, 2015) (**Figure 16**).

Figure 16. Priority hierarchy for solid waste management, from European Union Framework, compared to Política Nacional de Resíduos Sólidos - National Solid Waste Policy (PNRS).



Source: (PALERMO; BRANCO; FREITAS, 2020).

The PNRS defined economic instruments based on plans, inventories, monitoring, inspection, research, education and tax incentives for the integrated management of solid urban waste in the states, municipalities and their respective territories (BERTÉ, 2009; MMA, 2012) (**Chart 2**).

Chart 2. Framework of Brazilian legislation and technical standards for waste management.

Residues	**Classification**	**Packaging**	**Storage**	**Transport**	**End Destination**
Agrosilvopastoral	NBR 10.004/2004	NBR 7.500/2013	NBR 12.235/1992 7.500/2013	NBR 13.221/2003 7.500/2013	Law n. 9.974/2000
Industrials	NBR 1.004/2004	NBR 12.235/1992	NBR 12.235/1992 7.500/2013	NBR 13.221/2003 7.500/2013	NBR 1.004/2004

Source: (DESPORTO et al., 2016).

Also, according to the Law, establishments generating waste classified as industrial, including agro-industrial ones, are subject to the elaboration of the Plano de Gerenciamento de Resíduos Sólidos (Solid Waste Management Plan - PGRS), with the minimum content established in Art. 21 of said law (HOFMEISTER et al., 2019; MMA, 2012). In practice, there is still no consolidated PGRS, the plans aimed at agro-industrial waste are the responsibility of the municipalities, in their urban cleaning projects, and of private companies in their activities, which in most cases do not have summarized information on the management and disposal of waste (FERREIRA, 2015; HENZ; PORPINO, 2017; MORAIS et al., 2015; SCHENINI, 2011).

Therefore, according to Fundação de Estudos e Pesquisas Agrícolas e Florestais (Foundation for Agricultural and Forest Studies and Research - FEPAF) (2006), there is little investment in secondary materials, which are available in the form of waste, having to find economic viability and agents in the market with the technology employed (SPADOTTO; RIBEIRO, 2006).

In 2020, a new law was published, on an emergency basis due to the Covid-19 pandemic, aimed at food waste (Law n. 14.016/20), authorizing establishments such as bars, snack bars, cooperatives, restaurants and supermarkets to donate food to human consumption (FILHO et al., 2021). Some bills have been pending in the legislature for over 20 years without definition (SANTOS et al., 2020b). Given this scenario, it is necessary to include food losses and waste as variables in economic planning for the coming years (CEDES, 2018).

4.4. Sustainability and Industrial Ecology for Waste Management and Material Design

4.4.1. Sustainability

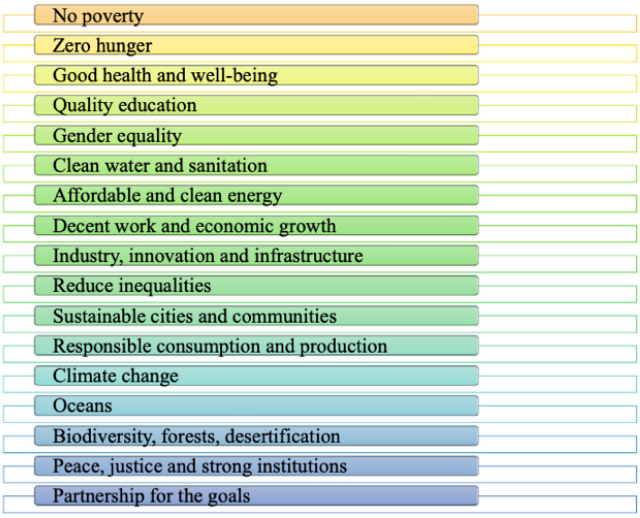
The human being is going through cultural changes and ethical values that triggered in the 60's and 70's, reflections on themes related to environmental sustainability (ALESSIO, 2014). The perception of a series of disasters and imbalances led the scientific community and governments to consider the issue as a world-wide problem (MORANDI, 2000). The first milestone towards sustainable development began in 1972, in Stockholm, Sweden, with the holding of the United Nations Conference on the Human Environment. Environmental disasters are no longer small localized problems, reaching global proportions and scale during the 1980s, in which specific laws were created for the installation and control of industries (MANO; PACHECO; BONELLI, 2010; MIKHAILOVA, 2004).

The concept of sustainable development has gained strength since the publication of the Relatório da Comissão Mundial sobre o Meio Ambiente e Desenvolvimento (Report of the World Commission on Environment and Development - CMMD), da Organização das Nações Unidas (United Nations Organization -ONU), in 1987 known as the Brundtland Report (MANO; PACHECO; BONELLI, 2010). Sustainable development is defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (KEEBLE, 1988). The Brundtland report also highlights the interest in three main pillars: (i) environmental preservation; (ii) social equity; (iii) and economic growth (AKIYODE et al., 2017). Actions promoted by the World Summit on Sustainable Development in 2000 reveal that resource management and allocation are approaches to controlling global depletion in ecosystem conservation (ONU; MBOHWA, 2021e).

Sant'Anna (2010) reports that environmental degradation was finally perceived on all continents: “we witnessed the extinction of species, the pollution of watersheds, the excess of solid and liquid waste from industrial production, deforestation, and the appearance of landfills" (SANT'ANNA, 2010). And only in the 1990s was it possible to take a big step forward in Brazil with the holding of ECO-92, where action objectives were outlined, although the Política Nacional do Meio Ambiente (National Environmental Policy) , beginning of the 1980s, has provided instruments for the creation of protected territorial spaces (FREIRIA, 2011). There have been a whole series of other meetings or summits focusing on aspects of sustainable development (BECKER, 2014a).

Sustainability has multifaceted concepts (SALLEH et al., 2021). he Science of Sustainability asserts the need to be able to integrate such a range of time scales (BECKER, 2014b). In 2015, the so-called Sustainable Development Goals (SDGs) (**Figure 17**) were readopted to address climate change and environmental protection, divided into 17 goals that address social and economic issues. These are directly linked to sustainable industry, infrastructure, clean energy, responsible consumption and production, which concern the efficient use of natural resources and waste reduction. (ISHAK; MANSOR; AB GHANI, 2021).

Figure 17. Sustainable Development Goals.



Source: (ISHAK; MANSOR; AB GHANI, 2021).

Summits were responsible for raising awareness and multilateral agreements Sustainability reporting serves multiple purposes (ASHBY, 2016c). The answers to sustainability are also intrinsically complex and wanting assessments, as a term is absolute about something that survives (ASHBY, 2016d).

For Cechin (2010), development cannot be seen only from an economic perspective, the studies have as their central theme the social morphogenesis. Therefore, for the author, the debate behind sustainable development is in the resources that the economic process uses, the inevitable dumping of waste in ecosystems, which connect the challenges of environmental sustainability with social and economic dimensions of development (CECHIN, 2010). Therefore, sustainable development represents a shared commitment to stable economic growth in the satisfactory and available management of resources (BECKER, 2014c). The allocation of these resources can be managed in a solid way that guarantees new supplies (EL-HAGGAR, 2007c; VIVIEN, 2011).

4.4.1.1.Sustainability in the Textile and Fashion Industry

By analyzing the history of the textile sector, technology can be highlighted as a strategic factor for change and development (BRUNO, 2016a; FLETCHER; GROSE, 2011b). It is because of the inevitability of textile manufacturers, to contribute to the industrial and academic communities, that in 1995, world conferences turned to "ecotextiles" (MIRAFTAB; HORROCKS, 2007b). Sustainability became a crucial and prominent feature and factor of the textile industry, increasing the concern to produce materials that meet environmental and social demands (ISLAM; AHMED; AZADY, 2021b; MORENO; SPROUL; QUINN, 2022). The greatest environmental impacts are imposed during the acquisition of raw materials (DHIR, 2021).

The yarn and fabric industry, one of the most impactful, has a relevant role in this scenario, as it allows these technological innovations to be practiced (UDALE, 2011). When thinking about new fibers and fabrics, materials have been great precursors of a new perspective on fashion (BRUNO, 2016b; FUJITA; JORENTE, 2015; SENAI, 2016b). Studies reveal that mentions of sustainability have increased. For two-thirds of respondents, sustainability has become a priority in combating climate change after COVID-19 (ARICI; LEHMANN, 2020; LEHMANN; ARICI; MARTINEZ-PARDO, 2019; WONG et al., 2021). For Textile Exchange Institution (2019), the textile industry operates mainly in 14 of the 17 SDGs (TEXTILE EXCHANGE, 2019b).

Progress is noted in the development of polymers and fibers from renewable biomass with biodegradable properties, such as coatings and lamination to extend and adapt their functionality (SHISHOO, 2012b, 2012c). A strong alternative to artificial fibers based on petrochemical products (STEGMAIER, 2012b). In addition to the search for new and innovative management with tools and business models (HERGETH, 2012). The main challenges faced by the modern textile industry involve high innovation in to use of ecological materials and processes with high performance and functionality (SHISHOO, 2012c), with effective technology transfer to industry (SHISHOO, 2012d).

Textile products have one of the shortest life cycles due to the logic of the fashion industry (LOPES et al., 2021b). The linear model established in the textile industry causes restrictions in the supply of products and high costs and environmental risks (GARDETTI, 2018; SENTHIL KUMAR; FEMINA CAROLIN, 2018). Industrial systems follow the context of an open flow, that is, the use of materials and energy that generate unusable waste. The current situation still does not contemplate the closing of the cycle efficiently (COSTE-MANIERE et al., 2018). Biofibers are among the most researched and demanded materials in this century (NISHINO, 2017). Among the innovations, the biomimetic approach is also focused on the development of fibers and composites (BAILLIE; JAYASINGHE, 2017) (**Figure 18**).

Figure 18. Circular design cycles: (a) biological cycle; (b) technical cycle.

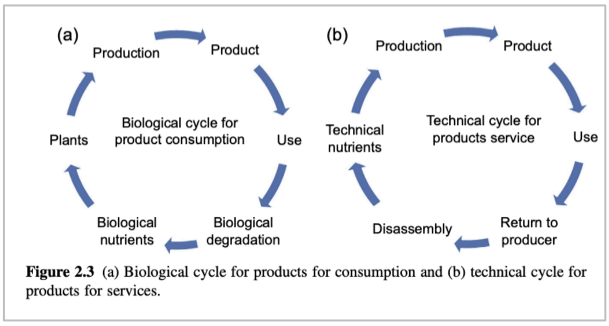


Figure 2.3 (a) Biological cycle for products for consumption and (b) technical cycle for products for services.

Source: (SILLANPÄÄ; NCIBI, 2019b).

Design concepts for circularity are incorporated in the textile industry, which results in two approaches such as the technical cycle: (i) manufacturing products with extended durability; (ii) product design for recyclability and disassembly of suitable materials. And the biological cycle: (i) biological materials safely returned to the biosphere (KOZLOWSKI; SEARCY; BARDECKI, 2018; MESTRE; COOPER, 2017a; NAYAK et al., 2021b; SENAI-SP, 2020; TOMANEY, 2015).

In the Science of Materials, green materials are defined as materials that are synthesized from sustainable sources using energy-efficient processes with minimal footprint, to the International Union of Pure and Applied Chemistry (RATHINAMOORTHY, 2018b). These may have superior or special properties in biocompatibility, biodegradability, and non-toxicity (NURFAIZEY et al., 2021). The process content and the most important sub-processes in the pulp fiber material manufacturing process provide a basis for innovative research (LÖNNBERG, 2000). Natural fibers being used as reinforcements or biopolymers are numerous and depend only on the functional requirements of the products (SAPUAN, 2021). The characteristics of green materials, when applied to processes and products, can help reduce the effects of the carbon footprint and high energy consumption throughout the life cycle, with the selection of materials being one of the factors of great importance for implementation design for sustainability success (SHAHARUZAMAN; SAPUAN; MANSOR, 2021). Biodegradable absorbent materials in engineering are in remarkable progress and are studied on a large scale (CIOVICA; LÖNNBERG; LÖNNQVIST, 2000).

Sustainable practices in the textile industry are based not only on the conservation of natural resources but on improving the quality of life of workers (WOJCIECHOWSKA, 2021).

4.4.2. The Industrial Ecology field

Definitions of industrial ecology comprise similar attributes and different emphases (CLIFT; DRUCKMAN, 2015). Among these, El-haggar (2007) highlights, in summary, a systemic and balanced view of the interactions between industrial and ecological systems, based on the study of flows and transformations of materials and energies, as an ideal model for managing natural resources and waste industrial. Cooperation between industrial processes and environmental sustainability (EL-HAGGAR, 2007b, 2007a). Authors talk about industrial ecology integrating the circular economy in search of eco-efficiency.

Ayres (2002) exemplifies the field of Industrial Ecology as an enabler, which can highlight the importance of efficient biogeochemical cycles through concepts, metaphors, applications and analyses, comprising technological knowledge and environmentally informed processes for such. The author identifies that the study of material flows as a raw material has a great contribution to the development of types of efficiency and cycling of materials already produced by natural ecosystems (AYRES, 2002). Gianetti and Almeida (2006) understand that EI proposes to close cycles, considering that the industrial system interacts, is part of and depends on the environment. Intending to facilitate the evolution of industrial systems, by offering a systemic view and the interrelation between companies, their products and processes (GIANNETTI, B. F.; ALMEIDA, 2006).

Thus, the addition of value to agro-waste by converting it into useful products is currently one of the main areas of basic research in laboratories, and which will soon reach an economic potential that can collaborate with green technologies (KAPOOR; PANWAR; KAIRA, 2016). The incorporation of industrial ecology involves the biological, systematic and technological field, through instruments such as Life Cycle Analysis and Material Flow (AYRES, 2002; LIFSET; GRAEDEL, 2015).

Food industry by-products can be seen as waste or resources when recovery technologies are implemented (HERRERO et al., 2020). However, the reprocessing of organic matter does not include the recovery of energy used in the recycling process. (WIESMETH, 2021b). For this, the concepts of circularity become restricted when focused only on waste management (SILLANPÄÄ; NCIBI, 2019a, 2019b, 2019c).

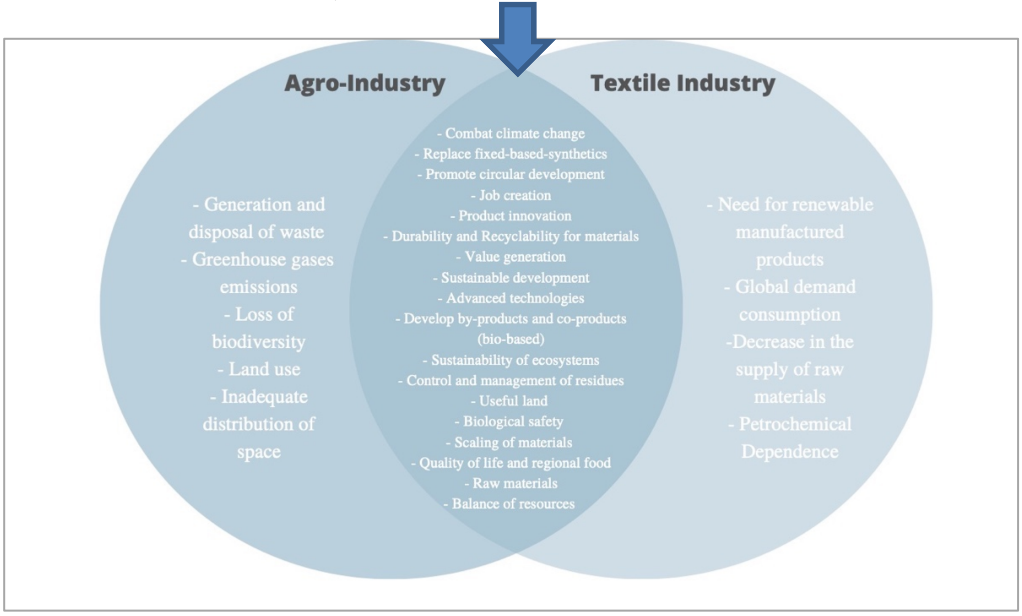
4.4.3. Design of Sustainable Materials from waste

Due to the growing concern for the environment and the search for more sustainable solutions in industrial production, the design of sustainable materials in Brazil has become increasingly relevant. Designers adopt strategies such as the use of renewable and biodegradable materials, as well as the reduction of energy consumption in the production of materials, and the development of new materials and technologies that can replace conventional materials with more sustainable options. The Brazilian government has encouraged the adoption of more sustainable practices in the industry, and there are several organizations and companies that work in the development and promotion of sustainable materials in the country (ASHBY, 2016c; BAILLIE; JAYASINGHE, 2017;

MACAULAY, 2007; SHAHARUZAMAN; SAPUAN; MANSOR, 2021; SIQUEIRA et al., 2022b) (**Chart 3**).

Chart 3. Principles of industrial ecology related to agro and textile industry.

Principles of Industrial Ecology	*Management of Agro-Industrial Waste*	*Development of Sustainable Materials for the Textile Industry*
Reduce material and energy use	Implement waste reduction strategies such as reducing, reusing, and recycling agro-industrial waste in textile production	Explore the use of agro-industrial waste as a source of sustainable materials for textile production, such as using pineapple or banana fiber as an alternative to cotton
Close material loops	Implement closed-loop systems in which waste from textile production is reused or recycled back into the production process, reducing the need for virgin materials	Explore the use of waste from the textile production process, such as leftover cotton fibers, as a source of new materials
Optimize resource efficiency	Implement measures to optimize the use of water, energy, and other resources in the production process	Develop new materials that require fewer resources to produce, such as biodegradable or compostable textiles
Emphasize life-cycle thinking	Consider the environmental impact of the entire life cycle of a product, from production to disposal	Develop sustainable materials that are designed to have a lower environmental impact throughout their entire life cycle
Foster innovation	Encourage the development of new technologies and processes that promote sustainability in the textile industry	Explore new materials and processes, printing to create textiles or using biotechnology to develop new sustainable materials



Source: (AYRES, 2002; CLIFT; DRUCKMAN, 2015; LIFSET; GRAEDEL, 2015; RATHINAMOORTHY, 2018a; SENTHIL KUMAR; FEMINA CAROLIN, 2018; SILLANPÄÄ; NCIBI, 2019a, 2019b; WIESMETH, 2021a).

The design of materials from waste has emerged as a promising alternative to reduce the amount of waste sent to landfills and incinerators and to reduce the extraction of virgin raw materials. One of the main advantages of this approach is the possibility of obtaining materials with unique characteristics and adaptable to different purposes. In addition, the design of materials from waste can contribute to the reduction of the environmental impact in other stages of the life cycle of the products, such as the emission of greenhouse gases and other pollutants. Although there are technical and economic challenges involved in the process of designing materials from waste, many researchers and companies have invested in innovative solutions in this area. Methods such as mechanical recycling, chemical recycling and pyrolysis make it possible to transform waste into new materials with surprising properties that can be applied in different areas (ASHBY, 2016d; NISHINO, 2017; SHISHOO, 2007) .

The design of sustainable materials and the design of materials from waste are areas in constant evolution and with great potential for reducing the environmental impact of human activities. With the advancement of research and technology, it is possible to expect the emergence of new materials that are increasingly efficient and sustainable, capable of meeting the needs of industries and society in general (ASHBY, 2016a; COSTE-MANIERE et al., 2018; GARDETTI, 2018; MESTRE; COOPER, 2017b; SENTHIL KUMAR; FEMINA CAROLIN, 2018; SILLANPÄÄ; NCIBI, 2019b; WIESMETH, 2021d; WILTS; SCHINKEL; KOOP, 2020).

4.5. *Cocos nucifera*

Coconut palm is a tropical crop, widely distributed in Asia, Africa, Latin America and the Pacific region (SIQUEIRA; ARAGÃO; TUPINAMBÁ, 2002a). It is considered one of the most important trees in the world, a base and sustenance in coastal and island ecosystems. Responsible for generating employment in all its exploration and commercialization stages, which generates income in about 90 countries, its fruits can be consumed in natura or processed in more than 100 different products and by-products (AGEITEC, 2012). This large amount and variety of products obtained from this plant makes it popularly known as "tree of life", "tree of well-being" and "tree of heaven"(CAMBUI; ARAGÃO; LEAL, 2007; MATHAI, 2005a).

The global coconut harvested area is about 12 million hectares, producing 61.1 million tons (BRAINER, 2018b). The world's production of coconut is concentrated in three countries, Indonesia (30.1%), the Philippines (24.7%), and India (19.0%). Brazil occupies the place of 5th largest producer, participating in 4.5% of the total produced, after Sri Lanka (BRAINER; XIMENES, 2020a).

Production is mostly carried out by small and medium-sized family farming producers (about 85%), to a lesser extent, by large agro-industrial companies (NORDESTE RURAL, 2015).

4.5.1. Origin and History

There are different opinions about the origin of the coconut tree, although the culture is considered to have a prehistoric origin in Asia, in the Philippine Islands (300 BC), with evidence confirming its existence in India (3,000 years ago) (MATHAI, 2005a). The spontaneous dispersion of the fruits in the sea currents, in theory, could have taken the fruits to distant beaches. The coconut tree is found in tropical countries and other countries, along the coastal strip between the tropics of Cancer and Capricorn, concentrated between latitudes 20º N and 20º S (SIQUEIRA; ARAGÃO; TUPINAMBÁ, 2002a).

When analyzing the historical productive behavior of the coconut, expressive growth is visible. The total world productivity increased substantially from 35 million tons around 1980 to almost 50 million tons (DAM, 2002a) mainly in the Brazilian market, due to technological incentives (FONTES; FERREIRA; SIQUEIRA, 2002a). From 1990 to 2009, Brazil ranked from the 10th to the 4th largest producer in the world, and the prospects for growth in both productivity and market coverage tend to grow (MARTINS; JESUS JUNIOR, 2011a) (**Chart 4**).

Chart 4. Introduction of coconut tree giant variation to Brazil.

Year	Ecotypes/Variety	Origin	Provenance	Importer	Planting Location
1553	Giant	India or Sri Lanka	Cape Verde Islands	Portuguese colonizers	Bahia
1939	Caboclo	Kuala Lampur	Malaysia	Paulo Burle e Carlos Browne	Cabo Frio- Rio de Janeiro
1978	West African Giant	Southeast Asia	Ivory Coast	CEPLAC	Una- Bahia
1981	West African Giant	Southeast Asia	Ivory Coast	SOCOCO	Mojú- Pará
1983	West African Giant	Southeast Asia	Ivory Coast	Embrapa-CNPCo	Neopólis-Sergipe
1983	Giant of Malaysia	Malaysia	Ivory Coast	Embrapa-CNPCo	Neopólis-Sergipe
1983	Polynesian Giant	Tahiti	Ivory Coast	Embrapa-CNPCo	Neopólis-Sergipe
1983	Giant of Rennel	Solomon	Ivory Coast	Embrapa-CNPCo	Neopólis-Sergipe
1983	Giant of Rotum	Fiji	Ivory Coast	Embrapa-CNPCo	Neopólis-Sergipe
1983	Tonga giant	Tonga	Ivory Coast	Embrapa-CNPCo	Neopólis-Sergipe
1983	Giant of Vanuatu	Vanuatu (Ex. New Hebrides)	Ivory Coast	Embrapa-CNPCo	Neopólis-Sergipe

Source: (SIQUEIRA; ARAGÃO; TUPINAMBÁ, 2002a).

The giant coconut tree, coming from the Cape Verde Islands, was first introduced in Brazil in the State of Bahia in 1533, by Portuguese colonizers, for this reason, given the popular name coco-da-baía or coco-da-bahia. With a second introduction only in 1939, coming from Malaysia, in Rio de Janeiro (LANDAU, 2018a; SIQUEIRA; ARAGÃO; TUPINAMBÁ, 2002b). The dwarf coconut tree had its first introduction in 1935, also in Bahia (**Chart 4**).

Chart 5. Introduction of coconut dwarf variabilities in Brazil.

Year	Ecotypes/Variety	Origin	Provenance	Importer	Planting Location
1925	Green Dwarf	Unknown	India	Mapa	Rio, Bahia, Pernambuco
1938	Yellow Dwarf	Malaysia	Malaysia	Paulo Burle e Carlos Browne	Araruama, Cabo Frio-Rio
1939	Red Dwarf	Malaysia	Malaysia	Paulo Burle e Carlos Browne	Araruama, Cabo Frio-Rio
1939	Green Dwarf	Unknown	Malaysia	Paulo Burle e Carlos Browne	Araruama, Cabo Frio-Rio
1978	Yellow Dwarf	Malaysia	Ivory Coast	CEPLAC	Ilhéus- Bahia
1981	Yellow Dwarf	Malaysia	Ivory Coast	SOCOCO	Mojú- Pará
1982	Yellow Dwarf	Malaysia	Ivory Coast	Embrapa-CNPCo	Neópolis Sergipe
1982	Red Dwarf	Malaysia	Ivory Coast	Embrapa-CNPCo	Neópolis Sergipe
1982	Red Dwarf	Cameroon	Ivory Coast	Embrapa-CNPCo	Neópolis Sergipe

Source: (SIQUEIRA; ARAGÃO; TUPINAMBÁ, 2002a).

The introduction of the coconut tree in Brazil and its adaptation allowed the emergence of a new producer class, occupying an ecosystem whose productivity is very diversified and of great social significance. In addition to its economic importance, coconut plays a very important role in the sustainability of fragile ecosystems, such as coastal communities and islanders (MARTINS; JESUS JUNIOR, 2011b; SIQUEIRA; ARAGÃO; TUPINAMBÁ, 2002b).

4.5.2. Classification

The Arecaceae family consists of a group of species generically known as palm trees, which comprises about 2,700 species and 250 genera distributed mainly in the tropics and subtropics (BAKER; DRANSFIELD, 2016). In Brazil, there are 38 genera naturally and about 270 to 300 species, which have greater diversity in the Amazon Forest and Cerrado (MENDES et al., 2019; SOARES et al., 2014). Palm trees represent the third most important botanical family for humans (JOHNSON, 1998).

Arecoideae, the largest subfamily found in the Northeast of the country, grows in many different biomes, including the tropical forest, caatinga, coastal restinga (sandbank), cerrado, and rupestrian field. Arecoideae consists of three tribes: Cocoseae, Euterpeae, and Geonomateae. Cocoseae is the largest tribe that occurs in the Northeast (NOBLICK, 2019).

The coconut tree belongs to the Arecaceae family (also known as Palmae), popularly used by the common name of palm trees. Subfamily Arecoideae (one of five subfamilies), tribe Cocoseae (one of 14 tribes in subfamily Arecoideae), subtribe Attaleinae (one of three subtribes in tribe Cocoseae), and genus Cocos L. (one of 12 genera in subtribe Attaleinae). Currently, the genus Cocos is monospecific, with only one species, nucifera, included in it (NAYAR, 2017). Botanical Classification, Origin and Distribution Division is Spermatophyte; class Angiosperm; subclass Monocot; order Principes (= Arecales) and popular name like coconut tree and coco-da-baía (ARUNACHALAM, 2012; SIQUEIRA; ARAGÃO; TUPINAMBÁ, 2002a) (**Chart 6**).

Chart 6. Taxonomic classification of coconut palm tree.

Division	Spermatophyte
Class	Angiosperm
Subclass	Monocotyledoneae
Order	Arecales
Family	Aracaceae (Palmae)
Sub Family	Arecoideae
Tribe	Cocoseae
Sub Tribe	Attaleinae
Gender	Cocos
Species	*Nucifera*, L.
Popular name	Coqueiro, Coco-da-baía

Source: Adapted from (NAYAR, 2017; SIQUEIRA; ARAGÃO; TUPINAMBÁ, 2002a).

The systematics of the families are based on morphological characteristics of the leaves, fruits, flowers, stems, on the anatomical particularities of their organs, on the comparison of cytological and histological characteristics, studies of the current geographic distributions and history of the evolution of the family and its genera (BAKER; DRANSFIELD, 2016).

4.5.2.1. Genetics

Coconut culture has great intraspecific variability (NAYAR, 2017). However, Siqueira et al. (SIQUEIRA; ARAGÃO; TUPINAMBÁ, 2002b) argue that, for the Brazilian coconut, the variability is small due to the existence of a single species and only two varieties. For the development of studies, the collection and introduction of genetic material allow storing genes, for future evaluations, and evolutionary studies such as productivity, resistance to pests, and diseases. For the authors, genetic drift occurs in small and isolated populations, with fluctuations and random factors.

Coconut palm is a diploid species (2n=2x=32) with a large genome size of 2.15 Gb nucleotide pairs (ARUNACHALAM, 2012). Studies that aim to determine the size of the coconut genome in 14 genotypes (six of the dwarf type and eight of the giant type), reveal that the coefficients of variation ranged from 2.5% - 3.1%, without big variation (FREITAS NETO et al., 2009).

The genomic work of the coconut is of recent origin, with research done on the cloning of a similar element in 1992 (RAMOS, 2003).

4.5.2.2. Morphological aspects

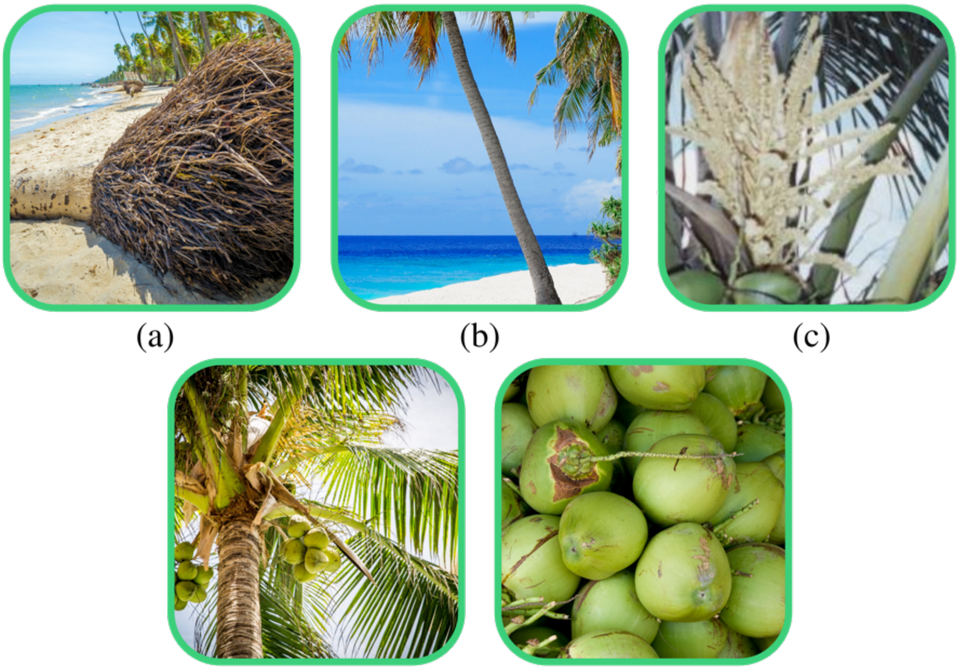
Under conditions of environmental impoverishment and unfavorable situations, the physiology and morphology can be affected, reducing the number of leaves or traditional diameters (ALVES et al., 2007).

The genus Cocos has leaflets arranged in a uniform shape with a fibrous leaf sheath. The root (**Figure 19a**) of the coconut tree has a fasciculated root system, without a main root, characteristic of monocotyledons. The base of the trunk produces thicker roots, 8 to 10 mm in diameter, varying from 2,000 to 10,000 roots (FONTES, 2006a)

The stem (**Figure 19b**) is stipe-style, due to being monocotyledonous, the coconut tree does not change and does not undergo growth in thickness and laterally (PASSOS; PASSOS, 2003). The inflorescence (**Figure 19c**) is a single branch (modified cauline branch), which are paniculate and axillary protected by large bracts (spathes) (SOUZA; MELO; MANCIN, 1999)

The leaf (**Figure 19d**) is pennate, with variable length, depending on the environment and age of the plant, and can reach 6 meters, with 200 to 300 leaflets from 90 to 130 cm with 12 to 18 leaves per year (FONTES, 2006a).

Figure 19. Morphological coconut palm tree aspects.



(a) (b) (c)

(d) (e)

Source: Getty Images. Adapted from (SOUZA; MELO; MANCIN, 1999).

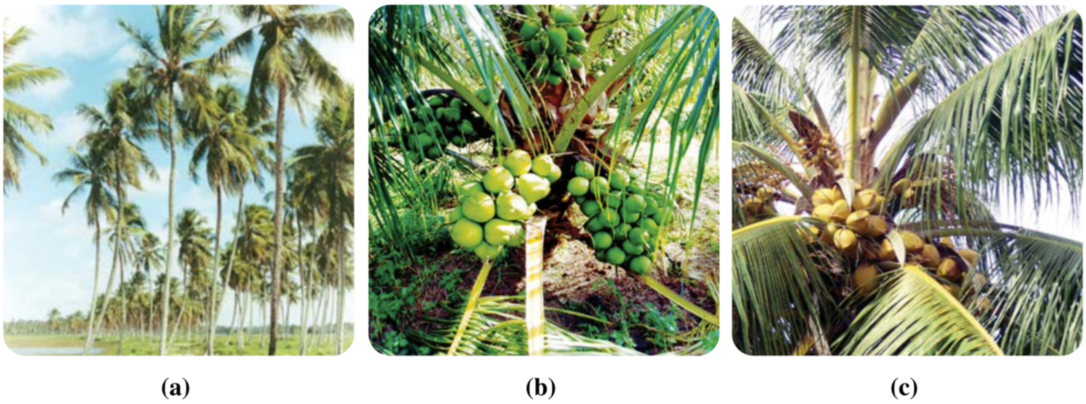
Ripe fruits (**Figure 19e**) are ovoid or ellipsoid, 30 to 45 cm long and 15 to 20 cm in diameter. The thick fibrous shell encloses a single-seeded nut (drupe), weighing between 1 and 2 kg (MISHRA; BASU, 2020a). The fruit has a very hard epicarp, a very thick fibrous mesocarp, a hard, thick and bony endocarp, and an endosperm with a very large central interior cavity (NOBLICK, 2019).

For morphological analyses, Alves et al. (2007) points out that the evaluative morphological characters are: (i) number of living leaves (NFV); (ii) number of sheets issued (NFE); (iii) collar circumference (CC); (iv) leaf length, petioles, leaflets, blade and leaflets (CLF).

4.5.2.3.Variety and Diversity

Within the genus Cocos, there are three main varieties in cultivation in Brazil: typical variety Nar. (giant variety), nana Griff variety (dwarf variety), and the hybrid variety formed by crossing these varieties (BRAINER, 2018b; FONTES; FERREIRA; SIQUEIRA, 2002b). It is estimated that the hybrid coconut (**Figure 20a**) occupies 10%, 20% with the dwarf variety (**Figure 20b**), predominantly the Green Dwarf, and 70% with the giant variety (**Figure 20c**) (AGEITEC, 2012; RIBEIRO; COSTA; ARAGAO, 2012).

Figure 20. Coconut palm trees varieties: Giant coconut tree; (b) Dwarf coconut palm; (c) Hybrid coconut.



Source: Adapted from (FONTES, 2006a).

The use of each coconut tree can provide advantages and disadvantages to the desired agroecological conditions. According to (COHIBRA, 2018a, 2019), working on the genetic improvement of coconut trees, the following characteristics are identified (**Table 2**).

Table 2. Characteristics of coconut cultivars.

Characteristics	**Cultivars**		
	Dwarf	**Hybrid**	**Giant**
Beginning of flowering (years)	2 - 3	3 - 4	5 - 7
Useful life (years)	30 - 40	50 - 60	60 - 70
Fruit Size	Small	Medium/Large	Large
Growth	Slow	Intermediary	Fast
Size (height)	10 - 12 m	20 m	20 - 30 m
Production (fruits/year)	150 - 200	130 - 150	60 - 80
Average fruit weight	900 g	1200 g	1400 g
Average walnut weight	550 g	800 g	700 g
Average albumen weight	200 g	400 g	350 g
Requirement	High	Intermediary	Low
Production destination	Water	Water/Agribusiness/ Cuisine	Agribusiness/ Cuisine

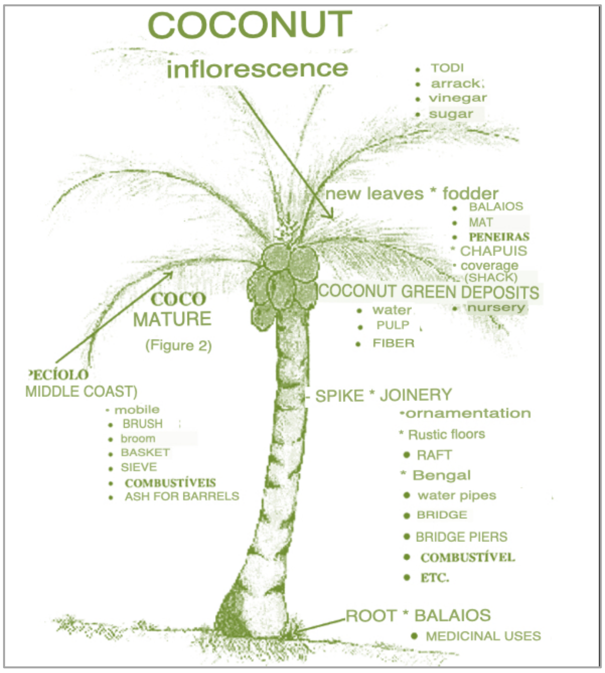
Source: (COHIBRA, 2019)

According to the author, the production and destination of coconut follow different flows from the main producers and global markets. Brazilian crops are intended for the production of dried coconut *in natura* such as coconut milk, grated coconut, and coconut water, especially in other markets, the focus is mainly on the production of copra, with main derivatives of coconut oil and flour (BRAINER; XIMENES, 2020b; SIMONE; PEREIRA; DOUTOR, 2020b). In general, dry coconut (solid albumen) is the most used in fresh consumption of dry pulp, and in industrialization, the production of grated coconut, coconut milk, and derivatives comes from the Giant variety. Green coconut (liquid albumen) for the production of coconut water is obtained from the dwarf variety, also used in agribusiness, and the hybrid is intended for two purposes, both for the production of dry coconut and green coconut (BRAINER, 2018b; LANDAU, 2018b).

4.5.2.4.Use of the palm tree

Coconut is considered a multipurpose tree. Every part of the coconut tree can be used economically. Throughout history, the emphasis on the part used in coconut shows different use in regions of the world (NAYAR, 2017) (**Figure 21**).

Figure 21. Coconut products and use.



Source: (DE CARVALHO, 2007).

The use of the trunk of palm trees is unlikely, and the use for fibers and production of panels and pulp is the only promising way (AKMAR et al., 2000). Nonetheless, (MORORO, 1998), in a base book for the Coconut Industrialization series, states that the uses can happen:

> (1) **Log or Spike:** It can be used for wood used in joinery, marquetry (inlaid work), floors, ornamental pieces and structural elements in bridges, fences, houses, corrals, and other rural constructions [...]
> (2) **Coconut leaves:** For covering and walls of native houses, warehouses and nurseries, and/or traced for carpets, panels, hats, fans, fans and other articles. The petiole is used to make baskets, animal feed [...]
> (3) **Coconut tree root:** Used for baskets, and by native populations as a toothpaste (roasted and ground roots) for medicinal purposes and as an antiseptic for wounds [...]
> (4) **The tender shoots:** Consumed in salads as preserves (palm hearts, pickles) [...]
> (5) **Inflorescences:** A sap known as "tódi" is extracted which is used as refreshment in the regions collected daily (product of natural fermentation) with about 8% alcohol, high as vinegar, sugar and yeast for bread [...]
> (6) **Coconut:** The fruit of the coconut tree is considered most important and used. Of the more than 100 products, the following are mentioned: (i) whole coconut; copra (dry almonds for oil extraction); (iii) coconut oil (from copra or almond); (iv) coconut cake (oil extraction residue); (v) fibers and other food products (MORORO, 1998, p. 10,11 e 13).

Studies, when not directed to the use of fiber, show that the treatment of coconut palm waste is aimed at transforming it into fertilizers and organic compounds (NUNES, 2011).

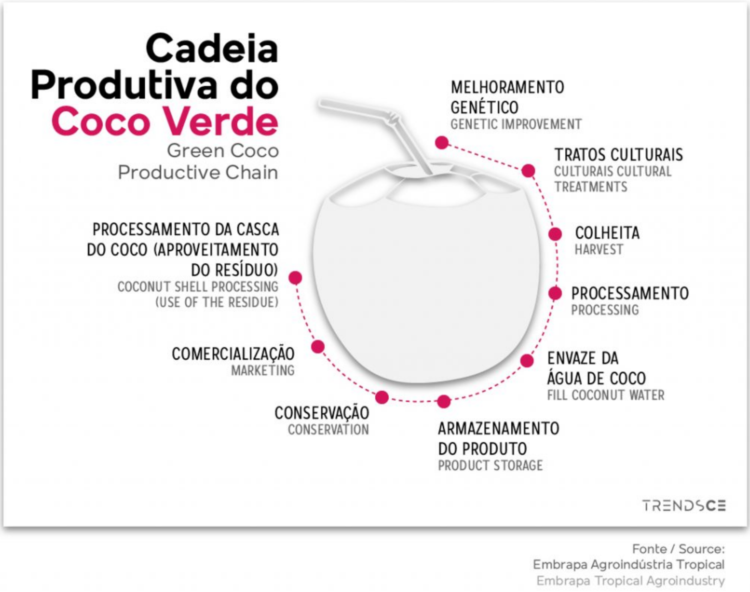
4.5.3. Green Coconut Productive Cycle

EMBRAPA Agroindustry provides the Coconut Knowledge Tree, a tool that offers information about the coconut tree, covering the pre-production, production and post-production phases, as well as access to publications, technical and support works in full. In order to synthesize the coconut production cycle, the image and information in **Figure 22:**

> 1. Soil preparation: Soil preparation for planting the coconut seedlings, which includes cleaning, leveling and fertilizing the soil.
> 2. Planting: Planting of the coconut seedlings in previously prepared pits, respecting the recommended distance between plants.
> 3. Care of the seedlings: Care of the seedlings, including irrigation, pest and disease control, and regular fertilization.
> 4. Growth and development: As the seedlings grow and develop, pruning and cleaning of dry leaves is necessary.
> 5. Flowering: When the seedlings reach the right age, they begin to flower, producing inflorescences with male and female flowers.

6. Pollination: Pollination is carried out manually or by insects, such as bees.
7. Fruit formation: After pollination, the fruits begin to develop.
8. Harvesting: When the fruits reach maturity, they are harvested manually or with the help of machines.
9. Processing: The fruits are processed according to their purpose, coconut oil and coconut milk can be produced, among others.
10. Commercialization: The coconut products are commercialized in different forms, such as food products, cosmetics and oils.

Figure 22. Green Coconut Productive Chain.



Source: (TRENDSCE, 2021).

It is important to remember that this flow chart is only a simplified representation of the green coconut production cycle and that there may be variations according to the region, climate, and purpose of the production.

4.5.3.1. Sustainable use

According to the exploration limits, researchers from Embrapa reveal that soil management is among one of the most important prerequisites in the management of coconut cultivation. The displacement of the coconut tree to unconventional regions has aggravated technological problems that are still being studied. The soils that predominate in Brazil are, in general, sandy, favorable, therefore, to the coconut tree, however they have low levels of organic matter and nutrients, low water retention capacity in some localities. As an aggravating factor, rainfall is unstable, generating water deficit for crops with a long cycle, perennial or without perennials, such as coconut trees, therefore requiring special care (FONTES; FERREIRA; SIQUEIRA, 2002a).

If the culture is done improperly, it can intensify erosion, which in soils with a cohesive layer is very serious, and can accelerate the degradation process, creating unsustainable situations for agricultural exploitation and environmental preservation. (AZEMI; NOOR; SARIP, 2000). Post-consumer coconut residues are considered inevitable; therefore, they do not change the structure of the food chain.

4.5.4. Commercialization and economic aspects: Data and Data and Brazilian Economy Production and Use of Coconut

Currently, Brazil is the 5th largest producer, with a 4.5% share of the world produced, highlighting an annual growth of 0.8% of the harvested area and 0.1% of the world production, in the last decade (SIMONE; PEREIRA; DOUTOR, 2020b). This increase in production is mainly due to productivity, as while the cultivated area grew by 13.2% between 1990 and 2015, production and productivity increased by 143.2 and 114.8% (BRAINER, 2018b).

Studies in the area estimate that, on average, 1 hectare of coconut occupies three people in direct employment and each direct job provides four jobs indirectly (CUENCA, 2016). Considering the area harvested in Brazil in 2019 (**Table 3**) of 186,950 ha, they generate 560,850 thousand direct jobs and 2,243,400 indirect jobs along the coconut production chain. This is relevant because small farms (less than 10 ha) of family farming predominate, which are characterized by the use of semi-extractive production systems (FONTES, 2006b).

Despite the subsequent loss in recent years due to climatic adversities (**Table 3)**. Brazil has the 6th largest area in the world, standing out in the value of production US$5.277.676 (2019); quantity produced 1,553,966 thousand fruits (2019); 37,515 establishments units (2017); number of palm trees 25,170 thousand units (2017) (IBGE, 2020a; INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATISTICA- IBGE, 2021a, 2021b).

Table 3. Area for harvesting, quantity and value of coconut production.

Coco-da-baía*	**2016**	**2017**	**2018**	**2019**
Variable - Area for harvesting (Hectares)	234.781	210.612	199.572	188.113
Variable - Harvested area (Hectares)	233.933	209.406	198.655	186.950
Variable - Quantity produced (Tons)	1.756.264	1.756.264	1.563.600	1.553.966
Variable - Production Value (Thousand Dollars)	6.199.363	5.913.484	5.351.885	5.112.767

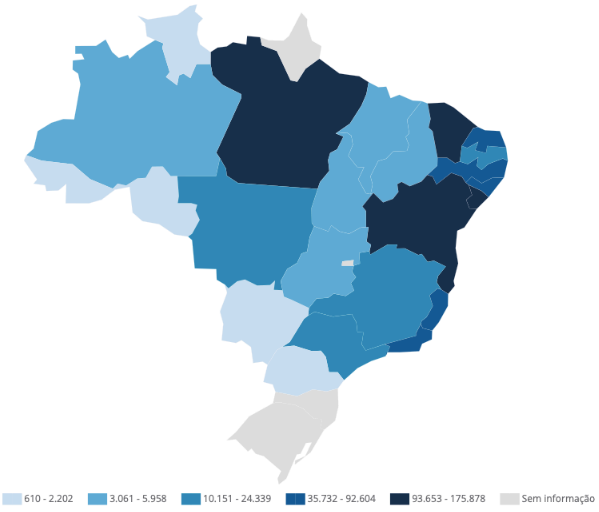
* The amount of coconut produced is expressed in thousand fruits and the average yield in fruits/ha.

Source: IBGE - Produção Agrícola Municipal (PAM, 2021).

Green coconut commercialization can be considered strong from October to January, a period that coincides with warmer months in the South and Southeast regions of the country, when there is an increase in coconut water consumption (MARTINS; BARROS; RODRIGUES, 2016). That is, the supply and demand for coconuts are greater during the tourism period along the entire Brazilian coast, and the intensity of consumption can be defined by climatic seasons, with 56% in summer, 19% in autumn, 19% in spring, and 6% in the winter (CUENCA et al., 2002). Green coconut can be harvested every 20-35 days (MISHRA; BASU, 2020a).

The Brazilian Northeast region remains the largest producer, with 81.3% of the area and 71.2% of the national production (SOUZA; LIMA, 2019). The highlight are the states of Bahia, the largest producer (175,878), Ceará (157,742), Sergipe (106.354), Pará (93,653) and Espírito Santo (92,604) (IBGE, 2020b) (**Figure 23**).

Figure 23. Production Value Coco-da-Baía Brazil (Thousand Reais) 2019.



Source: (IBGE, 2020a).

The volume of coconut water can be evidenced through imports that in 2016 totaled 3.3 thousand tons, and between 2017 and 2019 they increased by 450.7% (AGROSTAT, 2021). The bottled coconut water market in Brazil in 2019 was valued at US$ 740.75 million The Brazilian Congress of Agribusiness 2020 (ABAG) explains that there was the Brazilian agro crisis, affecting producers during the year 2020 with losses due to the closing of factories, however, the nutritional benefits offered by the water ensured success in the market, which projects, the coconut water market packaged in 637.82 million liters by 2025, growing by 23.19% compared to 2019, valued at US$ 740.75 million (ABAG, 2020; COHIBRA, 2018b; SIMONE; PEREIRA; DOUTOR, 2020b). Considering the period between January 2018 and December 2019, there were exports to 41 countries (SINDCOCO, 2020).

However, the increase in consumption and industrial production of coconut contributes to the generation of about 2.7 million tons per year, of which 74.5% is green coconut, which is more difficult to degrade than dry coconut (BRAINER; XIMENES, 2020b). It is discarded on average, about 7 million tons of coconut per year in Brazil. There is a big question in the post-consumption of coconut in Brazil regarding the accumulation of this material, which represents a problem for the sanitary management of several rural and urban areas, in addition to being harmful to the environment when dumped in landfills (MARTINS et al., 2016b; MOURÃO et al., 2016) (**Figure 24**).

Figure 24. Emsurb (Aracaju) collects 190 tons/waste per week.

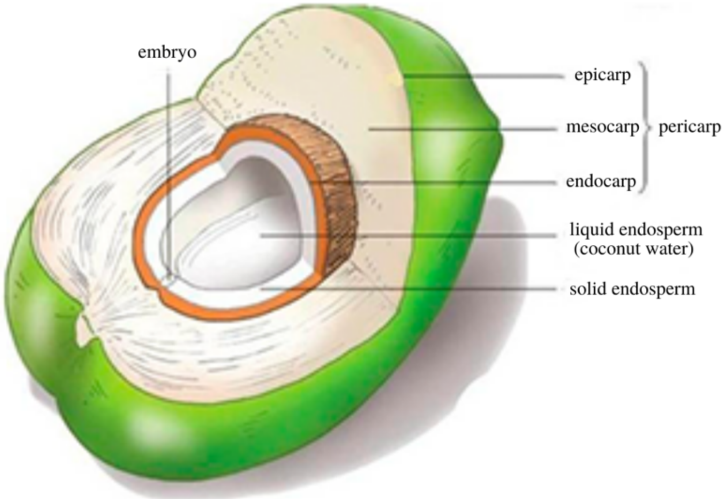
Source: (JÚNIOR, 2019).

The husks, when deposited incorrectly, in addition to occupying large spaces, the decomposition generated is responsible for the production and release of methane, a major contributor to global warming (PASSOS, 2005a). For the processing of this residue, the research agency EMBRAPA Tropical Agroindústria, in partnership with metallurgical companies, has developed technologies for the transformation of the bark into powder and fiber, as a possible opportunity to generate income for the producer and reduce the impacts generated by the increase in waste (CORREA, 2006a; JÚNIOR, 2020; ROSA, 2002).

4.5.5. Coconut fiber

Coconut fibers belong to the lignocellulosic class, composed mainly of cellulose and lignin (MATHAI, 2005). Coconut husk (source of fiber) has been treated as waste for many years. Scientific technologies and the characteristics of elasticity, durability and resistance to traction and humidity, made possible its use as a possible industrial raw material for Brazil (CORREA, 2006b) (**Figure 25**).

Figure 25. Green Coconut Structure.



Source: (MATTOS; FIGUEIREDO; ARAÚJO, 2013).

The green coconut husk contains: (i) epicarp (outer layer), the "husk" of the fruit; (ii) mesocarp, located between epicarp and endocarp; (iii) endocarp (stone layer) more internal than the pericarp, rigid part that surrounds the seed, has three circular depressions at the base (carpels) forming the embryo; (iv) albumen, tissue with nourishing substances in the seed (CARVALHO, 2009). The mesocarp is the thick part and fiber source of the fruit. It can contain from 3 to 5 cm in thickness, consisting of a fraction of short and long fibers and another fraction called powder, which is aggregated to the fibers (ROSA, 2002) (**Figure 26**).

Figure 26. Green Coconut Fruit and Coconut fiber in natura.

Source: Mylena Uhlig Siqueira.

Coconut fibers are classified into three varieties as: (i) finer and shorter fiber, (ii) moderately coarser and longer fiber, and (iii) harder and very long fiber. For the author, the thinnest and shortest fibers are used as filling for mattresses, and the medium-length fibers are those applicable to textiles, as are the harder fibers used for brushes and brooms (MISHRA; BASU, 2020a; SAVASTANO JR, 1986).

4.5.5.1.Characterization, physical and chemical properties of coconut fiber

The fibers of coconut cultivars have different compositions depending on their origin, maturity and form of extraction. Therefore, similar thermal and mechanical properties are highlighted, which demonstrate potential to be used on an industrial scale (JERONIMO; SILVA, 2013; MARTINS; JESUS JUNIOR, 2011a). There are different data regarding its chemical composition due to the origin, extraction, location and cultivation of the fiber of the analyzed fruit (**Table 4**).

They are extracted from the fibrous mesocarp of the fruit and about 20.6% of its chemical composition is related to the number of total extractives (fatty acids, some resins, tannins, gums, sugars, starch and dyes), 54% Lignin and 25.4% % ash (inorganic matter such as calcium and potassium) (CATUNDA; AMAZONAS; MATOS, 2016). Coconut fibers represent approximately 32% of the lignin, 45% of the cellulose, 20% of the hemicelluloses and 1.3% of the ash (PAZ; PEDROZA; OLIVEIRA, 2017). Lignin represents 37% to 43% of coconut fiber, while cellulose varies from 31% to 37% (CORRADINI et al., 2009). Basically, the high degree of lignin explains its durability and resistance, cellulose, its possibility of obtaining second-hand ethanol, and the ash, filtering (CABRAL; SANTOS, 2017). Lignin, present in a large part of the composition of coconut fiber, constitutes a natural binder function, which under suitable conditions of pressure and temperature, can dispense with the use of synthetic resins. Being an alternative to the use of conventional adhesives that are based on formaldehyde, a substance considered toxic and carcinogenic, derived from petroleum These characteristics, among others, such as the optimal levels of porosity, absorption and resistance to fertilizers, make different applications possible (ARAGÃO; SANTOS; ARAGÃO, 2005) (**Table 4**).

Table 4. Chemical compositions of coconut fiber.

	(ARAGAO, 2002)	(CORRADINI et al., 2009)	(KHALIL; ALWANI; OMAR, 2006)	(AGOPYAN et al., 2005b; JOHN et al., 2005)
Cellulose (%)	23-43	31-37	44.2	35-60
Lignin (%)	35-45	37-43	32.8	20-48
Hemicellulose (%)	3-12	-	6.4	15-28

Source: Adapted from (AGOPYAN et al., 2005b; ARAGAO, 2002; CORRADINI et al., 2009; JOHN et al., 2005; KHALIL; ALWANI; OMAR, 2006).

The fibrous yarns are highly lignified cellulose, having rough and rigid characteristics (MISHRA; BASU, 2020a). Lignin plays an important role in the physical characteristics of fibers, making them harder and stiffer than pure lignocellulosic fibers, such as cotton, and harder than other lignocellulosic fibers such as sisal, pineapple and ramie (ARUNACHALAM, 2012).

In addition to the chemical composition, the physical properties must be mentioned such as elongation (42%), linear density (19 tex) and values of average toughness parameters (11 cN/tex) (RAO; DUTTA; UJWALA, 2005). These ensure high tensile strength and elongation properties, with advantages including acceptable specific strength properties, high elasticity, low cost, low density and biodegradability (MARTINS; SANCHES, 2019a) (**Table 5**).

Table 5. Characteristics and properties of coconut fibers.

Properties	Values
pH	5.4
Electric conductivity	1.8 dS/m
C/N Ratio	132
Density	70 g/L
Total Porosity	95.6%
Water retention	538 mL/L
Assimilable water	19.8%
Length	12 – 33 cm
Diameter	0.05 a 0.4 mm
Resistance	dry: fiber (8-20km). yarn (8-12km). Wet :93% dry resistance
Hygroscopicity	moisture combination 13.00%

Source: Adapted from (ARAGAO, 2002) e (ERHARDT, 1976b).

These characteristics show its technological potential, even superior to other vegetable fibers, favoring its reuse as an alternative raw material in the composition of new products (CATUNDA; AMAZONAS; MATOS, 2016) (**Table 6**).

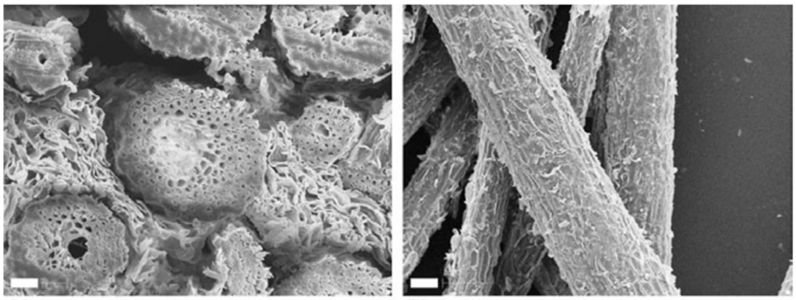
Table 6. Chemical composition of some vegetable fibers.

	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Extractives (%)
Coconut	**32-43**	**0.15-0.25**	**40-45**	**-**
Sisal	65	12	9.9	2
Rami	68.6-76.2	13-16	0.6-0.7	0.3
Jute	61-71	14-20	12-13	0.5
Hemp	68	15	10	0.8
Linen	71	18.6-20.6	2.2	1.5
Pineapple Leaf	70-82	18	5-10	-
Banana Tree leaf	60-65	6-8	5-10	-
Sugarcane Bagasse	32-48	19-24	23-32	-

Source: Adapted from (FARUK et al., 2012) and (SILVA, 2003).

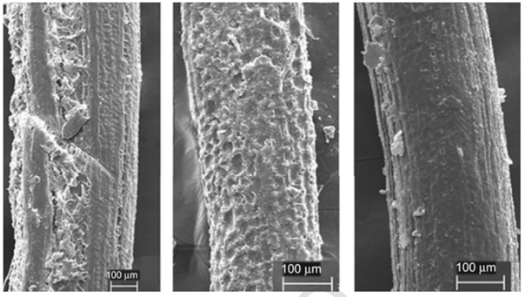
Coconut fiber cells are oval in shape with small air cavities near the center of the filaments (about one third of the fiber volume is filled by this air). Air gives rise to elasticity (resilience), buoyancy in water and increased time for water penetration into fibers (MATHAI, 2005a) (**Figures 27** e **28**)

Figure 27. Photomicrographs of coir stalk cross and longitudinal sections.



Source: (MATHAI, 2005)

Figure 28. SEM micrographs of coconut fiber raw, backwater retted and chemically retted.



Source: (MISHRA; BASU, 2020a)

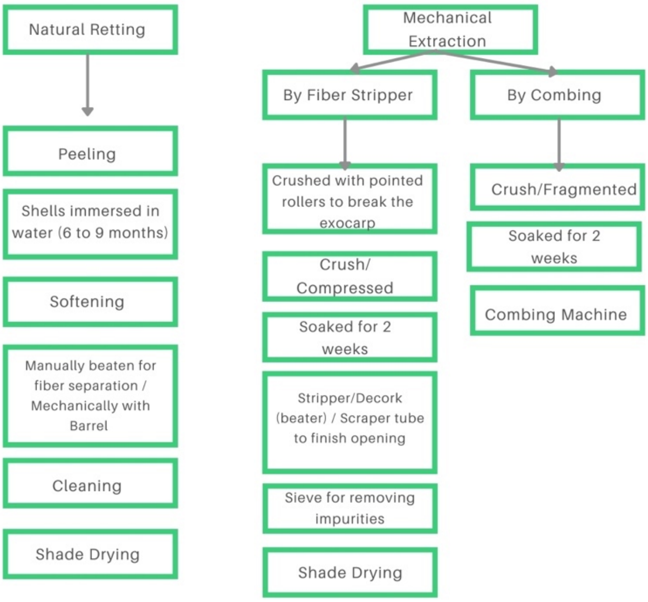
For the author, this indicates that the properties of coconut fiber are less affected in humid conditions in relation to other hard fibers, resistant to bacteria and salt water.

Note globular protrusions making the fiber surface heterogeneous with prominent cracks, micropores and irregular deposition (MISHRA; BASU, 2020a)**.**

4.5.5.2.Coconut Fiber extraction

For Mathai (2005), the fiber can be extracted from the fibrous coconut husk after natural retting or mechanical extraction. Mechanical extraction by a decorticator has no separation of short and long fibers, while by a comber it has separation of fibers (**Figure 29**).

Figure 29. Flowchart types of coconut fiber extraction.



Source: Adapted from MATHAI (2005).

The green husk has 30 -50% fiber, in which the fiber yield is 10 to 17.5%, 1000 husks can yield about 140kg of fiber (MEENATCHISUNDARM, 1979). Lignin normally occurs in vascular tissues in fluid transport and mechanical resistance. Fibrillation can be performed by mechanical means and/or chemical treatment. In mechanical pulping, lignin removal is not possible (AKMAR et al., 2000). While EMBRAPA normally extracts the fibers within 3 days of collecting the husks, another method is to carry out the extraction by "retting", where the green walnuts are kept under water for 2-4 months and then the fibers are extracted as in India [Private communication of the authors with EMBRAPA] (SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b)

The processing of coconut waste generates three types of fibers, classified as: long white fiber (extracted from the husk at 8 to 10 months of age), long brown fiber and short brown fiber (extracted from mature coconuts at 12 months of age) (**Figure 30**). White fiber is thinner, longer and softer than brown fiber (CORREA, 2006b).

Figure 30. Long and short coconut brown fibers

Source: Adapted from (CORREA, 2006a)

However, with the increase in demand for ecological materials, the production of brown fiber (from mechanical extraction) has increased from 335 to 459 thousand tons, while there is a reduction in the production of white fiber, from 95 to 81 thousand tons of conventional extraction, in India (MISHRA; BASU, 2020a).

As a method of processing the Brazilian fiber, little information is available at the fiber level, however, in the research by WIEDMAN et al., (2002), in technical visits to projects in Brazil and India, it was possible to observe the process of removing fibers from POEMA, linked to the Universidade Federal do Pará -UFPA, works with needy communities in the state producing headrests for truck seats in a cooperative system, with a daily production of 100 units (**Figure 31**).

Figure 31. POEMA Processing structure

Source: (WIEDMAN et al., 2002)

> **1. Nut harvesting and separation:** The coconuts are received and undergo a manual nut separation process (endocarp + pulp), in which the whole fruit is pressed against an oval-shaped blade driven into the ground, separating the nut of the fibrous part (mesocarp). Coconuts must be dry to facilitate cracking and separation of the shell. The chestnuts are sold at the local market, and the shells go into retting tanks.
> **2. Retting:** Retting is a process of biological origin, and consists of deposition of the peels in tanks with water so that the spontaneous fermentation of the vegetable matter helps the release of the fibrous bundles. Retting lasts from four to twelve weeks, depending on chemical and physical factors such as pH and water temperature.
> **3. Shredding:** After the retting period, the husks are introduced into shredding machines, adapted forage machines, which, driven by a gasoline engine and fed by a constant water flow, rotate a hammer shaft that strikes the husks, separating the fibers of the non-fibrous material, or coconut powder.
> **4. Drying and stringing:** the fibers are left to dry in a covered area, and then packed in a manual stringing mechanism. The ropes are rolled into 2 to 3 kg bales, which are placed in an autoclave for the purpose of memorizing the fibers. The bales are transported to another unit of the cooperative, where the ropes, after being undone, are sprayed with latex and molded, the state in which they are used in that unit to stuff upholstered seat backs for trucks (p. 98-107)

In another Brazilian cooperative in Igarassú, the largest coconut producing region in the state of Pernambuco:

> • **Receipt of raw material** - Coconut shells are brought in trucks. Each truck transports, on average, 32 m3 of bark that will yield, at the end of the process, approximately 1.3 tons of fiber.
> • **Defibration** - The barks are introduced, through a conveyor belt, inside the “desfibradeira”, a hammer-cylinder with a 150 hp engine, where they are retting, at the same time that a large amount of water is introduced. 50,000 liters/hour of water are consumed to wash the fibers and remove residues.
> • **Drying -** The fibers are air-dried on free patios, acquiring a dark brown color.
> • **Combing and sorting -** The fibers are packaged in equipment consisting of a nail roller, which, while combing, lets the fibers of less than 80mm fall.
> • **Stringing -** Through a scale and in a continuous process, the “ericadeiras”, or stringing machines, are fed with determined amounts of fiber. Metal cylinders compress the fibers, and a rotating shaft twists the fiber bundle into coils of rope. The rolls will serve to feed the “blankets” machines in the upholstery industries

(p. 98-107)

These processes, similar to those carried out in India, but with diversity in retting time and size of demand and technological investment.

4.5.5.3. Handcrafted and industrial processing

Spinning still doesn't show advances in mechanization, done by mainly manual methods, 23 varieties of yarn have already been developed and registered in India, in rigid, medium and soft twist. An estimated 20% of the fibers are being bleached for use, however, the process is carried out in the spinning process due to the bulk of the fiber (MATHAI, 2005). Currently, there are more than 300 variations and ecotypes of coconut in fiber quality and quantity in Southeast Asian countries (MISHRA; BASU, 2020b).

Until the development of the study, parameters for commercial industrial use of fiber quality were not established, and no specific machine for precise separation of fibers was established (MISHRA; BASU, 2020a).

In Brazil, green coconut husks have a late technology compared to mature coconuts, however, for the processing technology of green coconut husks, Embrapa Agroindústria Tropical has developed equipment for this material (CARVALHO, 2009; CORREA, 2006b) (**Figure 32**).

Figure 32. Equipment for processing green coconut shell

Source: (MATTOS; FIGUEIREDO; ARAÚJO, 2013)

After the crushing, pressing and sorting process, the fibers correspond to 30% of the final product, while the powder corresponds to 70% of the sorting machine. The machine is used for when coconut tree residues are crushed, washed and hydrolyzed before being composted in 3m x 1.2-1.4m x variable length windrows. The bark is combined with cow manure in a 2:1 ratio and treated with a biological accelerator to reach the humification stage in 120-150 days. The addition of leaves and bunches facilitates biodegradation (MATTOS; FIGUEIREDO; ARAÚJO, 2013) (**Figure 33**).

Figure 33. A) Crusher of dry coconut shell, B) immersion of shell in water to be crushed

Source: (CORREA, 2006a; CUENCA, 2016)

4.5.5.4. Coconut fiber treatment methods

The fibers have impurities, wax, greasy and globular protrusions on their surface, with detectable cracks and micropores. The main treatments identified in the literature involve: (i) alkaline treatment; (ii) acid treatments (HCl, CH3COOH, HNO3); (iii) oxidizing treatments (NaOCl, H2O2); (iv) treatment with ethylene dimethacrylate (EMA) and UV radiation; (v) treatment involving dinitrophenylation, diazo coupling and combined diazo-cyanoethylation coupling; (vi) urea treatment of acid hydrolyzed and mercerized coconut fiber fibers; and (vii) accelerated chemical softening in combination of strong reducing agent and alkalis (BILAL et al., 2020; CHIOCHETTA et al., 2017; KHALIL; ALWANI; OMAR, 2006; MADHAV et al., 2018a; MATHAI, 2005a; MISHRA; BASU, 2020a, 2020b; NUNES et al., 2020a)

4.5.5.5. Fiber processing

In India, the production of fabrics in the coconut industry can be broadly classified as woven and non-woven. Most fabrics are manufactured using simple warp and weft interlacing methods in hand weaving, traditional hand looms and power looms (MATHAI, 2005b, 2005a; MEENATCHISUNDARM, 1979; MISHRA; BASU, 2020a).

4.5.5.6. Applicability of coconut fiber and main products

For Mathai (2005), spinning coconut yarn from coconut fiber has been practiced over the centuries, but its industrial manufacture began in the mid-19th century. Residual by-products of coconut cultivation, especially the fruit, classified as hard fibers, were used in the manufacture of low value-added products, often considered as waste or residual material (REGINA; CARNEIRO, 2020a; SANTANA; SILVA; MULDER, 2020). Over the years, the polymer industry has leveraged its use of materials with sustainable characteristics (MACHADO et al., 2014).

The coconut shell wrapped around the fruit represents the fibrous material, which makes up the internal endocarp (liquid and solid of the food) and the external mesocarp (fibrous part), and attributes such as fineness and length, and maturity is crucial in its application. The thinnest and shortest, used in internal filling and mattresses, medium length, and softer are those that are suitable for textile application, while the harder fibers are used in the manufacture of brushes and brooms (DAM, 2002b; MADHAV et al., 2018b; MISHRA; BASU, 2020b).

According to the Associação Nacional dos Produtores de Coco no Brasil (National Association of Coconut Producers in Brazil – APROCOCO), the use of fibers can be diverse, however, when subjected to stripping processing, short fiber groups are obtained, used as padding material, and long fibers, for industrial brushes. The applicability and use of these fibers include mattress manufacturing; mats; brooms; filling; wood manufacturing; blankets for reforestation; and packaging, but commonly applied in gardening and decorating; substrate for seedlings, and the manufacture of pots in Brazil. It is observed that there is no wide current application of fiber in the textile aspect (APROCOCO, 2021).

Because it is completely absorbed by the soil and its long-lasting qualities, coconut fiber has offered better performance to natural geotextiles in erosion control, soil stabilization, and river protection (MATHAI, 2005a, 2005c).

To add value, and avoid/reduce the negative effect of this residue on the environment, alternatives have been studied. The automobile industry is one of the first industries to use vegetable fibers in their production processes, using natural fiber composites, a viable alternative to the use of synthetic fibers (FERNANDES et al., 2021b; JERONIMO; SILVA, 2013; LECOUBLET et al., 2021; SIQUEIRA et al., 2022a). Composites reinforced by coconut fibers, in addition to their biodegradability and ease of composting at the end of their useful life, can be produced simply and with low energy consumption. In their tests, coconut fiber showed positive results in mechanical properties such as maximum breaking strength, elongation and modulus of elasticity, and better physicochemical interactions between the reinforcement and the matrix (GIACOMINI, 2017). The use of coconut fiber has been studied as an alternative to obtain fuel, allowing for more sustainable economic growth, and avoiding the current energy scenario of depletion (PASSOS, 2005b). By modifying the physical structure and composition of coconut fiber, it is possible to enable (GONÇALVES et al., 2014a) (**Figure 34**).

Figure 34. Coconut Fiber Applicated

(Martins et al., 2013) (Davis, 2007) (www.tradekorea.com)

(Monteiro et al., 2004) DailerCrysler. (JERONIMO; SILVA, 2013) – 1992.

Source: Adapted from (DOLLET; QUAICOE; PILET, 2008; JERONIMO; SILVA, 2013; MARTINS et al., 2013; WEI et al., 2007)

In the literature, studies addressed the use of coconut fiber in wastewater treatments and, mainly, as a filtering material in organic filters. However, its properties make the material a potential alternative. Green coconut husk fiber ash is an effective adsorbent and has a great adsorption potential in the treatment of effluents containing Iron and Aluminum, due to its properties (CATUNDA; AMAZONAS; MATOS, 2016; REGINA; CARNEIRO, 2020b). The porous morphology also adds to the removal of metals in effluents, due to its surface that allows the adsorption of metals in the interstices present in the material (SILVA et al., 2015). The use of alternative filtering material, coming from agricultural activities is of great interest, due to its abundance, renewable source, low acquisition cost, and also the possibility of being composted after filtration and used as agricultural fertilizer (MONACO et al., 2009).

In addition, studies identified the possible textile applicability of coconut-green fiber involving furniture, footwear, design of home objects, composites, paper, and packaging sectors, as well as other areas such as civil construction, enzymes, and geotextiles (MARTINS et al., 2013).

4.6. Analytical Procedures for the Characterization of Vegetable Fibers

The characterization of the properties of textile fibers is carried out by several tests, which must be precise, have repeatability of results and be as simple and easy to perform as possible (MOTTA; AGOPIAN, 2007).

The identification and characterization of natural fibers is important for predicting behavior in textile products. Reliable characterization allows selection of suitable pretreatment and processing methods for textiles or composites (LOPES et al., 2021a).

Some characteristics of the fibers, such as their length, ability to absorb moisture or not, tensile strength, modulus of elasticity, among others, are fundamental to determine their application.

In the case of vegetable fibers, as they are natural materials, their mechanical properties vary considerably according to the characteristics of the soil and the climatic conditions of the environment where the plants grow. The age of the plant from which the fibers are extracted also influences the mechanical properties of the fibers; fibers from older plants tend to have higher strength than those extracted from younger plants (CAMPBELL; COUTTS, 1980; MOTTA; AGOPIAN, 2007).

In the present study, the fundamental tests performed on coconut vegetable fibers to characterize them were as follows.

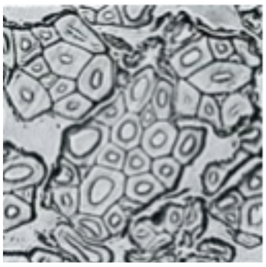
4.6.1. Length

Length is a very important criterion in the sizing of a fiber, especially in the case of natural fibers because they present great variability. According to Silveira (2011), a chemical fiber manufacturing industry, the length of the fiber is not exactly a problem, as it can manufacture fibers in a continuous way. On the other hand, natural fibers show great variation in length, even within the same batch (SILVEIRA, 2011).

4.6.2. Microscopy

The microscope is the main tool for fiber analysis (HOUCK, 2009), especially vegetable fibers, require microscopic observation of the cross section of a small bundle of fibers for their identification, as in **Figure 35**, for example.

Figure 35. Cross-sectional microscopy of jute



Source: (MALUF; KOLBE, 2003)

However, carrying out this test is not as significant in the case of synthetic fibers, as these are produced in the desired way for the application for which they will be intended (SANTOS et al., 2009).

4.6.3. Scanning Electron Microscopy (SEM)

The principle of a scanning electron microscope (SEM) consists of using a small diameter electron beam to explore the surface of the sample, the image signal results from the interaction of the incident beam with the surface of the sample, which “scans” its surface. and is then downloaded, recording its morphology and structure. A fine beam of high energy electrons strikes the surface of the sample where, when an interaction occurs, part of the beam is reflected and collected by a detector that converts this signal into a BSE image (or ERE) - image of backscattered electrons - or in this interaction the sample emits electrons producing the so-called ES image (secondary electrons) (KLAUSS, 2003). Most instruments use a heated tungsten filament as an electron source, these filaments are required to be electron conductors in the coated materials (MALISKA, 2008). This whole process avoids loading the image, which is the result of the capture of charges by the sample and their non-flow (KLAUSS, 2003). In this volume, the electrons and electromagnetic waves produced are used to form images or to carry out physical-chemical analyses.

4.6.4. Regain and moisture

The variations in humidity that occur in the fibers are directly related to the relative humidity of the air in the environment, which may result in changes in the weight of the fiber, depending on the relative humidity of the air at that time (SILVEIRA, 2011).

The amount of natural moisture found in the fibers has an influence on their properties (SILVEIRA, 2011), in this sense, it becomes important for the complete characterization of the fibers and their potential use to determine the regain and moisture content.

Percent Moisture Recovery (or “Regain”) is defined as the weight of water calculated as a percentage of the dry weight (FONSECA; SANTANA, 2003).

4.6.5. Tensile Tensile Test

The tensile test measures the behavior of the fiber, in terms of tenacity, percentage of elongation and initial modulus (or Young's Modulus), when a deformation force is applied along the fiber axis.

Tenacity is the specific stress, that is, it corresponds to the maximum ratio of load per linear density (count number) of the fiber, in a tenacity-elongation curve, that a fiber can withstand before it breaks. Typically, natural fibers have a higher tenacity associated with a lower elongation, or vice versa (REDDY; YANG, 2005a).

Breaking strength or toughness is expressed in g/tex or mN/tex, where:

i) mN is a measure of force meaning “milliNewton”;

ii) tex means the fiber or yarn count representing grams per 1000 meters of fiber or yarn; It is

iii) (1 mN/tex) = (9.81 x 1 g/tex).

Toughness is an intrinsic value of the material regardless of its dimensions. Fibers with higher strength will allow the production of yarns with good tenacity at high speeds and draw rates (KASWELL, 1963; SAVILLE, 2007).

The initial modulus or “Young's Modulus” is the ratio of the change in stress to the change in stretch within the elastic limit of the material. The ratio is calculated by the strain, expressed as force per unit cross-sectional area, and the strain, expressed as a fraction of the original length.

Young's Modulus is a very important measurement for engineering professionals using wood, structural steel and concrete, as these materials are used below their elastic limits and small strains and low loads can be calculated with a reasonable degree of accuracy.

In textiles, the load-elongation diagrams generally present linear variations in their entire range of use, that is, the “tensional modulus” of a fiber is not constant and should only be used in conditions where it is properly defined.

And, according to Kaswell (1963), the Young's Modulus can also be related to the strength and stiffness of the textile fiber. In this sense, the greater the modulus of a material, the less it extends due to the application of a certain force. Cotton has a lower modulus than linen and jute and is therefore more flexible and softer (REEDY; YANG, 2005).

4.6.6. FTIR

Infrared spectroscopy can be considered as one of the most important analytical techniques currently available, and can be used both to characterize fibers and to investigate their condition (HOUCK, 2009).

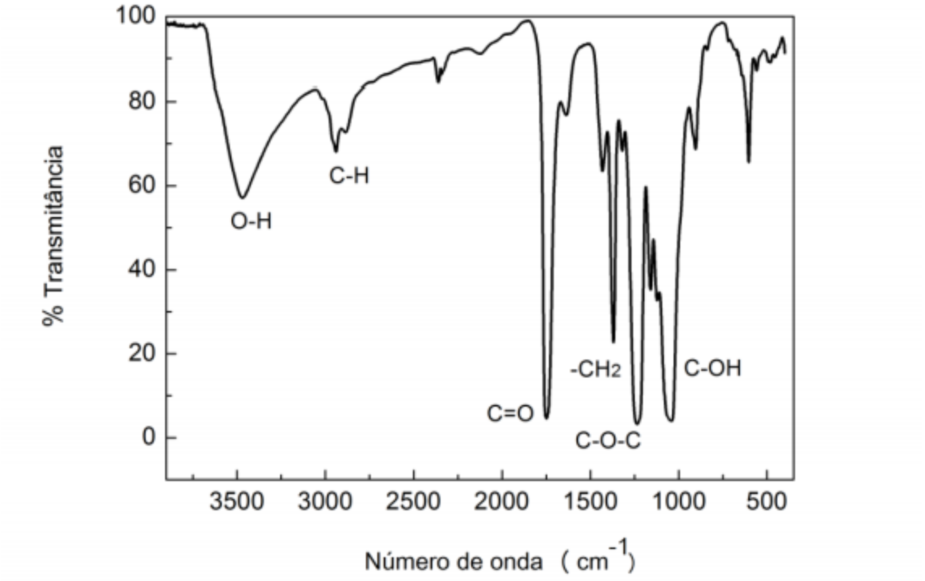
One of the great advantages of infrared spectroscopy is that practically any sample can be studied in different states: liquids, solutions, pastes, powders, films, fibers, gases and surfaces can be analyzed with a careful choice of sampling technique. As a consequence of improved instrumentation, a variety of sensitive new techniques have been developed in order to analyze previously intractable samples (STUART, 2004).

Infrared radiation (IR) roughly corresponds to the part of the electromagnetic spectrum lying between the visible and microwave regions. The most useful portion in the analysis and identification of materials is located between 4000 cm-1 and 400 cm-1 (2.5 µm and 25 µm), the so-called mid-infrared (HAACK, 2010).

In the case of fibers, very chemically differentiated materials, such as synthetic fibers, wool, silk and vegetable fibers, can be easily distinguished. Subtle chemical differences between more closely related fibers can then be exploited to differentiate these materials; for example, it has been shown that it is possible to identify plant fibers based on their lignin content (HOUCK, 2009).

The most usual analysis is performed using a graph of transmittance by wavelength, as shown in **Figure 36.**

Figure 36. Infrared spectrum obtained for transmittance versus wavelength cellulose acetate membranes



Source: (BAPTISTA; BORGES; FERREIRA, 2010; GUIMARÃES, 2014)

It is often used in infrared spectroscopy, a baseline that joins the lowest absorbance points in a peak, preferably in flat parts in a reproducible way to the absorption line, to make a quantitative analysis (HAACK, 2010).

Accordingly, transmittance is the fraction of incident light of a specific wavelength that passes through a sample of matter (**Equations 1 and 2**) (VOGEL, 2002).

Transmittance can be used to classify the different atomic types, since each one has a distinct ability to absorb or transmit radiation. On the other hand, absorbance is the intrinsic capacity of materials to absorb radiation at a specific frequency (**Equation 3**). In this way, the incident radiation I0 when crossing the sample will have part of its intensity absorbed, and the radiation that leaves the sample I, being that:

$$\textbf{Transmittance } T = (I/I0) \qquad \textbf{(Eq. 1)}$$

$$\textbf{Transmittance \%: } \%T = 100.T \qquad \textbf{(Eq. 2)}$$

$$\textbf{Absorbance } A = \log10(I0/I) = \log10(1/T) = \log10(100/\%T) = 2 - \log10(\%T) \qquad \textbf{(Eq. 3)}$$

So, if light passes through a solution with no absorption at all, the absorbance is zero, and the percent transmittance is 100%. In the case where all the light is absorbed, the percent transmittance is zero and the absorbance is infinite.

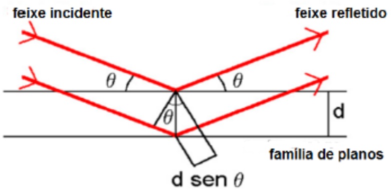
Still according to Vogel (2002), the Lambert-Beer Law states that the absorbance (A) will be directly proportional to the concentration of the element that absorbs (c). This means that the percentage transmittance (%T) will be proportional to the exponential of the negative value of this concentration. That is, A = k.c or %T = e-kc, where k corresponds to the value of a constant relative to the absorbance and length of the optical path.

4.6.7. X-Ray Diffraction (XRD)

Determining the degree of crystallinity is important for understanding the behavior of cellulosic materials, since these materials have crystalline and amorphous regions(PEREIRA et al., 2012).

In the XRD analysis, the beams strike the sample at an angle θ and are reflected with an angle of reflection equal to the angle of incidence, as shown in **Figure 37**. The planes formed by the sample atoms are parallel to each other and are separated by a constant interplanar distance *d* (PADILHA, 2000).

Figure 37. Schematic representation of the diffraction phenomenon

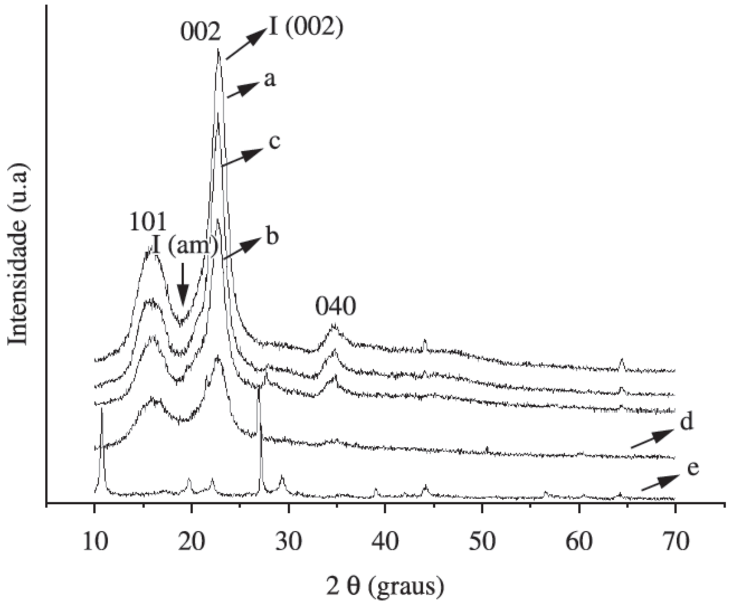


Source: PADILHA, 2000.

The crystallinity index of the fibers can be calculated by the empirical method developed by Segal and his collaborators (1959) which has been widely used in studies of natural fibers (MARTIN et al., 2009).

Still according to MARTIN et al (2009), this method uses the data provided by the diffractogram (**Figure 38**), relating the intensity of the diffraction that represents the crystalline material (maximum peak) close to 2θ = 22° with the intensity of the diffraction that represents the amorphous material (minimum valley) close to 2θ = 18° (PENNAS, 2019).

Figure 38. Example of X-ray Diffractograms



Source: PEREIRA et al., 2012.

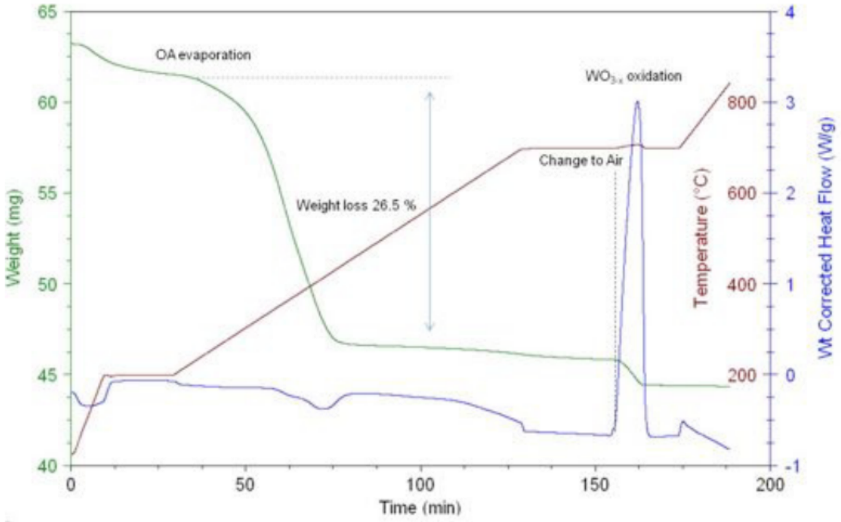
4.6.8. Thermogravimetric Analysis (TGA)

The analysis via TGA can be understood as a test in which it is possible to evaluate the mass variation of a given sample as a function of its temperature. The analysis can be performed by heating, cooling or even at constant temperature. The results are obtained through a graph that shows time or temperature and the percentage of mass gained or lost (LUCAS; SOARES; MONTEIRO, 2001).

This test is performed with the sample placed on a microbalance, which in turn is inserted into an oven. A heating program is then established, at a predetermined rate, and the sample weight variation is detected (SILVA; SILVA, 2003).

Usually, the DSC and TGA graphics are analyzed together, and they can be performed in the same equipment or in two different equipment. In the first case, the interpretation of the results is facilitated, for example **Figure 39**.

Figure 39. TGA / DSC assay for tungsten trioxide nanorods.



Source: (GUIMARÃES, 2014; SOULTANIDIS; BARRON, 2009)

The analyzes are carried out by evaluating the moisture content, weight loss, time, temperature in the TGA graphs, as well as in its derivative (Derivative Thermogravimetry - DTG). In the DSC graphs, the initial and final temperatures of the peaks are analyzed and whether they are endothermic or exothermic (SOULTANIDIS; BARRON, 2009).

5. METHODOLOGY

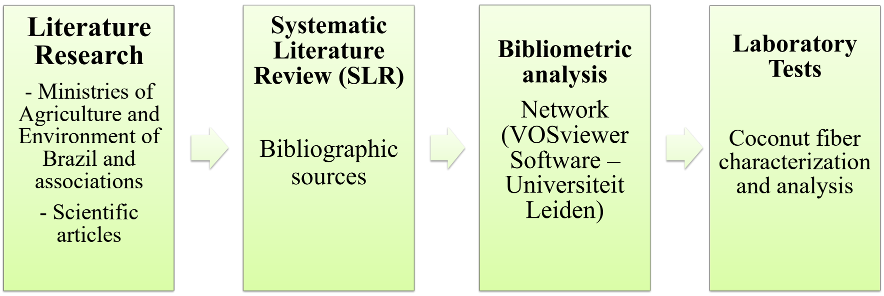
5.1. Project Structure

The methodological approach of the research is characterized as a qualitative-quantitative investigation, with a descriptive character and exploratory content (GIL, 2008; MISHRA; ALOK, 2017). The methodology was based on a bibliographic survey and analysis by Systematic Literature Review (RSL) followed by bibliometrics. According to DENYER; TRANFIELD, (2009a), the RSL is an important scientific tool that groups, evaluates contributions, selects, analyzes, and synthesizes data that allow obtaining concrete evidence for known and uncovering new goals (DENYER; TRANFIELD, 2009b). Bibliometric analysis, on the other hand, through variable studies, provides guidance and dynamics, through performance analysis and scientific mapping of research fields and cognitive structures, such as the study of link frequencies, implemented in this work (COBO et al., 2011; MACIAS-CHAPULA, 1998).

The review process involved aspects of planning, execution, and analysis of results. The planning consisted of the definition of the research design and the criteria in the analysis process, delimiting the coconut, according to guidelines of a renewable biological basis, residual, and sustainability in line with the needs of the current textile industry. The execution stage consisted of searching for terms, such as variations between international bibliographic databases such as Web of Science and Scopus, internet resources, government institutions, and associated companies, followed by reading titles, abstracts, keywords for selected data, tabulation, and evaluation of data and identification of the application segment of the articles. Finally, the analysis of the results generated a diagram of coconut residues for possible application addressed by scientific research, revealing existing gaps and future possibilities (BA; CHARTERS, 2007).

In order to index a bibliometric analysis of the data, it was decided to build two networks based on the grouping of bibliographic sources from the Scopus platform, diagrammed in the VOS viewer software (*Leiden University*). For research analysis, the laboratory tests description of phenomena and the understanding of their totality in the process of collecting information and applicability in addition to the other methodologies used in this study (**Figure 40**).

Figure 40. Methodology Flux gram



Source: Mylena Uhlig Siqueira

5.1.1.1. Fundamental Problem: Synthetic Statement

- What notable aspects emerge from the use of agro-industrial waste in Brazil in its potential application as raw materials in the textile industry, following sustainability guidelines?

- What notable aspects emerge from the investigation of the use of green coconut fiber, through the study of its physical-chemical characteristics, for textile production and use in Brazil?

5.2.Materials

5.2.1. Origin of Fibers

To carry out this study, coconut fibers (*Cocos nucifera*) were taken from their intermediate layer, in the fibrous mesocarp of the unripe fruit of the green Coco palm tree, purchased at a local market in the Central Zone of São Paulo (from distributor BENASSI CD Anhagabau) and planting and harvesting in Minas Gerais, it is estimated that in the northeastern region of the state there is a growing movement towards the expansion of local coconut agriculture.

It should be noted that obtaining the researched plant material (coconut fiber) does not require authorization from IBAMA (Brazilian Institute for the Environment) or any other federal or state environmental agency, since it is material normally sold in Brazil and whose purchase and possession does not have any legal restriction in any of the Brazilian states.

5.2.2. Installations for Carrying Out Experimental Tests

The physical-chemical characterization tests of coconut fiber (*Cocos nucifera*) were carried out in:

- Laboratory of Textile Fibers at the School of Arts, Sciences and Humanities of the University of São Paulo (**EACH-USP**) (São Paulo - SP) – length, count number, optical microscopy (transversal and longitudinal), cellular dimension, regain and tensile tests of the fibers;
- Laboratory of Materials Engineering at the School of Animal Science and Food Engineering at USP (**FZEA-USP**) (Pirassununga – SP) – confirmatory analysis of XRD; fiber density, FTIR;
- Multiuser Laboratory of Nanoscience's and Nanotechnology (LABNANO) of the Brazilian Center for Physical Research (**CBPF**) (Rio de Janeiro – RJ) – confirmatory SEM analysis;
- Engineering and Environmental Control Laboratory (LENCA) - Federal University of São Paulo (**UNIFESP**) – (Campus Diadema – SP). Department of Chemical Engineering – TGA preliminary and confirmatory analysis.

5.3. Methods

5.3.1. Systematic Literature Review and Bibliometric Analysis

The methodology was based on a bibliographic survey and analysis by Systematic Literature Review (RSL) followed by bibliometrics. The focus, based on industrial ecology concepts (GIANNETTI, B. F.; ALMEIDA, 2006; LIFSET; GRAEDEL, 2015), examined researches on the use of agro-wastes for the development of sustainable textile materials. The results were compared with data from the Brazilian Ministries of Agriculture and Environment and related associations. To index a descriptive exploratory bibliometric analysis of the data with greater precision to the object of study, it was built a network from the grouping of bibliographic sources in the Scopus platform (from December 2020 to January 2021 that encompass the years from 2021 to 2006) and transcribed by Software VOS viewer (*Universiteit Leiden*).

To generate the first database, the searches performed used the variation of the terms “agro-industrial”, “agro, “waste”, “fiber”, “textile”, “fashion” and “bio-based” limited to Brazil. When diagramming the network, 3,296 significant expressions were identified, out of the 305 articles selected, of which 2,496 meet the correlation requirement. The same database was used to develop a diagram focusing on the highest incidence of materials citation by classification and types; crops; formats; conversion technology and end-of-use researches. Crops were divided following the Food and Agriculture Organization of the United Nations (FAO) food classification (FAO, 2021b).

To generate the second database of coconut fiber, the searches performed used the variation of the terms “coconut”, “coir”, “coconut fiber”, “waste”, “fiber”, “textile”, “fashion”, “materials” and “applications” limited to Brazil (from May 2021 to June 2021 that encompass the years from 2007 to 2020). The coconut fiber issue is reveled through the analysis of 59 articles and co-occurrence of 921 specific expressions. The same database was used to develop a diagram focusing on the highest incidence of materials citation by classification and types; crops; formats; conversion technology and end-of-use researches (FAO, 2021b).

5.3.2. Physical-Chemical Characterization of Coconut Fiber

5.3.2.1. Removal and Preparation of Coconut Fiber

The natural fibers were prepared in order to eliminate all the impurities contained in the fibers. Collection and manual extraction were carried out, followed by cleaning by retting in water with drying at 60º C for 48 hours.

5.3.2.2. Conditioning of Samples

According to the ABNT NBR ISO 139:2008 standard (former ABNT NBR 8428:1984), all tests were carried out with previously acclimatized samples, for a minimum period of 48 hours, at 20oC and 65% relative humidity in a Mesdan air conditioner (model Climatest M250-RH, Italy).

5.3.2.3. Length

It is the dimension of the fiber in its natural state. The commercial length was determined manually using a ruler (REF. 534.030, Famastil Taurus Tools, China)

(ARAÚJO; E.M.M., 1984; BAYER - FIBRAS 100%., 2005; RIBEIRO; ANDRADE FILHO, 1987; SAVILLE, 2007)

5.3.2.4.Size of the constituent cells of the fibers

The procedure used the ISO 1973-1995 standard. However, this method is adapted so that to calculate the average fiber count, the fiber length is measured using a ruler and the fiber bundles are weighed on an analytical balance (Sartorius, model ED124S, Germany). The bundles (with 50 fibers each) are weighed and the average weight of each one is calculated. The average count number is calculated using **Equation 4**:

$$T_m = \frac{M_m.1000}{L}$$

T_m = Average count number (tex)
M_m = Average mass of the beam (g)
L = Fiber length (m)

(Eq. 4)

5.3.2.5.Fiber Tensile Test

Based on the samples obtained from the different processes for obtaining fibers, a test was performed, according to ASTM D 3 822-2001, for the tensile properties of single textile fibers, obtaining the following measurements: breaking load, elongation and tenacity. An Instron dynamometer ("tester machine"), (model 5569, Norwood, USA) was used, with a distance between grips of 20 mm, gripping speed of 20 mm/min. The device provides the values of breaking load and elongation, being necessary to calculate the toughness value from **Equation 5**, provided by the procedure, presented below:

$$\gamma = \frac{F}{T_m}$$

γ = Toughness (cN/tex)
F = Breaking Load (cN)
T = Count number (tex)

(Eq. 5)

The Young's modulus (or initial modulus or textile modulus) of a fiber is determined by the slope of the tenacity-elongation curve in its initial part according to **Equation 6** (SAVILLE, 2007; KASWELL, 1963):

Young's modulus $= \frac{\gamma 1}{\varepsilon 1}$

γ_1 = Toughness in the early part of the toughness-elongation curve (cN/tex)

ε_1 = Elongation in the early part of the toughness-elongation curve (%)

(Eq. 6)

5.3.2.6. Determination of Regain Content

The method is adapted from ISO/TR 6741-4:1987. The amount of moisture was determined by weighing a conditioned sample (20oC and 65% relative humidity) on an analytical balance (Sartorius, model ED124S, Germany). Then, drying was carried out in an oven with forced air recirculation (Binder, model FD 115, Germany) at 70oC until reaching constant weight (overnight) and then the sample will be taxed again.

Percent Moisture Recovery (or “Regain”) is defined as the water weight calculated as a percentage of the dry weight (**Equation 7**):

$$\%\,Regain = \frac{original\,mass - dry\,mass}{dry\,mass} * 100 \qquad \textbf{(Eq. 7)}$$

5.3.2.7.Optical Microscopy of Fibers

Based on prepared fiber samples, according to the ABNT NBR 13 538-1995 standard, the textile fiber identification test was carried out by optical microscopy of the longitudinal and transverse sections.

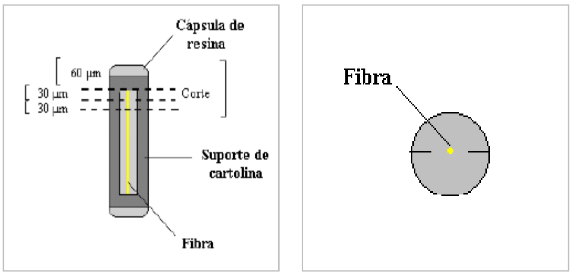
5.3.2.8. Longitudinal View

Longitudinal views were taken with the dry fibers, attached to cardboard duly cut, glued and identified, deposited directly for microscopy performed in a stereo-microscope (Leica, model MS5, Germany) coupled to a video camera for digital image capture (Vista, Protos IV, model VPC 122/CH, 1/2" CCD, Great Britain). The magnifications correspond to 20, 32, 51, 80 and 128 times. The images were captured and processed by the Video Analyzer 2000 code 250 system (Mesdan, Italy) (CATTANI, 2016; GUIMARÃES, 2014). Through this system, the diameters of the coconut fibers were determined, through 114 measurements on each sample (228 in all) which were determined means and standard deviation.

5.3.2.9. Cross section

For the transverse cut, it was necessary to prepare a cardboard support and use resin to encapsulate the single fiber (next to the support), in order to leave it well stretched and centralized to carry out the transverse cut itself, as shown in the **Figure 41**.

Figure 41. (a) Diagram of the fiber in resin capsule; (b) Scheme of the cross-section.



(a) **(b)**

Source: QUEIROZ, 2007.

The capsules were cut in thicknesses of 70 µm, to eliminate the top, where there is no fiber and, from there, with 35 µm of thickness, through a rotational semi-automated microtome (Leica, model RM 2245, Germany). After the cuts were made, two transverse sections of the same specimen were placed on microscopy slides spread with a drop of liquid petrolatum mineral oil (Nujol, Mantecorp, Brazil), covered with cover slips and identified with the sample number. The materials were analyzed in a biological microscope (Leica, model BME, Germany) coupled to a video camera for digital image capture (Sony, Color Video Camera ESWAVEHAD, model 55C-DC93-P, China). The magnifications corresponded to 128, 320, 640, 1280 and 2016 times. The images were captured and processed by the Video Analyzer 2000 code 250 system (Mesdan, Italy).

5.3.2.10. Fiber encapsulation

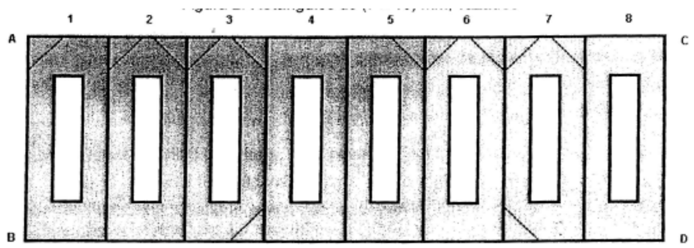
The methodology described below for fiber encapsulation is routinely used in the laboratory of the Technological Center for Textiles and Fashion of the Technological Research Institute (CETIM – IPT), whose protocol is presented below.

The following intended process is developed for preparing the fiber cross-section for four specimens per fiber:

- A sequence of eight small rectangles of (7 x 18) mm was marked on a piece of cardboard cutout in the dimensions of (56 x 18) mm, having centralized rectangles of (3 x 12) mm in their interior, for later cutting. These rectangle dimensions may vary depending on the size of the capsule. The rectangle must have such dimensions that it is possible to insert it into the gelatin capsule;

- Rectangle A, B, C, D will be covered along its entire length, on its back, with double-sided adhesive tape, 20 mm wide. The larger rectangles were hollowed out, cutting the smaller rectangles with the aid of a stylus (**Figure 42**).

Figure 42. White cardboard rectangles measuring (7 x 18) mm, perforated.



Source: PENNAS (2019)

- The eight rectangles of (7 x 18) mm was separated by cutting;

- In rectangles numbered 1 to 4, successively remove the silicone paper from the gummed tape, and mount a small bundle of fibers or parallel filament threads, maintained under low tension, in the center on the gummed tape the hollow part, parallel to the long axis of the rectangle;

- Rectangles 5 to 8 were adhered to the rectangles prepared as above, after removing the silicone paper, joining them by the tape, forming the support;

- To identify the supports for the test pieces, one of the four ends of the support for the test piece 1, two ends for the test piece 2, three tips for the test piece were cut 3 and none for specimen 4, on the indicated lines;

- A small amount of solution consisting of 0.5 ml of Technovit 7100 resin base (Heraeus, Germany) and 0.5 ml of P.A. to 96%. The specimens were immersed in this solution, where they will remain for 1.5 h, to completely swell;

- In the last minutes of the swelling period, a second solution consisting of 0.0375 g of hardener I (powder) (reagent that accompanies the resin) and 3.75 ml of Technovit 7100 base were prepared in a 10 ml beaker, mixed until complete dissolution of the powder;

- Immediately after finishing the preparation of the above solution, the supports of the first solution were removed and immersed in this second solution, in which they should remain immersed for another 1.5 h, at room temperature;

- Removing the supports from the second solution, add 0.25 ml of hardener II (liquid) (reagent that comes with the resin) and mix until complete homogenization. This new solution was poured into a gelatin capsule (Capsugel - Pfizer, Cápsula Gel no 00 colorless, Brazil) and then the support was introduced inside the capsule. Carefully center the support so that the fibers or threads are perfectly perpendicular to the opening of the capsule. The material was allowed to rest for at least two hours at room temperature;

- After the resin hardened, the gelatin capsule was dissolved with warm water.

5.3.2.11. Size of the constituent cells of the fibers

The microscopies of cross sections, with magnification of up to 1,280 times, were captured and processed by the Video Analyzer 2000 code 250 system (Mesdan, Italy). The magnifications correspond to 128, 320, 640 and 1280 times. Through this system, the dimensions of the constituent cells of their respective fibers were determined. For each species, the diameter was estimated by the mean and standard deviation of 3 measurements in units of micrometers.

5.3.2.12. Scanning Electron Microscopy of Cross Sections of Fibers

It was analyzed at Multiuser Laboratory of Nanosciences and Nanotechnology (LABNANO) of the Brazilian Center for Physical Research (**CBPF**) (Rio de Janeiro – RJ).

5.3.2.13. Fiber Density Determination

The density of the fibers was determined from the ratio between their dry mass in muffle and their saturated volume in water. The fibers were cut into average lengths of 30 mm and dried in a muffle until the mass became constant (with a variation of less than 0.1%) in consecutive weighings, spaced approximately 2 hours apart. When placing the fibers in the muffle, the container used will be filled with a certain volume of water, being immersed for 24 hours to verify the increase in fiber volume when in an aqueous medium, then allowing the holes in the fibers to be completely filled with water. Subsequently, a pycnometer was used, with a gas filling chamber, to confirm the initial determinations (LEÃO, 2008).

Density was obtained by gas pycnometer, following the methodology described below. The pycnometer used was the helium gas multipycnometer/Model MVP-6DC, manufacturer Quantachrome Instruments Ultrapycnometer 1000, which consists of two chambers with known volumes (by previous calibration): the chamber where the sample is placed and the expansion chamber, connected by a valve (expansion valve).

Assuming ideal helium behavior, the volume of the solid can be calculated from **Equations 8 and 9** (SMITH, 1996):

$$P1(Vc - Vp) = P2(Vc - Vp + Vr) \quad \textbf{(Eq. 8)}$$

$$Vp = Vc - \frac{Vr}{\frac{P1}{P2} - 1} \quad \textbf{(Eq.9)}$$

Vp = Sample volume (cm^3)
Va = Sample holder volume (cm^3)
Vr = Reference volume (cm^3)

The density is automatically calculated by the device, through the relationship between the mass of the solid (introduced as input data) and the volume derived from **Equation 8.**

5.3.2.14. Chemical Determination of Lignin, Hemicellulose and Cellulose Contents

The lignin content was calculated by the weight loss of the sample in acid detergent (ADF) in relation to oxidation with potassium permanganate and demineralizing solution. The amount of hemicellulose was determined from the difference between digestion of the sample in acid detergent fiber (ADF) solution and neutral detergent fiber (NDF) solution. The cellulose content was determined by the difference in mass between the dry residue generated through the lignin analysis and this same residue calcined in a muffle at 500ºC for 2 hours (HOLTZ, 2008)

5.3.2.15. TGA (Thermogravimetric Analysis)

The analysis via TGA is a test in which it is possible to evaluate the mass variation of a given sample as a function of its temperature. The analysis can be performed by heating, cooling, or even at constant temperature. The results are obtained through a graph that shows time or temperature and the percentage of mass gained or lost (LUCAS; SOARES; MONTEIRO, 2001).

The TGA tests were carried out in a Robson Operator N. Series C30574500224TK, DTG-60H detector, at a temperature between 0-800°C, at a heating rate of 10°C/min, under a nitrogen flow of 20mL/min.

To carry out the test, the sample is placed in a crucible, which is taken to the oven to then start the measurements. You must wait until the sample burns completely and, as the test is carried out, the device's software will generate the graph of mass loss versus temperature and its derivative corresponding to Derivative Thermogravimetry (DTG) (GUIMARÃES, 2014).

According to the methodology developed by the author, for lignocellulosic materials, the events (peaks characterized by inflection points) in the DTG curves can be associated with processes that occur to the different constituents of the analyzed material. Thus, in many cases it is possible to estimate, by comparing the DTG and TGA curves, the approximate composition of the lignocellulosic material analyzed and compare these results with those obtained through chemical determination (BOUCHARD et al., 1986).

5.3.2.16. FTIR (Fourier Transform Infrared Spectroscopy)

The fibers were analyzed using the spectroscopy technique in the mid-infrared region, in PerkinElmer Precisely equipment, model Spectrum One (FT-IR Spectrometer), using ATR crystal: Diamond/ZnSe. Scan range: 4000 to 550 cm-1 / Number of scans: 32 / Resolution: 4cm-1. (**Figure 43**)

Figure 43. FTIR Equipment PerkinElmer Precisely, Spectrum One (FT-IR Spectrometer)

Source: Mylena Uhlig Siqueira

5.3.2.17. XRD (X-Ray Diffraction)

The XRD spectra were obtained at room temperature (25 ºC) with a Rigaku diffractometer, model miniFlex 600. The parameters adopted for the analysis were 50 kV of voltage, 100 mA of electric current and test speed of 1°/ min at a step of 0.02°.

The crystallinity index of the fibers will be calculated by the empirical method developed by Segal and his collaborators (1959) (**Equation 10)**, which has been widely used in studies of natural fibers.

$$Ic = \left(\frac{I002 - Iam}{I002}\right) x100$$

Ic = crystallinity index, in percentage; **(Eq. 11)**

I(002) = Diffraction intensity representing the crystalline material (maximum peak) near 2θ = 22°;

I(am) = peak diffraction intensity representing the amorphous material (minimum valley) near 2θ = 18°

6. RESULTS AND DISCUSSION

6.1. Food Loss and Waste (FLW)

The issue of Food Loss and Waste (FLW) is highlighted in regional, national, and international political agendas, still on the rise in Brazil (FAO, 2021c; HENZ; PORPINO, 2017; TEUBER; JENSEN, 2020). The Committee on World Food Security (CFS) highlights the importance of FLW in the search for more sustainable and equitable food systems and societies (FAO, 2015).

The dumping of agricultural waste is one of the great eminent challenges that are highly expensive, harmful to soil contamination, greenhouse gas emissions (GHG), toxic to local waters, damage to land, and compromise environmental safety and quality of life and regional food (ONU; MBOHWA, 2021c; WILTS; SCHINKEL; KOOP, 2020). According to the 2021 Food Waste Index, 931 million tons of food were wasted, 20% of the volume belongs to Latin America, where 55% are fruits and vegetables; however, there is no consistent information on each developing country (FAO, 2016; UNITED NATIONS ENVIRONMENT PROGRAMME, 2021).

The FAO Food Loss Index estimates that about 14% of all food from post-harvest to, however excluded, retail is lost. In terms of FW, it is estimated that 931 million tons of food waste were generated in 2019, 61% of which came from families, 26% from food service and 13% from retail (UNITED NATIONS ENVIRONMENT PROGRAMME, 2021).

Food waste began to be studied in Brazil, with emphasis in the 1990s, regarding debates on Brazilian food security. However, in-depth discussions about FLW are recent in the country. Only in March 2017, the government officially established the Technical Committee on FLW by a CAISAN resolution published in the Government Gazette (HENZ; PORPINO, 2017). For Henz (2018), there are no reliable estimates on the topic in Brazil, with a complexity that involves agriculture, food, food safety, economic aspects, legislation, social policies, private sector (industries), supermarkets, distribution, logistics, habits and behavior of the consumer (HENZ, 2018). Brazil, in 2015, lost 35% of its production annually, occupying the ranking of the 10 largest countries (SANTOS et al., 2020a). Among the main occasions of loss, mechanical damage resulting from improper handling in the field, improper packaging, vehicles and precarious roads, commercialization and excessive exposure in retail. These add up, on average, to 30% in fruits, 35% in vegetables, and up to 50% in grain storage, reaching up to 20% of the total produced (PALHARES et al., 2018).

The definitions of Food Loss and Waste take different approaches. The loss of food considers the decrease in the quality or quantity of food resulting from suppliers along the harvest/slaughter/capture supply chain that is not used as feed or seed, whereas food waste is related to a decrease in the quantity or quality of food from service providers and consumers (**Chart 7)** (FAO, 2018; SOFA/FAO, 2019, 2020).

There is an overlap between the definition of FL and FW (FILHO et al., 2021). The divisions of the sources of generated losses are agricultural production, post-harvest handling, storage, processing, transport and consumption (GUSTAVSSON et al., 2011). Considerations involve FL as unintentional reduction of food available for human consumption as a result of inefficiency in the production and supply chain. And FW to the intentional disposal of food items, particularly by retailers and consumers (CEDES, 2018). Groups can also be divided into food losses (during processing); unavoidable (perish during the consumption stage eg husks and pits); and avoidable (suitable for food, but wasted in the period of human consumption) (AHMAD; AHMAD; ABDULLAH, 2021) (**Chart** 7).

Chart 7. Definitions for food losses/waste in supply chain

Food Loss			**Waste of food**	
Production	**Postharvest and storage**	**Processing**	**Distribution, Retail**	**Consumption**
Loss occurs during and shortly after harvest	Loss occurs during handling, drying, local/regional transport, and storage	The loss occurs during processing and local or industrial treatment and packaging	The waste occurs during market and retail systems	The waste occurs at household and consumption levels

Source: Adapted from (RUVIARO et al., 2020).

Waste is liquid or solid materials that are generated from agricultural activities, direct consumption, or industrialization, are not useful to the process, which assumes concepts such as reduction, reuse, and recycling (BIGDELOO et al., 2021; LOEHR, 1974; ONU; MBOHWA, 2021a, 2021b). Some of the influencing factors are topography, precipitation, cover crop, season and location, even the chemicals, cultivation practices, and fertilizers used, which make impact assessments and measurements difficult (HANSON, 2014).

In large volumes, the residues are in the form of straw, stems, bark, wood, and forest residues, and commonly occupy land in the form of disposal by burning, which allows the start of fires and the proliferation of diseases. Residues and by-products are rich in lignocellulosic materials that can be recovered through chemical, physical and biotechnological treatments (BIGDELOO et al., 2021; DIETRICH et al., 2016; SCARLAT, N., MARTINOV, M., DALLEMAND, 2010).

Five segments classify the types of FLW, such as: (i) agricultural production (mechanical damage and harvesting operations); (ii) post-harvest handling and storage (spill and degradation); (iii) processing (industrial and domestic); (iv) distribution (market and retail systems), and (v) consumption (household) (FAO, 2011). About 45% of fruit and vegetable biomass is wasted during agriculture, post-harvest, processing, distribution, and consumption. Residues such as fruits and vegetables can be considered as valuable raw materials, as they are produced in large quantities all over the world (DIETRICH et al., 2016).

Losses and waste are classified into four categories along the supply chain: (i) primary and post-harvest production; (ii) processing and manufacturing; (iii) wholesale, food retail, service, and distribution; and (iv) consumption or household waste (WRAP, 2009). For (SIX et al., 2016), biomass recovery can be divided into groups of direct use (unchanged), material recovery (biochemical extraction, conversion of biomass and useful products), energy recovery (biogas/energy content). Developing countries, such as Brazil, face a higher rate of waste in the primary stages (FAO, 2020; HENZ; PORPINO, 2017; JÚNIOR, 2020).

There is insufficient world data on the edible fraction of food waste (UNEP, 2021). Although, fruit processing residues, as parts of the entire food waste processing sector, such as bagasse (peel, seed, and pulp), bark, seeds, and stems can be considered unavoidable residues (KAVITHA et al., 2020; KOSSEVA, 2020a, 2020b). Currently, the methods used in FW organizations are animal feed, mainly composed of organic fertilizer, anaerobic use, carbonization and landfill, no method has been supported for the ecologically correct use of FW. Therefore, FW can be used in the production of bio composites using sustainable FW management methods (BLAKENEY, 2019). For (DAI; LIU; SI, 2018), lignocellulosic biomass resources do not affect the food supply chain.

6.2. Sustainability and Industrial Ecology in Agro-Waste Management for Material Design

The importance of sustainability as a science and its interactions as an extremely multidisciplinary field that encompasses, in addition to natural sciences, social and technological knowledge. Goodland (1995) states that the best way to apply it would then be by understanding its three areas: social, economic and environmental. Understanding that environmental sustainability definitely seeks to sustain global life support systems, Goodland (1995) refers to the capabilities of this ecosystem as the natural capital that sustains human life, however, its excessive use, despite its large capacity, hinders the provision of life support services, due to its finiteness. That is, the entry and exit rules, emissions and harvests, must be kept within the regenerative capacities of the natural system that generates them, as well as in the settlement of established drains. In view of this, the transition to environmental sustainability as a guide for textile processes is urgent, as the deterioration of these systems imposes a time limit, and their regenerative properties are slow and cannot be boosted in a healthy way. Ndubuisi et al. (2014) reinstates that the effective management of waste, especially agricultural waste from food processing, is one of the interventions favorable to the environment, with biotechnology being of enormous wealth and competence for this (NDUBUISI EZEJIOFOR; E. ENEBAKU; OGUEKE, 2014). According to (CAVALCANTI, 2012) this market is based on a biophysical impossibility of nature, since there is no continuous healthy growth, and even irreversible ones, when fossil fuel-based production processes are used. Therefore, he states that the concept of development surpasses that of growth, in which development is not related to infinite expansion, but rather to improvements and potential.

Agroindustrial residues are an example of an expensive and inevitable result of human activity that poses a threat to the environment, while the decrease in the supply of raw materials is also a cause for concern (SUNDARRAJ, A. A., & RANGANATHAN, 2018). Ndubuisi et al. (2014) explains that, due to the peculiar nature of agricultural industry waste, the lack of management becomes particularly worrisome for environmental safety and human health, since biological items have greater potential for deterioration and can facilitate vectorized diseases by potential animals (NDUBUISI et al., 2014). Currently, Brazil follows a waste management structure similar to developed countries (NASCIMENTO et al., 2015). The Brazilian Solid Waste Plan (PNRS), law n. 2305/2010, valid since 2010, priorities to non-generation, reduction, reuse, recycling, waste treatment, and, finally, the final disposal of waste. In theory, all the possibilities of recovering available and economically viable technologies were considered (BRASIL, 2010; HENZ; PORPINO, 2017; NASCIMENTO et al., 2015).

Efforts are aimed at reducing the amount of waste according to the stipulated hierarchy, a large amount of unavoidable waste remains being generated. Therefore, agricultural innovation should apply sustainability at different levels and structures. Sustainable agriculture can facilitate technological integration and facilitate the production and processing of food as fiber and green resources, as greater knowledge of processes becomes presuppositions for significant advances (BARKER; MCLEMORE, 2005; ONU; MBOHWA, 2021d, 2021b; SHAHID-UL-ISLAM; SHAHID; MOHAMMAD, 2013).

Taking in account the growing scarcity of ecosystem services, the question would be how to reallocate the structure between the raw materials needed for production and survival. Otherwise, allocation strategies must be judged for their sustainability, fairness, and efficiency (FARLEY, 2010). Regarding at the 2030 Agenda with a focus on food and agriculture transformation, the 2nd key principle for sustainability is “protecting and enhancing natural resources”, which includes: “improving soil health and restoring the land; protect water and manage scarcity; conserve biodiversity and protect ecosystem functions; reduce losses and encourage reuse and recycling and promote sustainable consumption” (FAO, 2018). (ONU; MBOHWA, 2021a) highlight that all Sustainable Development Goals (SDG) centers contribute resources to these biodiversification opportunities. Target 12.3 addresses the issue of food waste and loss, which contributes not only to SDG 12, but also SDGs SDG 2 (“Zero hunger and sustainable agriculture”), 6 (“Drinking water and sanitation”), 13 (“Action against global climate change”), 14 (“Life in the water”) and 15 (“Terrestrial life”) (FILHO et al., 2021).

For Barket (2005), the difficulty in finding new sources of raw material while the safe disposal of waste is scarce, makes hierarchy and the total use of waste a necessity.

Minimization is a priority in the hierarchy of waste management strategies, rather than treating the end of the tube, however, there is no economic incentive and technology available, turning the importance of waste recovery as opportunities for sustainability (HERRERO et al., 2020); (SILLANPÄÄ; NCIBI, 2019c)

The LCA methodology can define the main impact areas, assess potential environmental threats, make environmental decisions and ensure the labeling and ecological certification of textiles (ERYURUK, 2015) For Laudes Foundation (2021), conscious sourcing decisions contribute to help farmers, agricultural communities and the textile industry to achieve greater sustainability, ensuring a possible balance of resources and people (LAUDES FOUNDATION, 2021a).

6.3. Overview of the Main Agroindustrial Waste Generated in Brazil

The “Panorama of Solid Waste in Brazil 2020” by the Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE), highlights that organic matter comprises 45.3% of the total solid waste generated in 2020, approximately 170 kg discarded per person/year, and it is estimated that this waste will increase 50% by the year 2050 (ABRELPE, 2020). In contrast, this report reveals that the total amount of waste generation and final destination remain inadequate, growing respectively 19% and 16%, even after the implementation of the Brazilian PNRS in 2010, which institutes the plan for integrated management, responsibility and economic instrumentation applicable to solid waste (ABRELPE, 2020; DE CAMPOS; GOULART, 2017; FREIRIA, 2011).

Biomass was defined as "any material, excluding fossil fuel, which was a living organism that could be used as fuel directly or after a conversion process" (ASTM, 1995). According to EMBRAPA, Brazil is responsible for 140 gigatons of agro-industrial residues, in which there are different types of biomasses of heterogeneous chemical composition from different physical states, such as: oily biomass, saccharide biomass, starchy and lignocellulosic biomass, which is more abundant (JÚNIOR, 2020).

Worldwide, the main crops responsible for agricultural residues are rice, wheat, cotton and corn (EL-HAGGAR, 2007d). Therefore, the report by the Institute of Applied Economic Research (IPEA) of Organic Waste (2012) was based on 7 temporary crops (**Table 7**) and 7 permanent crops (**Table 8**), which are the greatest representation ones in Brazil. Among the permanent crops, the following were selected: coffee (beans), cocoa (almonds), bananas (bunch), oranges, coconuts, cashew nuts, and grapes. For the temporary crops, in turn, the following were selected: soy (in grain), corn (in grain), sugar cane, beans (in grain), rice (in husk), wheat (in grain) and cassava. It highlights that these 14 largest crops in the country produce a total of 291.1 million tons of waste per year (SCHNEIDER et al., 2012).

Table 7. Data about the main Brazilian temporary crops.

Temporary Crops	Waste - million/ton	Residual Factor
Soybeans (grain)	41.862.129	73%
Corn (grain)	29.432.678	58% (straw and cob)
Sugar cane	201.418.487	30%
Beans (grain)	1.847.984	53%
Rice (paddy)	2.530.355	20%
Wheat (grain)	3.033.315	60%
Cassava	23.786.281	-

Sources: Adapted from (ABIB, 2011; MATOS, 2005; SCHNEIDER et al., 2012; SILVA, V.L.M.M. & GOMES, W.C. & ALSINA, 2007).

Table 8. Data about the main Brazilian permanent crops.

Permanent Crops	Waste - million/ton	Residual Factor
Coffee (beans)	1.220.029	45 a 55% (husks and straw)
Cocoa (beans)	83.025	38%
Banana (bunches)	99.640	50% (husks and stalks)
Orange	8.825.276	50%
Coconut	405.009	60%
Cashew nuts	80.484	73%
Grapes	300.459	40%

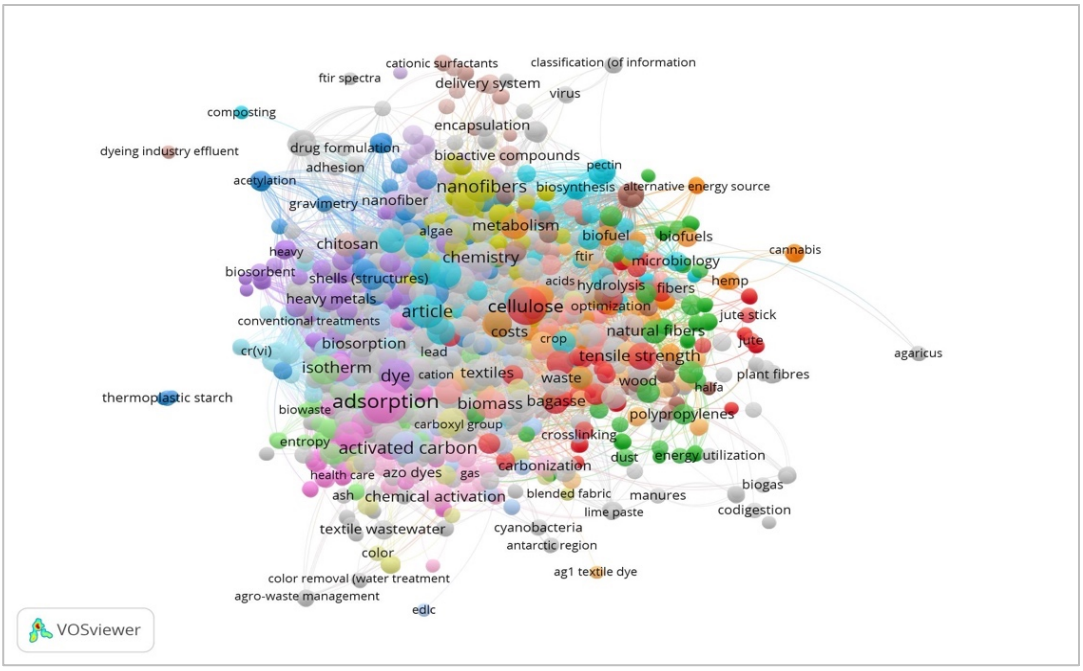
Sources: Adapted from (ABIB, 2011; MELLO, 2006; REZZADORII, K.; BENEDETTI, 2009; SILVA, 1AD; VALE, 2007).

According **Table 7**, only soybean crops correspond to 49% of the planted area in Brazil, producing about 2,700 tons of residues for every 1 thousand processed grains, around 73% of residues are generated from processing (MATOS, 2005; SCHNEIDER et al., 2012). This percentage is visible for each crop in **Tables 7 and 8**. Sugarcane crops stand out, distinguishing residues in liquid vinasse, filter cake, and bagasse. There is no estimate of percentage of waste generation for cassava crops.

The Systematic Survey of Agricultural Production (LSPA) by period (April 2021) highlights that the average yield per harvest of these main selected crops presents a stable growth variation in the country's agribusiness, which consequently projects a greater number of residues than those currently presented in **Tables 7 and 8**. According of productive amounts, respectively: sugar cane (654,727,996); cereals, pulses and oilseeds (264,453,928); soybean (131,927,408); corn (1st Crop 25,771,50/2nd Crop 76,727,987); cassava (18,708,437); orange (18,708,437); rice (11,081,650); wheat (7,394,918); banana (6,915,259); beans (1st Crop 1,281,098/ 2nd Crop 1,111,999/ 3rd Crop 562,935); Arabica coffee and canephora coffee (2,820,596); grapes (1,416,398) and cocoa (280,661). There is no data for “coco-da-baía” (Brazilian coconut varieties) crops (LSPA/IBGE, 2021).

In network analysis, it is possible to observe the large incidence of these crops (**Figure 44**).

Figure 44. Scientific literature database network built with VOS viewer software (*Universiteit Leiden*) through the analysis of 305 articles and co-occurrence of 2,496 specific expressions.



Source: Mylena Uhlig Siqueira

Through the network analysis, it is possible to observe the scientific advances in Brazil regarding the main materials used, formats, and applicability. The main agro-waste correlated terms in intensity are: "sugar cane", "fruit", "soy straw", "cassava" and "rice". The main formats indicated are for: "bagasse", "biomass", "fiber", "nanocrystals" and "polymer". The main applicability involves: "absorption", "enzymes", "wastewater", "textile fibers" and "ethanol". There is a great interest in the study of the physicochemical performance of materials, paying attention to the number of researches involving "crystallinity", "pH", "mechanical properties", "chemical composition" and "thermogravimetry".

The Brazilian Agroindustry Profile Report of the Institute for Applied Economic Research (IPEA), states that the inventories of existing products, material flows, and the functioning of circuits are still some of the challenges found in its main structure (IPEA, 2013). Although, according Organic Waste Report, wastes from the country's main crops presents distributive potential and Brazilian legal support for reverse logistics projects (SCHNEIDER et al., 2012).

6.3.1. By-products of agro-industrial waste

Worldwide, some of the main lignocellulosic crop residues are wheat straw, rice straw, barley straw, corn straw, sorghum stalks, coconut husks, sugarcane bagasse, pineapple leaves and banana leaves (LAUDES FOUNDATION, 2021a). The composition of waste and its physicochemical characteristics make it suitable for various applications, in accordance with location and economy of each region. The content of organic matter prioritizes its application on 4 main fronts: (i) animal fodder; (ii) briquetting; (iii) biogas, and (iv) composting; moreover, there is a surplus input for exploration in other industrial applications (EL-HAGGAR, 2007d).

One of the main difficulties in the converting process of biomass into products is the transport and storage protocol, in addition to the knowledge of the operational techniques that should be applied (ONU; MBOHWA, 2021e; WARF, 2014). As claimed by (ONU; MBOHWA, 2021c), the world's largest production crops such as sugarcane, corn, rice, and wheat are in discussion as food and fuel commodities as well as due to their important source of hemicellulose and lignocellulose for industrial manufacture. Waste treatment and disposal are only part of agricultural waste management systems (LOEHR, 1974).

The water content, pathogenic potential, biological instability makes the disposal of waste difficult to control, directing it generally to animal feed (DIETRICH et al., 2016). In the same way, the administration of large residues leads agrarian communities to opt for low-cost and low-effort options, such as burning to clear the scums for the next harvests (TEXTILE HORIZONS INTERNATIONAL, 1993). For Laudes Foundation (2021), the domestic uses such as forage, animal bedding, mulch and compost use a small part of the waste. Among the benefits of using waste materials are the protection and maintenance of natural resources, protection of human health and reduction in resource extraction (AHMAD; AHMAD; ABDULLAH, 2021).

In Brazilian scenario, agribusiness has gained great notoriety in the context of studies and political-economic-institutional focus (ABRA, 2013). The amount of biomass produced in Brazil is significant, reaching 1 Gt in 2030 (MORAES et al., 2017). There is a movement of research in the country in order to create viable alternatives for the relocation of waste. According the Brazilian Agricultural Research Corporation (EMBRAPA), the industrial processing of agricultural biomass from waste can be distributed in the generation of materials (polymers, resins, and fibers), energy, food and animal feed, chemical inputs (biofertilizers, surfactants, esters, acids organic) and biofuels (ethanol, biodiesel, and biogas) (JÚNIOR, 2020).

Soy straw, in particular, is an abundant and renewable form of biomass with enormous potential as a cheap and sustainable source. According to Martelli-Tosi et al. (2017), soy is a very significant agricultural commodity (MARTELLI-TOSI et al., 2017a, 2017b). However, its application in by-products is mainly used for rural energy, animal feed, and disposal in the field (ARAÚJO et al., 2020; LIU et al., 2015). (ARAÚJO; MACHADO; VILARINHO, 2019), evaluating parameters, which consider the chemical composition, growth rate, and disposition, state that soy straw is the most suitable residue to be used as raw material for the production of cellulosic-based materials, followed by sugarcane leaf, corn husk, sugarcane straw and bagasse, revealing that the main crops in the country are the most suitable residually.

6.3.2. Potential Applicability of Agroindustrial Waste in the Textile Industry

Continuous application of petroleum derivatives in textile industry involves high cost, intensive use of energy, and insecurity, while the diversity of agricultural residues is the basis for replacing the use of non-biodegradable synthetic materials (ONU; MBOHWA, 2021e).

Depending on the extraction methods, fibers can be prepared in various forms, such as: long continuous fibers, processed fibers, short-staple fibers, and powdered microfibers or nanometric fibers (YU, 2009). The most common source of natural fiber reinforcement extraction is from stems (bast fibers), while leaves are the least reported in previous studies (IZWAN et al., 2021). Worldwide, residues such as corn husks, rice, sorghum stalk and leaves, banana leaves, pineapple leaves, and others, have been studied to develop new cellulose fibers with similar mechanical properties that common textile fibers (REDDY; YANG, 2005b, 2009). Companies that embrace the concept of circularity of materials claim that banana crops, pineapple leaves, rice straws, and sugarcane husks together can provide more than 250 million tons of fiber per year, meeting 2.5 times the world demand for fibers (BIOMIMICRY, 2020).

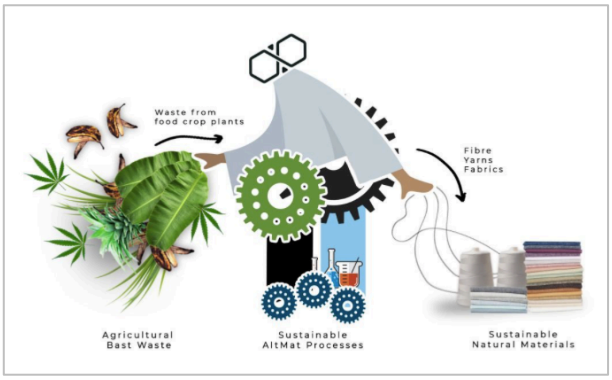
Agricultural-based fibers should present special quality criteria as: strengthening potential (strength), stiffness, wear resistance, brittleness, moisture-related properties (aging, dimensional stability, swelling), heat stability, purity, resistance to microorganisms, non-odor, resistance to chemicals, etc. (SHISHOO, 2007). However, not all residual agricultural fibers are suitable for textile applications, the main parameters such as cellulose composition, length and structure must be evaluated (LAUDES FOUNDATION, 2021a).

Fruit and vegetable waste mainly contain soluble materials and fibers, but they are the most commonly discarded in landfills and rot in industrial and retail establishments (SHARMA; OBEROI; DHILLON, 2016). Vegetables, cereals, roots and tubers, and fruits are the most promising resources for value-added production (GALANAKIS, 2012).

The adaptation of fibers to consumption needs, in order to be employed in conventional technologies and applications, have increased tremendously their market potential (NARASIMHAN; SRIKANTH; POLTRONIERI, 2016). The use of solid potential fibers, lack resilience and have low elasticity and elongation potential, being mixed with other sources of natural fibers can have better performance (LAUDES FOUNDATION, 2021a; SALLEH et al., 2021).

Some textile innovations such as Orange Fiber, Green Whisper, AltMat (**Figure 45**) and Agraloop, in collaboration with Fashion For Good, enable alternatives through bio-based products, processes and technologies in the production of fibers from pineapple, hemp, banana stem, fruit residues citrus and food crops for textile and clothing manufacturing (FFG, 2021; LAUDES FOUNDATION, 2021a).

Figure 45. AltMat representation processes.



Source: (ALTMAT, 2021).

Concerns about global warming, declining supply of fossils, and increased demand for energy have sparked the demand and need for alternative renewable polymers. Biopolymers accounted for 3.8 million tons (2019), about 1% of the fossil-based production volume (NURFAIZEY et al., 2021).

Mustafa (2021) highlights that agropolymers from agricultural residues such as starch and cellulose derivatives can be efficiently regulated by natural or chemical mechanisms for the development of green materials, highlighting the use of biofibers in structural performance as a significant reinforcement. Currently, natural fiber reinforcement composites are used in advancing technologies due to their low density, light weight and good mechanical strength, and ecological characteristics (AHMAD; AHMAD; ABDULLAH, 2021; BENYUS, 1997).

For Ahmad (2021), the advantages of using natural fiber in thermoplastic composites are: (i) biodegradability; (ii) lower greenhouse gas emissions; (iii) availability in variety and format; (iv) job creation in rural areas (v) non-linear economic development; (vi) efficient and (vii) economical energy consumption. The growing interest in technical lignins, by-products of cellulose, as a polymeric material is also due to their large-scale availability and biodegradability. These can play different roles in promoting and regulating adhesives, fillers and reinforcing agents in engineering, replacing synthetic fixed terms (LAPSA; BETKERS; SHULGA, 2000) (**Chart 8**).

Chart 8. Commercial Textile Products from Waste

Material	*Residual Source*	*Properties*
Piñatex	Pineapple leaves	Durable, lightweight, water-resistant, and breathable. Can be used as a leather substitute for shoes, bags, and clothing.
Orange Fiber	Orange peels	Soft, silky, and breathable. Can be used to make fabrics for clothing, scarves, and ties.
MycoTEX	Fungal mycelium	Flexible, lightweight, and biodegradable. Can be used to make fabrics for clothing and accessories.
Wine Leather	Wine production waste	Durable, flexible, and water-resistant. Can be used as a leather substitute for shoes, bags, and clothing.
SeaCell	Seaweed	Soft, breathable, and moisturizing. Can be used to make fabrics for clothing and bedding.
Econyl	Fishing nets and other nylon waste	Durable, elastic, and lightweight. Can be used to make swimwear, activewear, and other clothing.
Refibra	Cotton scraps and wood pulp	Soft, absorbent, and biodegradable. Can be used to make a wide range of textiles, including clothing, towels, and bedding.
QMilch	Milk protein	Soft, silky, and moisture-wicking. Can be used to make fabrics for clothing, underwear, and sportswear.
Upcycled Denim	Old denim clothing and scraps	Durable, versatile, and unique. Can be used to make a wide range of products, including clothing, accessories, and home goods.
Bionic Yarn	Plastic bottles and other waste	Strong, lightweight, and water-resistant. Can be used to make fabrics for a wide range of products, including clothing, bags, and shoes.

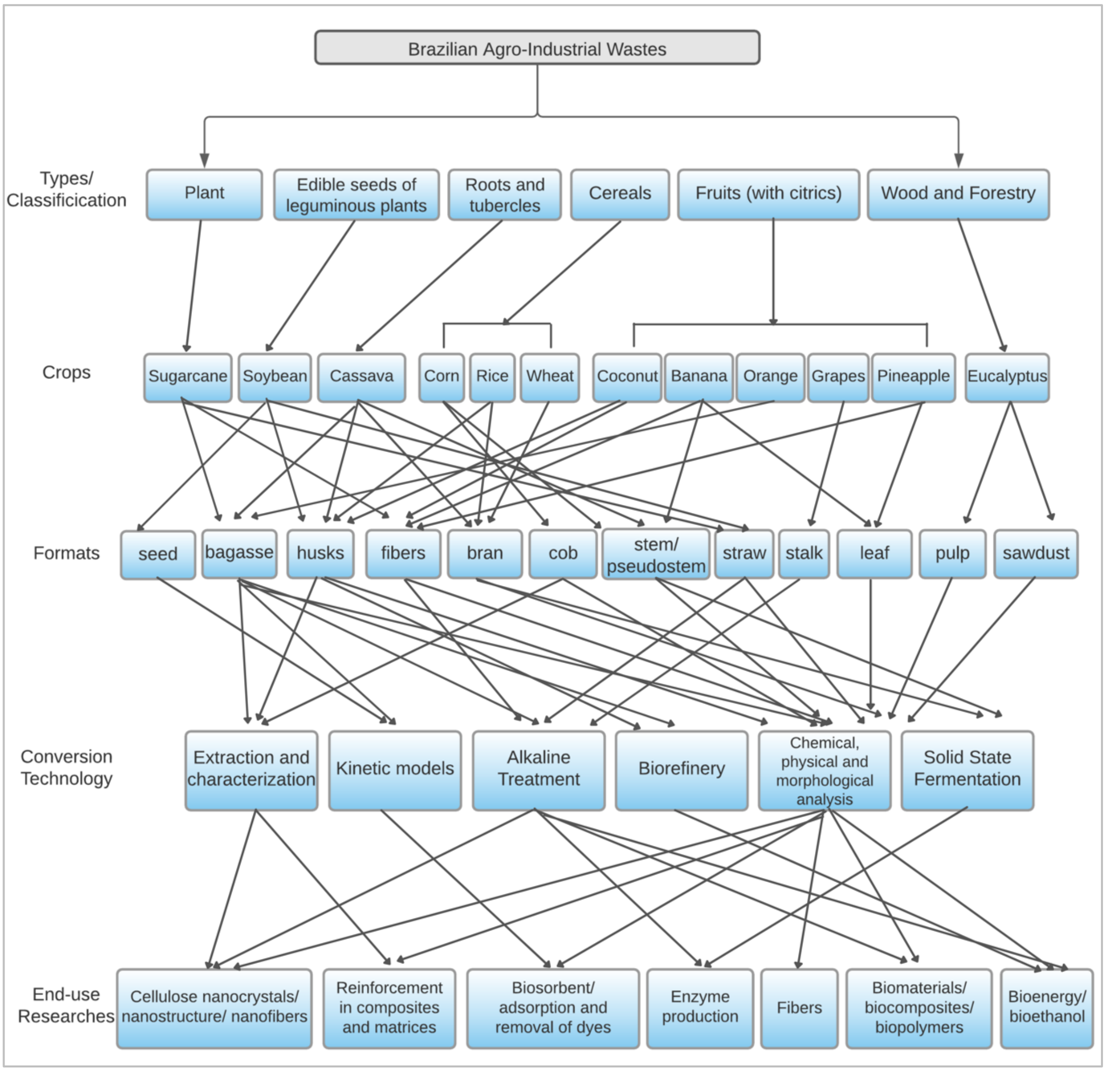
Source:(BIGDELOO et al., 2021; GRIES; VEIT; WULFHORST, 2015a; GUIMARÃES BARBOZA et al., 2017; LEÃO et al., 2015; SANTOS et al., 2013).

The economic and technological advantages of lignocellulosic fibers can increase the durability and also recyclability of incorporated products, leading to sustainable development (MUSTAFA et al., 2021) Fibers based on agricultural residues are promising innovations and can meet dual objectives. In the solution to the search for alternatives in the fashion industry and, in parallel, a path for millions of farmers who burn their agricultural residues and generate dangerous levels of emissions (LOUDES FOUNDATION, 2021).

6.4.Scientific literature database diagram on agro-industrial materials' researches

The same network database was used to develop a diagram focusing on the highest incidence of materials citations by classification and types; crops; formats; conversion technology and end-of-use researches (**Figure 46**).

Figure 46. Scientific literature database diagram focusing on the highest incidence of agro-industrial materials citations by classification and types; crops; formats; conversion technology and end-of-use researches.



Source: Partially adapted from (ONU; MBOHWA, 2021e) and partially Mylena Uhlig Siqueira.

Sugarcane is the largest incidence term from studies in the analyzed database (**Figure 46**). Brazil tightly generates bioenergy and bioethanol from sugarcane. Studies show the growing and improvements in these processes, employing bagasse, straw and fibers from the residual material (AGUIAR et al., 2021; ALARCON et al., 2021a; BARBOSA et al., 2020; CANILHA et al., 2012; GIESE et al., 2012; SOARES et al., 2020). In bagasse format, sugarcane presents a greater diversity of technology conversions for applicability for final use of cellulose nanocrystals (**Figure 46**) (BILATTO et al., 2020; DE OLIVEIRA JÚNIOR et al., 2020; LEÃO et al., 2017, 2020;

OLIVEIRA et al., 2016; PEREIRA; ARANTES, 2018, 2020). **Figure 46** also highlights: studies in which the plant works as a matrix for other textile fibers such as sisal for new biodegradable composites (DE CASTRO et al., 2021; SATYANARAYANA; ARIZAGA; WYPYCH, 2009); fibers are commonly used for reinforcement in composites (CARDOSO; SCAGLIUSI; LUGÃO, 2017; DE LEMOS; MAUSS; SANTANA, 2017; DOS SANTOS et al., 2018; FERREIRA et al., 2019; MULINARI; CAPRI; MAIA, 2012); production of multifunctional biocatalysts (BILAL et al., 2020; SILVEIRA et al., 2014b); enzymes such as peroxidase (QUEIROZ et al., 2018), amylase (ORLANDELLI et al., 2017), cellulase (DO NASCIMENTO; COELHO, 2011), hemicellulase (CAMASSOLA; DILLON, 2007) and xylanase (OLIVEIRA; PORTO; TAMBOURGI, 2006); dyes adsorption (CUNHA et al., 2018; FERREIRA et al., 2015; GIUSTO et al., 2017; MEILI et al., 2019; PIFFER et al., 2020). In addition, (COSTA et al., 2015) highlight the use of sugarcane as a material suitable for textile application and the development of bioproducts.

Soybean, the main cultivated area in Brazil, presents husks and straw in its main format (**Figure 46**): functioning like a chemical adsorbent (DE SOUZA et al., 2021); bioenergy (DE PRETTO et al., 2018); biomaterials (ROSA et al., 2015); and cellulose (SOUZA et al., 2020), in particular, nano fibrillated cellulose (DEBIAGI; FARIA-TISCHER; MALI, 2020; FLAUZINO NETO et al., 2013; MARTELLI-TOSI et al., 2016). One of the highlights is its potential for composites and films (MARTELLI-TOSI et al., 2017a).

Cassava presents its main formats in husks, stems, and leaves for: the generation of bioenergy (CRUZ et al., 2021); a substrate for composites (DE LIMA et al., 2020); a generator of cellulose nanocrystals (CZAIKOSKI; DA CUNHA; MENEGALLI, 2020; TRAVALINI et al., 2018); bio sorbent (DE OLIVEIRA et al., 2019a); and enzyme production (OLIVEIRA; PORTO; TAMBOURGI, 2006) (**Figure 46**).

In the cereals group, corn presents the main format as a cob and stem. Its main applications are: adsorption material (CAMPOS et al., 2020); to obtain cellulose (ARAÚJO et al., 2020; DITZEL et al., 2017; LONGARESI et al., 2019; SOUZA; QUADRI, 2014); biocatalysts (BILAL et al., 2020); green composites (RAMOS et al., 2019); reinforcement polymers (COIADO et al., 2017; SILVÉRIO et al., 2013); and enzyme productor (GRIGOREVSKI-LIMA et al., 2009; ORLANDELLI et al., 2017).

Rice, on the other hand, is presented in the form of husks and husk bran from the cultivation. Its main applications are: to obtain cellulose nanocrystals (HAFEMANN et al., 2020); enzymes (GAUTÉRIO et al., 2020); adsorption of violet dyes in textile industry (RIBEIRO et al., 2017); and biodegradable composites (PEREIRA et al., 2015). Wheat term appears less frequently, but it presents unique bran format for applications: in enzyme production (CAMASSOLA; DILLON, 2007; DO NASCIMENTO; COELHO, 2011; GRIGOREVSKI-LIMA et al., 2009; ORLANDELLI et al., 2017) and composites (PEREIRA et al., 2015) (**Figure 46**).

The fruit group contains also the citrus fruits. The study by (ALARCON et al., 2021a), mentions coconut and banana as references to textile fibers and their application to composites and polymeric films. The fermentation of banana pseudo stem and coconut fiber are potential producers of Lipase and Cellulase (FERREIRA DA SILVA et al., 2019a) and nano crystallized cellulose (PEREIRA et al., 2014). Coconut husk fibers, which represent a large amount of material mass, presents applicability as: bio sorbent for textile dyes (CARVALHO COSTA et al., 2020a; DE OLIVEIRA; COELHO; DE MELO, 2018a; MERCI et al., 2019a; S LOPES et al., 2020); and bioenergy and cellulosic ethanol (GONÇALVES et al., 2014a, 2019). The applicability with this fiber involves crafts (NUNES et al., 2020a), green composites (LOMELÍ-RAMÍREZ et al., 2018a) and copolymers (ROSA et al., 2009a). In particular, for the removal of chromium from tannery effluents (CUNHA et al., 2018). Orange term presents the greatest intensity of studies with the pomace, for the generation of nanofibers (MIRANDA et al., 2019), nanocellulose (MARIÑO; REZENDE; TASIC, 2018, 2016), and adsorbent of dyes (NASCIMENTO et al., 2014). The grape appears with its research in the stalk, in the development of polymeric composites (BORSOI et al., 2020; TAURINO et al., 2020), and removal of blue and brown textile dyes (BENVENUTI et al., 2020; OLIVEIRA et al., 2018). Pineapple has great potential for studies in the textile sector. Applications such as cellulose fibers and nanofibers from their residual crowns have been increasingly developed (PEREIRA et al., 2021; PRADO; JACINTO; SPINACÉ, 2020; PRADO; SPINACÉ, 2019), and the use of fibers from the sheets for reinforcement mechanics in polymer composites (DE AZÊVEDO et al., 2021; LEÃO et al., 2015; SENA NETO et al., 2015). (LEAO et al., 2010) highlighted the textile fibers from their sheets as the future of industrial applications (**Figure 46**).

Sawdust from eucalyptus wood provides a bio sorbent for removing textile dyes such as methylene blue (CEMIN et al., 2021), and its pulp, cellulose nanofibrils (CAMANI et al., 2020; DEMUNER et al., 2020; SIQUEIRA; DIAS; ARANTES, 2019) (**Figure 46**).

Other fruits, not shown in the diagram, stand out, such as: apple, khaki, avocado, and pomegranate for removal of dyes (BAZZO et al., 2016; BONETTO et al., 2021; SILVEIRA et al., 2014a). The seeds of açai in the adsorption and obtaining of fibers and application in composites (DE OLIVEIRA et al., 2019b; WATAYA et al., 2015, 2016; ZAVARIZE, 2021). Cashew and acerola for bio nanocomposites (DUARTE et al., 2015; VIEIRA AMORIM et al., 2021). Cocoa husks for cellulose nanofiber (SOUZA et al., 2019). Papaya and mango for the generation of enzymes for the textile industry (OKINO-DELGADO; PRADO; FLEURI, 2018). The cereal group also presents incidence of moreover materials, such as oat husks for the generation of nano fibrillated cellulose (DEBIAGI; FARIA-TISCHER; MALI, 2021). Tubers such as sweet potato also demonstrate have composite potential (PEREIRA et al., 2017). The group of nuts, which are not identified in the diagram, contains pecan nutshells for biosorption of cationic dyes (GEORGIN et al., 2018; PANG et al., 2019). Peanut husks stand out from the oleaginous grain in dye adsorption research (NASCIMENTO et al., 2014; VILLAR DA GAMA et al., 2018). Coffee beans, which are not very evident, act as reinforcing recycled polymers (COIADO et al., 2017).

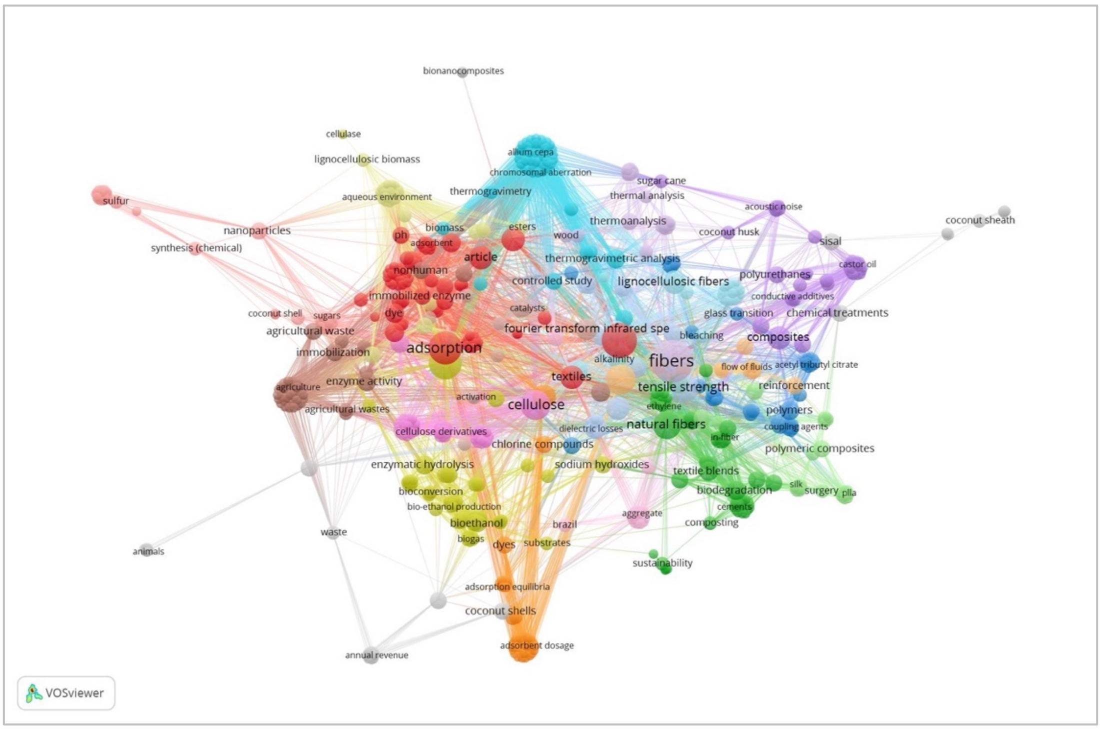
According all analyzed studies, the technology conversions are diverse: preliminary analysis of the chemical, physical and morphological structure are the most used in materials, added to thermal, rheological, and mechanical ones; alkaline treatment in synergy with spectroscopy, ultrasound, bleaching, hydrothermal, and chemical/acid treatment; extraction and characterization, on the other hand, appear as chemical sequential and moderate; kinetic analysis in examples with pseudo-first and second-order models, pyrolysis, and combustion; solid-state fermentation was mentioned most, but the data includes submerged fermentation with hydrolysis; the biorefinery includes a set of general analyzes that are not in-depth in the present study (**Figure 46**).

6.5. Scientific literature database diagram on coco's researches

Coconut represents about US$ 200 million production value (in 2019); 1,553,966 thousand fruits (in 2019); 37,515 producers (in 2017); 25,170 thousand palm trees (in 2017) (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATISTICA- IBGE, 2021b). In addition, 405,009 million tons of coconut waste with 60% of residual factor were generated in 2012 (SCHNEIDER et al., 2012).

In Brazil, only packaging gardening and decoration, substrate for seedlings and manufacture of pots options are produced and commercialized. There is no current wide application of coconut fiber in Brazilian textile industry (APROCOCO, 2021). Despite of this gap, many researches have been carried out in Brazil. Currently, the fiber is studied as bio sorbent for textile dyes (CARVALHO COSTA et al., 2020a; DO NASCIMENTO; DE OLIVEIRA; LEITE, 2019; MERCI et al., 2019a; S LOPES et al., 2020), handicrafts (NUNES et al., 2020a), green composites (LOMELÍ-RAMÍREZ et al., 2018a) and copolymers (ROSA et al., 2009a). It is possible to observe a high incidence of these terms in network analysis (**Figure 47**).

Figure 47. Network built with VOS viewer software (Universiteit Leiden) through the analysis of 59 articles and co-occurrence of 921 specific expressions.



Source: Mylena Uhlig Siqueira

The applications with the highest co-occurrence are: "adsorption", “tensile strength", "textiles" and "enzyme activity". The main formats demonstrate the need of expansion of textile incomes in coconut fiber as raw material. Thus, there is a great potential scope for expanding technological research in Brazil, including new sustainable materials for circularity.

According to the network analysis, the applications with the highest co-occurrence are: "adsorption", “tensile strength", "textiles" and "enzyme activity".

Although the main format is shown as “fibers”, “coconut fibers” and “natural fibers”, the material is not explored in its breadth, being limited to absorbent material. The terms “composites” and “polymers” are less frequent or in support of other studies.

The term “lignin” in particular appears in the second highest co-occurrence, demonstrating the interest in the high level of lignin present in the waste material.

There is a greater incidence of studies involving preliminary or initial studies of the fiber, involving its physical-chemical and strength characteristics, in terms such as "scanning electron microscopy", "tensile strength", "chemistry", "X-ray diffraction", thermogravimetric analysis”, than studies applicable or scalable to industry. The main applicability found in the database is presented in **Table 9.**

Table 9. Brazilian Coconut fiber currently applications studies.

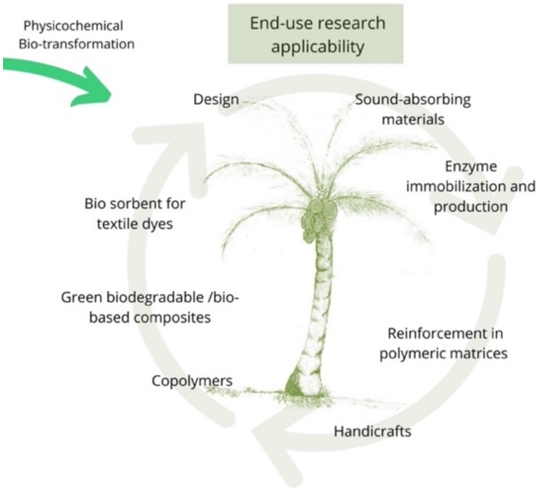
Applicability	References
Activated carbon producer/ carbon sources and surfactants	(CARMO RANGEL et al., 2017; FERREIRA DA SILVA et al., 2019a; MACEDO et al., 2008)
Agricultural substrate	(DUTRA et al., 2012; DUTRA; MASSAD; SANTANA, 2012)
Biodegradable and bio-based composites	(BARRETO et al., 2013; LOMELÍ-RAMÍREZ et al., 2018a; RODRIGUES et al., 2017; ROSA et al., 2009b; SATYANARAYANA; GUIMARÃES; WYPYCH, 2007a)
Bioethanol production	(GONÇALVES et al., 2014b, 2015, 2016)
Biomaterial/bioresource	(ESMERALDO et al., 2010; TOMCZAK; SYDENSTRICKER; SATYANARAYANA, 2007a)
Biorefinery	(GONÇALVES et al., 2019)
Cellulose nanocrystals	(NASCIMENTO et al., 2016a, 2016c)
Conductive additives / thermal conductor	(MERLINI et al., 2014; NEIRA; MARINHO; RAMOS, 2009a)
Copolymer	(ROSA et al., 2009a)
Design/ footwear	(KOHAN et al., 2019)

Enzyme immobilization and production	(BEZERRA et al., 2015; BILAL et al., 2020; CRISTÓVÃO et al., 2011, 2012a; DA SILVA BARBOSA et al., 2020; FERREIRA DA SILVA et al., 2019b)
Fiber cement	(SILVA et al., 2017)
Gardening, crafts and briquettes	(NUNES et al., 2020a)
Healing and surgical suture applications	(GUAMBO et al., 2020)
Oil (Fuels) and other bio sorbents	(CARVALHO COSTA et al., 2020a; DE LIMA et al., 2012; DE OLIVEIRA et al., 2017; DE OLIVEIRA SOUSA NETO et al., 2014; MORO et al., 2017; NASCIMENTO et al., 2019; VIEIRA et al., 2014)
Polymeric/micro polymeric and hybrid composites	(BENNET et al., 2015; DE LEMOS; DE MARTINS, 2014; FONTELES et al., 2016; KODAMA, 2017; PADILHA et al., 2020)
Reinforcement in polymeric matrices and biofilms	(CORRADINI et al., 2013; DA SILVA et al., 2015; KUMAR et al., 2014)
Spinning and weaving for use in textile applications	(MARTINS; SANCHES, 2019b)
Synthesis of lignin nanoparticles	(DE ARAÚJO PADILHA et al., 2020)
Sound-absorbing materials	(SILVA et al., 2019)
Textile dye and colorants bio sorbents/bio degraders	(CRISTÓVÃO et al., 2012b; DE OLIVEIRA; COELHO; DE MELO, 2018b; DE SOUZA et al., 2015; MERCI et al., 2019a; MONTEIRO et al., 2017)
Woven/non-woven composites	(NEIRA; MARINHO; RAMOS, 2009b)

Source: Mylena Uhlig Siqueira

Coconut fiber has been studied as bio sorbent for textile dyes (CARVALHO COSTA et al., 2020b; DO NASCIMENTO; DE OLIVEIRA; LEITE, 2019; MERCI et al., 2019b; S LOPES et al., 2020), handicrafts (NUNES et al., 2020b), green composites (LOMELÍ-RAMÍREZ et al., 2018b), and copolymers (ROSA et al., 2009c). It is possible to observe a high incidence of these terms in network (built with VOS viewer software) analysis.

Figure 48. End-use research applicability



Source: Mylena Uhlig Siqueira

In this way, the possibilities demonstrate the need for expansion of textile incomes in coconut fiber as raw material. Thus, there is a great potential scope for expanding technological research in Brazil, including new sustainable materials for circularity (**Figure 48**).

6.5.1. The commercial use of coir fiber and its applicability in material design: processing companies in Brazil

In order to understand the final destination of coconut waste, it was decided to question large companies that process coconut products about the destination of their waste. With the return of Empresa Sococo, the company now has more than 5,000 employees, more than 1.5 million coconut trees, 10,000 hectares of the largest coconut grove in Latin America and a reference in studies and projects with the Universidade Federal Rural da Amazônia (UFRA) and researchers from the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), recognized the pioneering work in fiber treatment by the company AMAFIBRA(“AMAFIBRA”, [s.d.]; “SOCOCO”, [s.d.]) (**Figure 49**).

Figure 49. AMAFIBRA production.

Source: ("AMAFIBRA", [s.d.]; "SOCOCO", [s.d.]).

AMAFIBRA is the first company in Brazil to produce substrate using coconut fiber as raw material, fully supplied by the parent company, Sococo, using its own technology to reuse waste from the coconut industry to manufacture blankets and biorolls, which are used in works to contain slopes, to control soil wear and to repopulate vegetation in degraded areas("AMAFIBRA", [s.d.]; "SOCOCO", [s.d.]).

However, it should be noted that the project Pronamazon - Indústria de Aproveitamento de Produtos Naturais da Amazônia Ltda (Industry for the Use of Natural Products of the Amazon Ltda) is located on the Island of Marajó, in the Municipality of Praia Grande. As part of the Programa Pobreza e Meio Ambiente na Amazônia – (Poverty and Environment Program in the Amazon - POEMA), it produces 100 headrests for truck seats daily in a cooperative system. The pieces are handmade using vegetable horsehair, which is a combination of coconut fiber and latex, and are formed into blankets with the fibers.

6.5.2. The commercial use of coir fiber and its applicability in material design: Biomaterials and co-products

Through research carried out in a virtual environment, scientific articles and institutions such as NGOs, companies and cooperatives, it is possible to identify the countless textile applicability of coconut fiber in Brazil and some other countries. The following were identified: applications in technical textiles from different areas such as engineering, fashion and decoration textiles, as mentioned in **Chart 9** and **Chart 10** are listed some of the different uses of coconut fiber found in synthesis.

Chart 9. Industrial Sector Coconut application.

Industrial Sector	**Products Used**
Decoration and Crafts	Rugs, mats, cushions, baskets, brushes, vases, and decorative objects
Textile Industry	Textile fibers, yarns, ropes, nets, fabrics, and knitwear
Construction Industry	Thermal and acoustic insulating panels, roofing tiles, flooring, cladding panels, and masonry blocks
Agriculture and Livestock	Substrates for seedlings, organic compost, animal fodder, and fertilizer
Automotive Industry	Upholstery for car seats, dashboards, and internal coverings
Food Industry	Substrates for growing mushrooms and other foods
Renewable Energy	Biofuels, briquettes, and pellets for use as fuel

Source: Adapted from (CARVALHO COSTA et al., 2020a, 2021; GONÇALVES et al., 2015; MARTINS; SANCHES, 2019b; NASCIMENTO et al., 2016a, 2016b, 2016c)

Chart 10. Design Sector Coconut application.

Design Sector	**Products Used**
Furniture Design	Chairs, tables, sofas, and other furniture items with coconut fiber as a filling material
Textile Design	Rugs, carpets, and other textile products made from coconut fiber
Product Design	Decorative objects, vases, baskets, and other items made from coconut fiber
Lighting Design	Lamp shades and other lighting products made from coconut fiber
Sustainable Design	Products made from coconut fiber as a sustainable and eco-friendly alternative to non-renewable materials

Source: Adapted from (AHMAD; AHMAD; ABDULLAH, 2021; CAIO CANARIN MRONINSKI; FABIO COSTA BRODBECK, 2020; FLETCHER; DEWBERRY; GOGGIN, 2001; ISHAK; MANSOR; AB GHANI, 2021; MARTINS; SANCHES, 2019c; WIEDMAN, 2018).

Coir fibers, within the lignocellulosic spectrum, have great potential for use in automotive applications and could become ideal competitors for non-renewable and expensive petroleum-based synthetic fibers in composite materials, especially in the automotive and construction industries. Awareness of ecological concerns related to the use and disposal of materials is increasing in many countries. It is likely that the use of compositions based on these fibers as structural members in automobiles will soon become a reality. Furthermore, it is possible to produce quality fibers for various applications through improved cultivation, including genetic engineering and treatment methods to obtain uniform properties. These trends indicate that the use of these fibers has both short-term goals (synthesis and characterization of composites based on these fibers) and long-term goals (alternatives to synthetic fibers and possible substitutes for wood)(CARVALHO COSTA et al., 2021; DAM, 2002a; LOMELÍ-RAMÍREZ et al., 2018c; MERCI et al., 2019c; MOTHÉ; DE MIRANDA, 2018; RAMESH; PALANIKUMAR; REDDY, 2017; SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b; TOMCZAK; SATYANARAYANA; SYDENSTRICKER, 2007; TOMCZAK; SYDENSTRICKER; SATYANARAYANA, 2007a, 2007b).

Coconut has several applications in different sectors. In the domestic sphere, it is used in the manufacture of materials for floor furniture, mattresses, sofas and in gardening. In the automotive sector, it is used as a support for seats, seat covers, roofs, domestic water tanks and other products. In addition, coconut is also used as an alternative source of energy in industrial ovens and in the production of buttons, cigar tubes, cane handles and various decorative items, including imitation pearls and ivory. However, these applications use only a small number of available fibers, which have great added value. Because of this, there are many research and development efforts to find new applications for coconut fibers, such as in composites (SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b)

Thus, in order to materialize the applicability of the material in several design units, **Figure 50** brings 3 national projects (**a, c and d**) and 1 international project (**b**) that involve the area of Product Design, Engineering Design, Interior/Furniture Design and Civil construction and Packaging design. However, most of the mentioned products are still in the research and development phase. Which states that within the Design area in general, coconut fiber has its greatest versatility and variability when applied to composites.

Figure 50. Current design applicability's of coconut fiber.

(a) (b) (c) (d)

Source: (a) (WIEDMAN, 2018) (b) ("COCOPALLET", [s.d.]) (c) (WIEDMAN, 2018) (d) ("AMEDESIGN-PROJETO BOTIA", [s.d.]).

These compounds have advantages because they originate from renewable resources and have the ability to degrade in the environment in a shorter period compared to materials derived from petrochemicals. However, there are some limitations to be considered, such as poor mechanical performance and sensitivity to humidity. Despite these limitations, these materials are still viable for use in products, as long as they are used in applications that are in line with their characteristics (CALEGARI; OLIVEIRA, 2016) (**Chart 11**).

Chart 11. Summary of coconut fiber possibilities for the textile industry

Material Name	*Description*	*Properties*	*Applications*
Coir Fiber	A natural fiber extracted from the outer husk of coconuts.	Durable, water- resistant, biodegradable, and eco-friendly.	Mats, ropes, doormats, brushes, and geotextiles.
Coir Geotextiles	Non-woven, permeable fabrics made from coir fibers.	Biodegradable, durable, water-resistant, and can control soil erosion.	Road construction, slope stabilization, and erosion control.
Coir Yarn	A strong and durable yarn made from coir fibers.	Abrasion-resistant, water-resistant, and can be dyed easily.	Carpet and rug manufacturing, upholstery, and wall hangings.
Coir Non-Woven Fabric	A fabric made from compressed coir fibers.	Biodegradable, water-resistant, durable, and can be easily molded into different shapes.	Home furnishing, automotive, and insulation.
Coir Composite Materials	Reinforced materials made from coir fibers and a binding agent such as resin.	Strong, lightweight, eco-friendly, and durable.	Furniture, construction, and packaging.

Source: Adapted from (CRISTÓVÃO et al., 2012a; MARTINS; SANCHES, 2019c, 2019a; MERCI et al., 2019c; NASCIMENTO et al., 2016c).

In particular, for the use of coconut fibers in textile applications in fabrics, only one material called Woocoa was found, according to the team that developed the product.

> WOOCOA consists on creating an animal free wool fabric from vegetable fibers found in Colombia. We specifically chose hemp and coconut fibers due to their biological and mechanical properties and because these fibers are often unexploited and wasted. Furthermore, we intend to support families that have lost their illegal harvesting jobs with the implementation of the Colombian peace agreement by offering them an opportunity to produce hemp in a legal context and promoting a new agroindustry in our country. The fibers are treated with lignin-degrading enzymes, laccases, extracted from the oyster mushroom, Pleurotus ostreatus, which makes the fibers soft and colorless. The resulting material is then woven into threads and fabrics which can be used to make clothes and create a vegan Colombian wool
> (OBREGÓN et al., 2023; “WOOCOA”, [s.d.]).

Figure 51. Woocoa Fabrics.

Source: (OBREGÓN et al., 2023; “WOOCOA”, [s.d.]).

WOOCOA is a fiber that resembles wool and is created through bio fabrication. It possesses hygroscopic, thermal, and antimicrobial properties, making it highly functional. The yarn is flexible, elastic, and durable, as well as easy to dye, environmentally friendly, and able to wick away humidity. The production process is circular and regenerative (**Figure 51**).

6.6. Physical-chemical characterization of ratted and non-ratted green coconut fibers (*Cocos nucifera*).

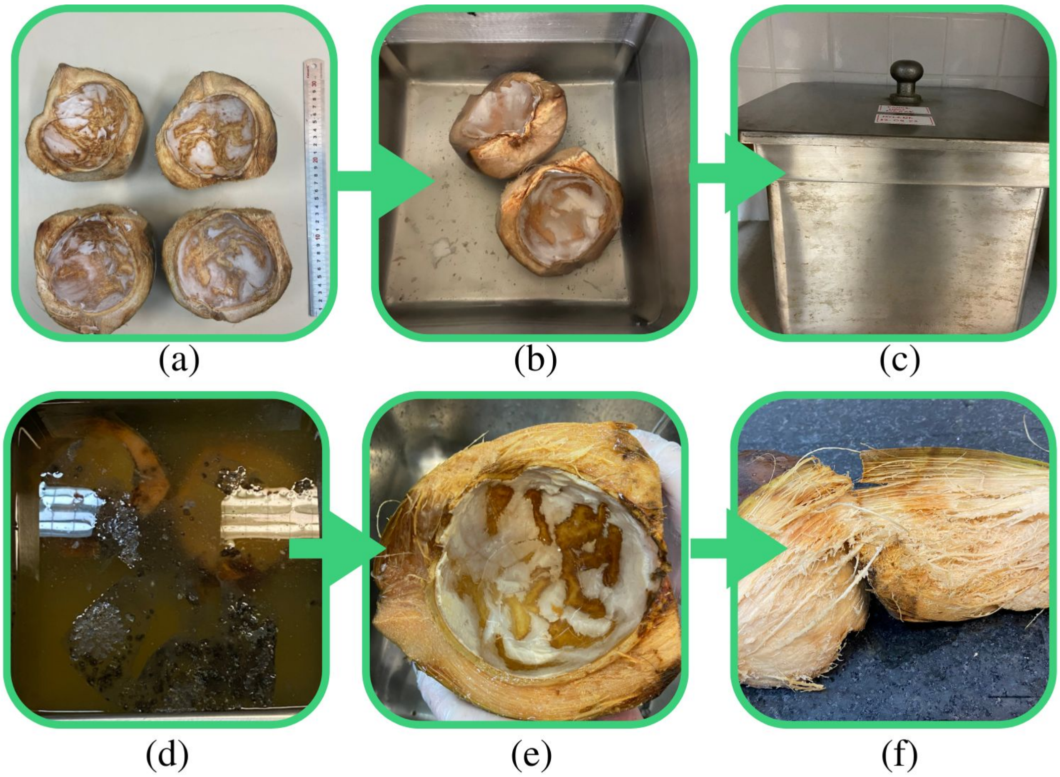
6.6.1. Removal and Preparation of Coconut Fiber

A total of 2 samples **(a)** were used to compare the following coconut fiber characterizations.

Firstly, the samples were divided into fresh coconut and ratted coconut segments. Both samples were weighed together, totaling an average of 1 kg each complete coconut. Sample 1 was separated for use in the analysis of in natura fiber and was reserved in a freezer until the fibers were removed.

Sample 2 destined for the retting process, after being weighed, 6 liters of distilled water **(b)** were used to cover the material. The material was submerged and deposited in a metal box free from the sun from 09/12/2022 to 10/10/2022 **(c) (Figure 52).**

Figure 52. Retting Process of Green Coconut fibers.

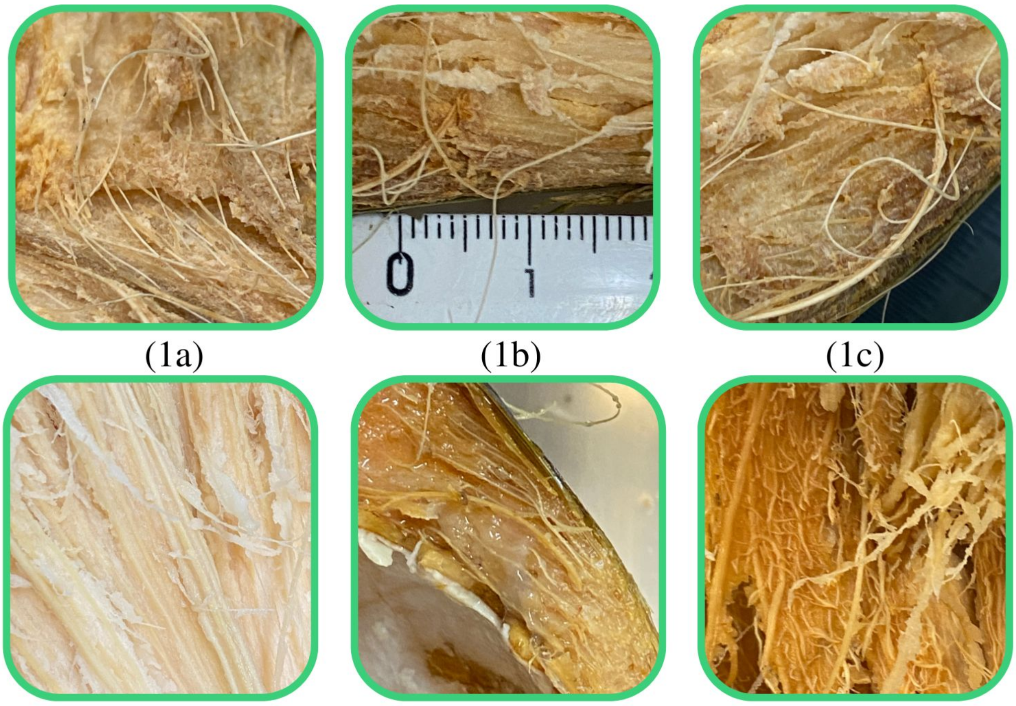


Source: Mylena Uhlig Siqueira.

After the month of analysis, when removing the material, the manifestation of microorganisms was noted (**d**), which did not affect the material, which was subsequently washed in running water, used to remove the ratted fibers (**e and f**).

Samples of in natura coconut fibers were manually removed from body 1 before the procedure, while samples from body 2, which were subjected to retting, were also removed and cleaned manually after the procedure (**Figure 53**).

Figure 53. Comparison of the result after retting and coconut in natura.



(1a) (1b) (1c)

(2a) (2b) (2c)

Source: Mylena Uhlig Siqueira.

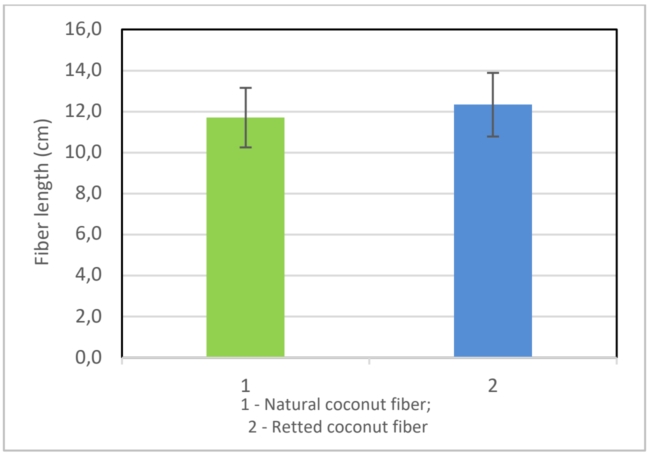
From the sequence of images 1 (in natura coconut), the fibers in their natural state can be seen, well fixed and with greater difficulty in removing, requiring the use of utensils and greater manual strength. In the sequence of images 2, the coconut can be seen after the retting process, with the fibers in greater malleability for removal.

Retting is a process used to separate the fiber from the coconut husk, resulting in high-quality, long, and strong fibers that are ideal for producing coir. This method not only improves the fiber's quality by removing impurities but also increases the yield of usable coir from each coconut. Moreover, the retting process is environmentally friendly, as it does not require harmful substances or chemicals and the by-products can be used as a natural fertilizer.

6.6.2. Fiber Length

A total of 114 fibers from each coconut (*Cocos nucifera*) sample were measured with a ruler. The coconut fiber in natura and retted fiber lengths were analyzed using a histogram, with an average of **11.7 cm** and **12.3 cm**, respectively, according **to Figure 54**.

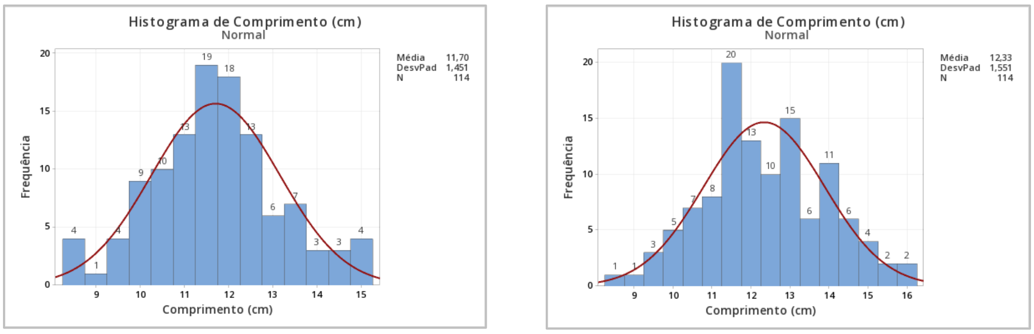
Figure 54. Fiber length of coconut fibers.



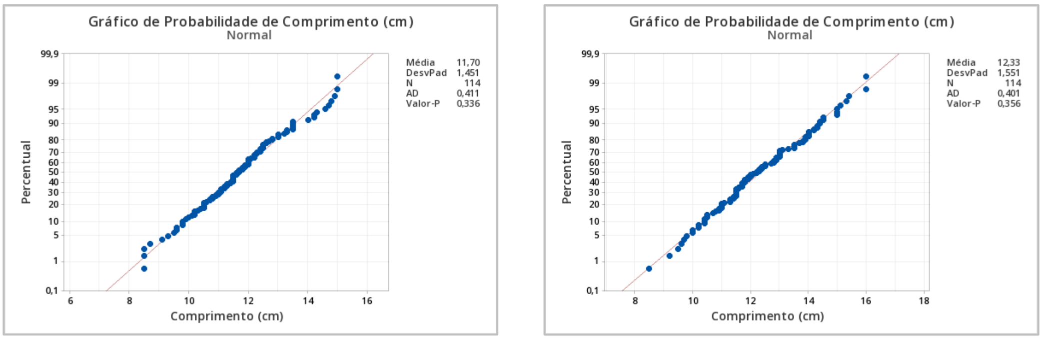
Source: Mylena Uhlig Siqueira.

Statistical analysis was performed using Minitab software (Minitab Inc.) based on the length values measured manually (Complete data in **Appendix A**). The normality test for the histogram distribution (**Figure 55**) was performed using the same software (Arderson-Darling normality test), indicating that both the distribution of the coconut fiber in natura and the retted fiber present a normal distribution, since the probability calculated is 33.6% and 35.6%, respectively (greater than 5%) (**Figure 55**).

Figure 55. Coconut Fiber Length Histogram (a) in natura; (b) retted, (c) and (d) correspondent normal tests.



(a) (b)



(c) (d)

Source: Mylena Uhlig Siqueira.

By analyzing the average plus or minus standard deviation graph, it can be seen that there is no statistically significant difference between the average length values between natural coconut fibers and retted coconut fibers (**Table 10**).

Table 10. Values calculated by Minitab software from the measured lengths of coconut fibers.

Fiber Length (cm)	Coconut Fiber in Natura	Retted Coconut Fiber
Average (cm)	**11,70**	**12.32**
Minimum (cm)	8.50	8.50
Maximum (cm)	15.00	16.00
Standard deviation	1.45	1.55
CV%	12.40	12.60

Source: Mylena Uhlig Siqueira.

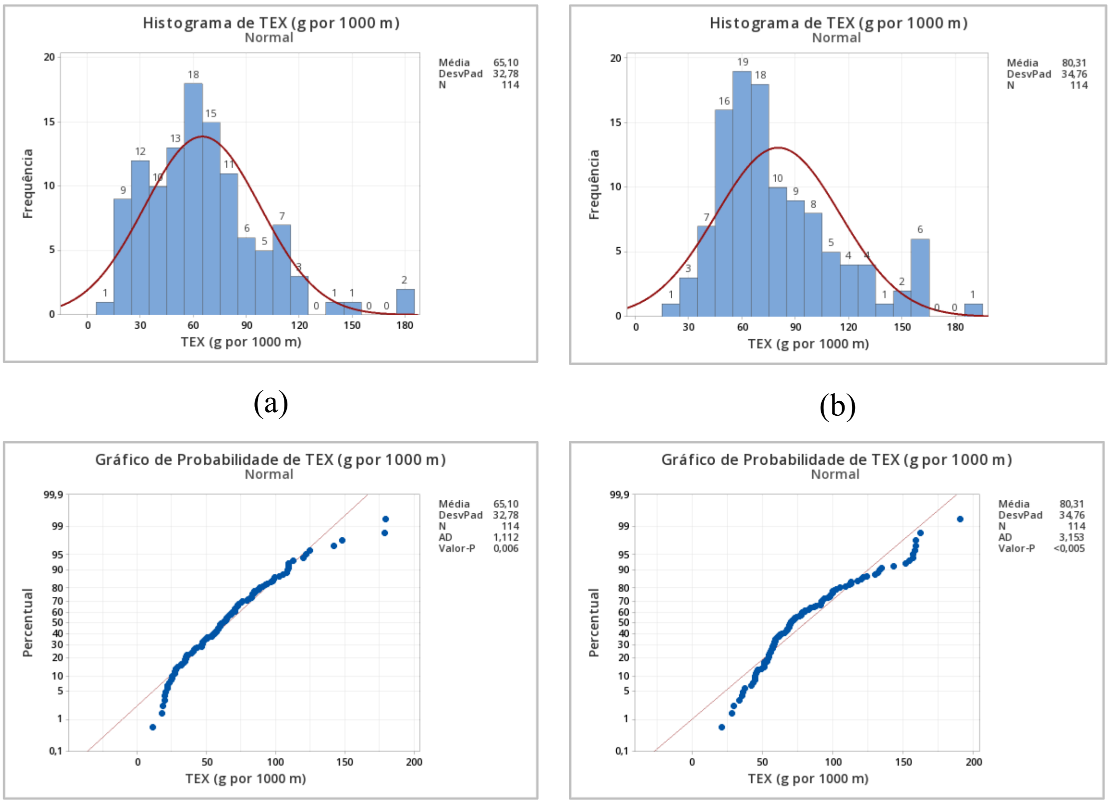
6.6.3. Fiber count number

After measuring the length of the fibers, their count number was calculated, in TEX (mass in grams of 1000 meters of fibers).

Each fiber was weighed individually, complete data are available in **Appendix B**.

The value obtained in the average calculation of the fiber count number of fresh coconut was 65.1 TEX and of retted coconut 80.3 TEX. To get an idea of the magnitude of this count number value, a 100% cotton sewing thread has around 34 Tex (COATS, 2019) (**Figure 56**).

Figure 56. Histogram of TEX titer of Coconut Fiber (a) in natura; (b) retted, (c) and (d) correspondent normal tests.



(a) (b)

(c) (d)

Source: Mylena Uhlig Siqueira.

Table 11. Values calculated by Minitab software from the measured count numbers of coconut fibers.

TEX (g per 1000 m)	Coconut Fiber in Natura	Retted Coconut Fiber
Average	**65.1**	**80.3**
Minimum	8.50	8.50
Maximum	15.00	16.00
Standard deviation	32.78	34.76
CV%	50.4	43.3

Source: Mylena Uhlig Siqueira.

The Tex probability of the fibers does not follow a normal one, influenced by the diameter, which directly influences textile developments in terms of tenacity. The normality test is a statistical measure used to verify whether a given sample of data follows a normal distribution, which is a statistical distribution commonly found in many natural phenomena. If a fiber does not follow the normality test, it means that the fiber data distribution is not normal (**Table 11**). This may indicate that the fiber has unusual or different characteristics or properties than other fibers in the sample. If the coconut fiber TEX normality test was negative, it means that the TEX data distribution does not follow a normal distribution. This could indicate that coir fiber has unusual or different characteristics or properties than other fibers.

6.6.4. Optical Microscopy of Fibers

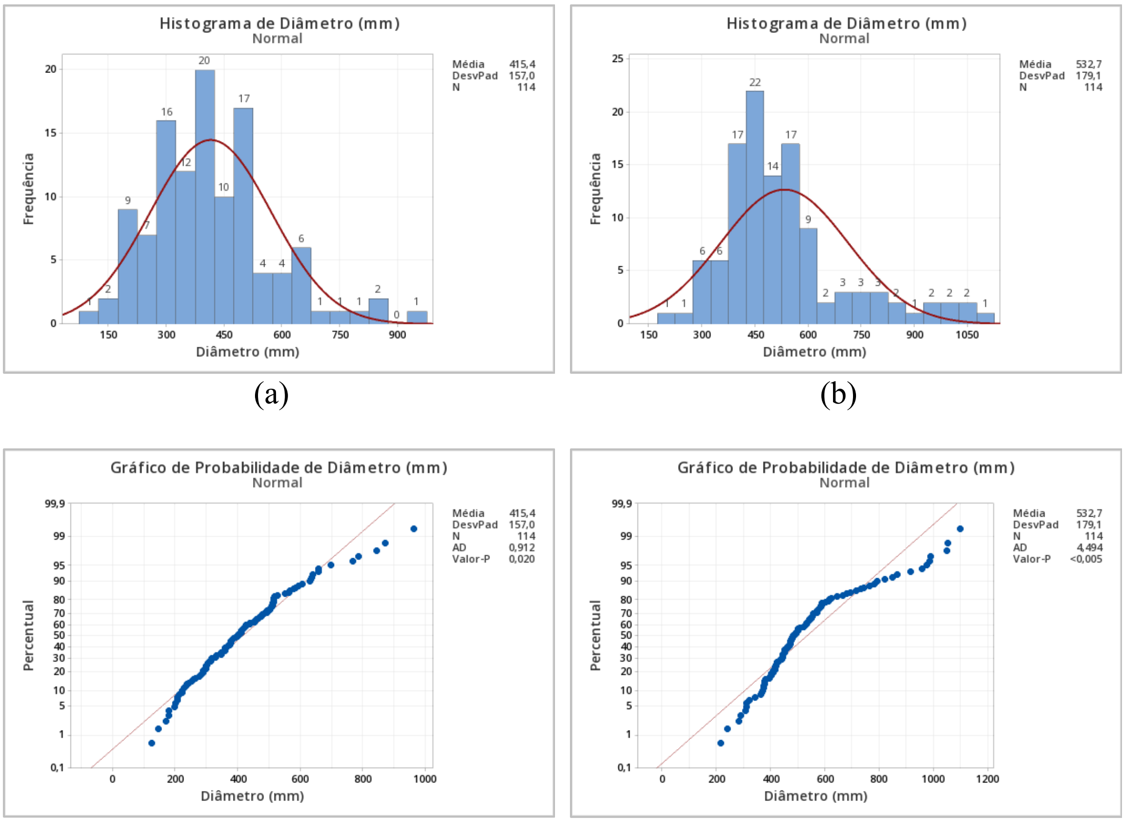
The identification of vegetable fibers can be complemented by observing the cross-section. The fibers were analyzed in longitudinal view (with a magnification of up to 128x) and cross section (with a magnification of up to 1280x) through optical microscopy.

6.6.4.1.Longitudinal Microscopy

Through longitudinal microscopy analysis, the diameters ("finenesses") of 114 in natura coconut fibers and 114 retted fibers were measured and later analyzed through histogram, with an average of 415.4 µm and 532.7 µm respectively, as shown **in Figure 57** and **Table 12**, with statistical analysis performed using Minitab software (Minitab Inc.) (Complete data in **Appendix C**).

The normality test for the histogram distribution was performed using the same software (Arderson-Darling normality test), indicating that it cannot be said that this distribution is normal, since the calculated probability is less than 5% in both the cases (**Figure 57**).

Figure 57. Histogram of diameter of Coconut Fiber (a) in natura; (b) retted, (c) and (d) correspondent normal tests.



(a) (b)

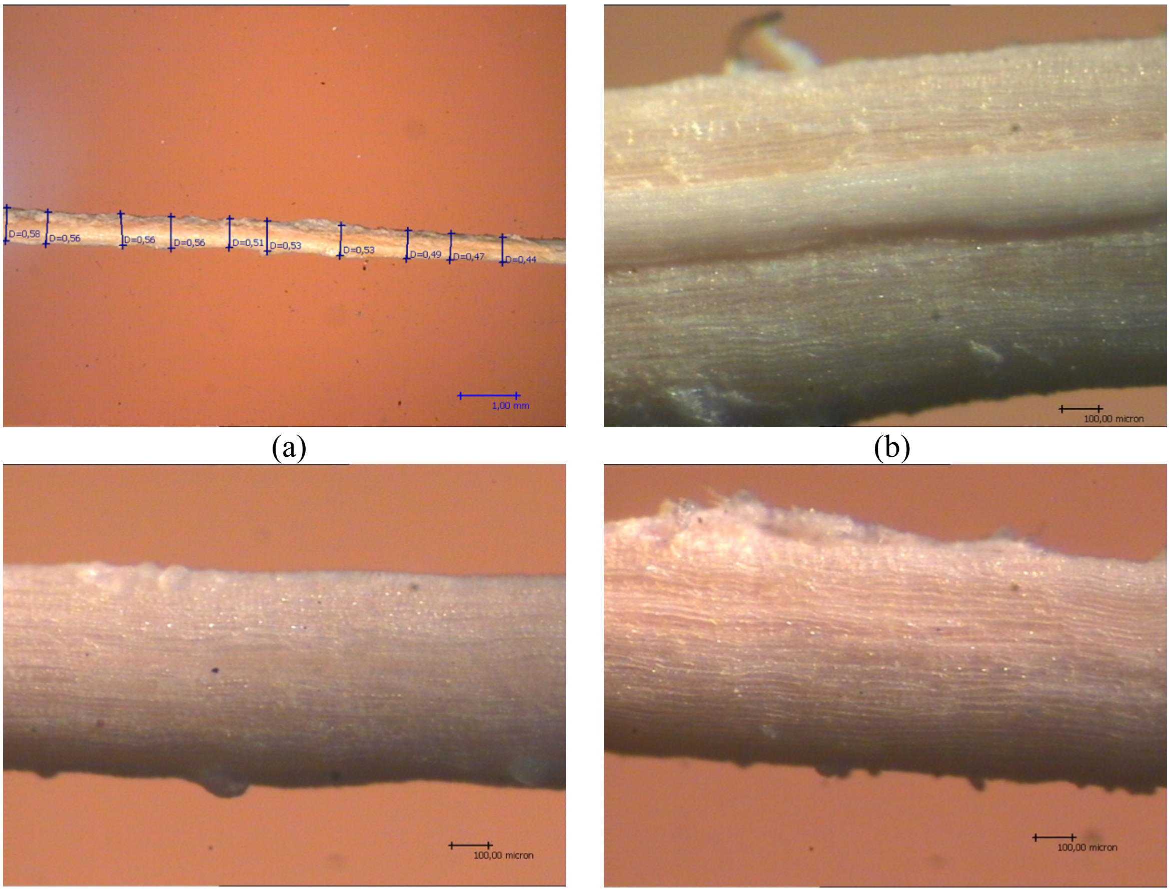
(c) (d)

Source: Mylena Uhlig Siqueira.

Based on the analysis of the Histogram and when observing the optical microscopies, it is noted that the samples do not refute normality due to some factors, such as: 1. The existence of more than one population of fibers in the fibrous mesocarp. 2. This population is more evident in retted fibers due to the ease of removal of thicker fibers after the retting process; 3. The diameter impacts directly on the Tex normal.

Longitudinal microscopies of coconut fiber are shown in **Figure 58 and 59**.

Figure 58. Longitudinal optical microscopy of coconut fiber in natura.

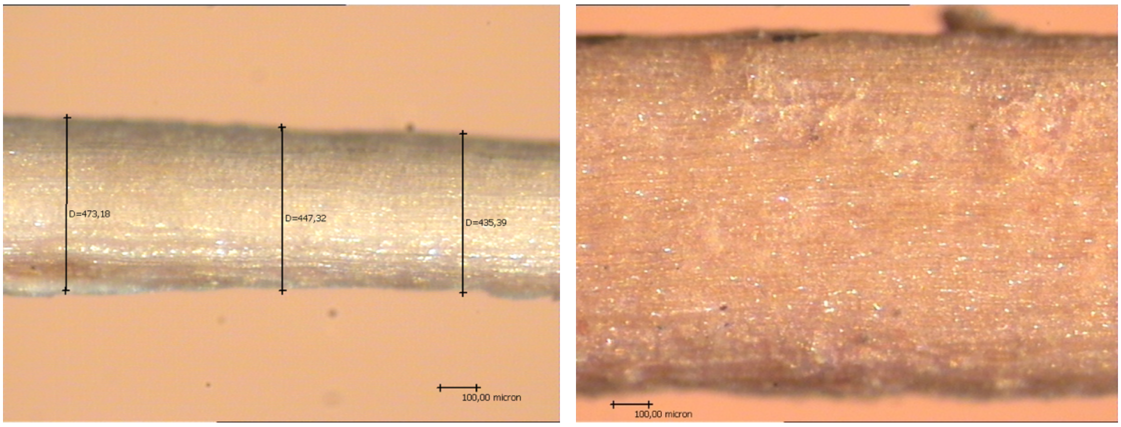


(a) (b)

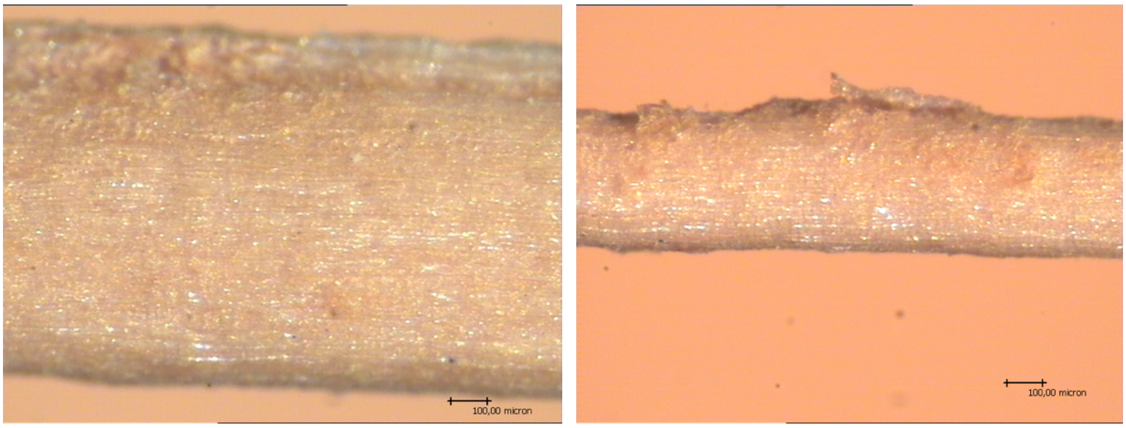
(c) (d)

Source: Mylena Uhlig Siqueira.

Figure 59. Longitudinal optical microscopy of retted coconut fiber.



(a) (b)



(c) (d)

Source: Mylena Uhlig Siqueira.

Table 12. Diameter Coconut fibers.

Diameter	Coconut Fiber in Natura	Retted Coconut Fiber
Average (µm)	**415.4**	**532.7**
Minimum (µm)	124.72	216.89
Maximum (µm)	962.56	1098.16
Standard deviation	157.02	179.09
CV(%)	37.8%	33.62%

Source: Mylena Uhlig Siqueira.

The presence of grooves, porosities and protuberances observed in the longitudinal view of the coconut fibers, may represent a high cohesiveness of the fiber. Coir fibers are elongated sclerenchyma cells with thick, lignified cell walls that provide strength and rigidity to the fibers. They are organized in parallel bundles that run the length of the fiber and have important air channels to allow ventilation and air circulation, preventing the accumulation of moisture and the proliferation of microorganisms. Coir fibers also contain parenchyma cells for nutrient storage and transport and a narrow, elongated lumen inside the cell.

6.6.4.2.Cross-sectional microscopy

Transversal optical microscopy was performed with the coconut fibers and, according to **Figure 60**, it is possible to see that the fibers are multicellular with a long and oval shape.

Table 13. Cross-sectional Microscopy data.

Cross-sectional microscopy	Coconut Fiber in Natura	Retted Coconut Fiber 1	Retted Coconut Fiber 2
Average	15.5	18.7	16.6
Standard deviation	1.4	3.4	3.1
CV%	9.1%	18.0%	18.8%

Source: Mylena Uhlig Siqueira.

For natural coconut the fiber dimensions in cross-sectional microscopy are: For fiber - 429.701 X 276.85 micrometers. For retted coconut (1st sample) For fiber - 360.782 X 213.036 micrometers. For the retted coconut (2nd sample) - For the fiber - 292.872 X 239.060 micrometers.

Figure 60. Coconut fiber transverse optical microscopy

(a) Coconut Fiber in Natura (b) Retted Coconut Fiber **1** (c) Retted Coconut Fiber **2**

Source: Mylena Uhlig Siqueira

Despite the presence of the lumen not being clear in the images, it was possible to observe the cell pattern well, which allowed the measurement of cell diameters (***b***), and it was also possible to observe the presence of lumens in some of these cells (**Table 13**).

The average of the values obtained from the cell diameters was 15.7 μm (ranging in standard deviation 1.4 μm) in fresh coconut fiber and 18.7-16.6 μm (ranging in standard deviation 3.4 - 3.1μm) in retted coconut fiber , which can be considered compatible with the values of cellular diameters of fibers of recognized textile use that vary from 12.0 –

25.0 µm for cotton, 5.0 – 76.0 µm for linen and 15.0 – 25 ,0 µm for jute (REDDY; YANG, 2005).

In optical microscopy, the cell wall of coconut fiber fibers can be visualized as a thick and dense layer around the fibers. The lumen of the fibers can be seen as a lighter area in the center of the fiber, while the knots appear as darker and denser areas in the fibers. In addition to cellulose, coconut fiber contains other extracellular substances, such as lignin and hemicellulose, which can also be visualized in optical microscopy.

There is no statistically significant difference between the cell diameters present in the natural coconut fiber analyzed and the cell diameters in the retted coconut fiber analyzed.

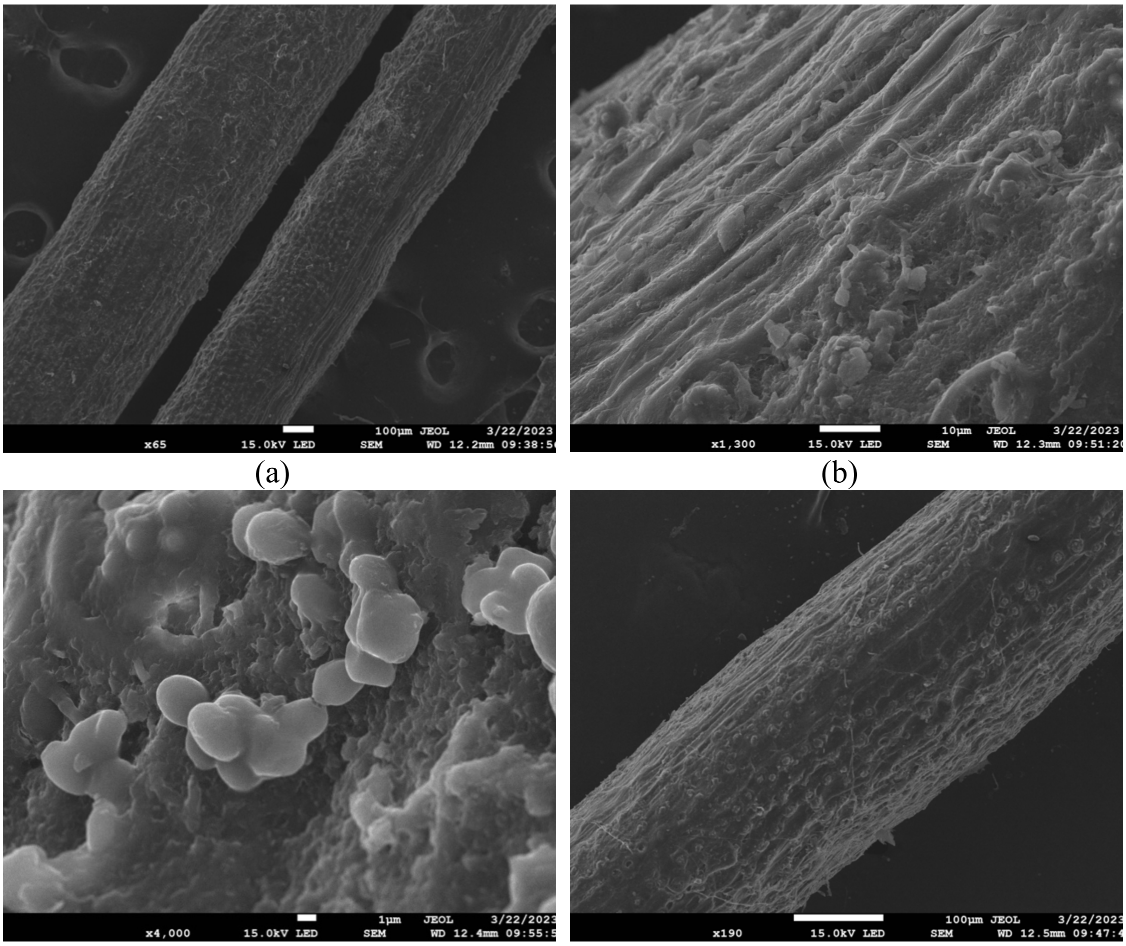
6.6.5. Scanning Electron Microscopy (SEM)

The images of the longitudinal and cross-sectional views of the coconut fiber made in a Scanning Electron Microscope (SEM) can be seen in **Figures 61, 62, 63 and 64**, and others can be found in **Appendix D**.

6.6.5.1.Longitudinal View

In the Scanning Electron Microscope (SEM), it is possible to observe several coconut fibers structures in ultrafine details, including the cuticle, an external layer that protects against physical damage and the action of microorganisms, consisting mainly of waxes and other organic compounds. In addition to the cuticle, other structures such as knots, cell wall, extracellular substances and lumens can also be observed on SEM, providing detailed information about the microstructure of coconut fiber, useful to understand its physical and mechanical properties and to develop new applications for this material (**Figure 61**).

Figure 61. SEM images of the longitudinal section of fresh green coconut fiber (*Cocos nucifera*) with magnification and scale.



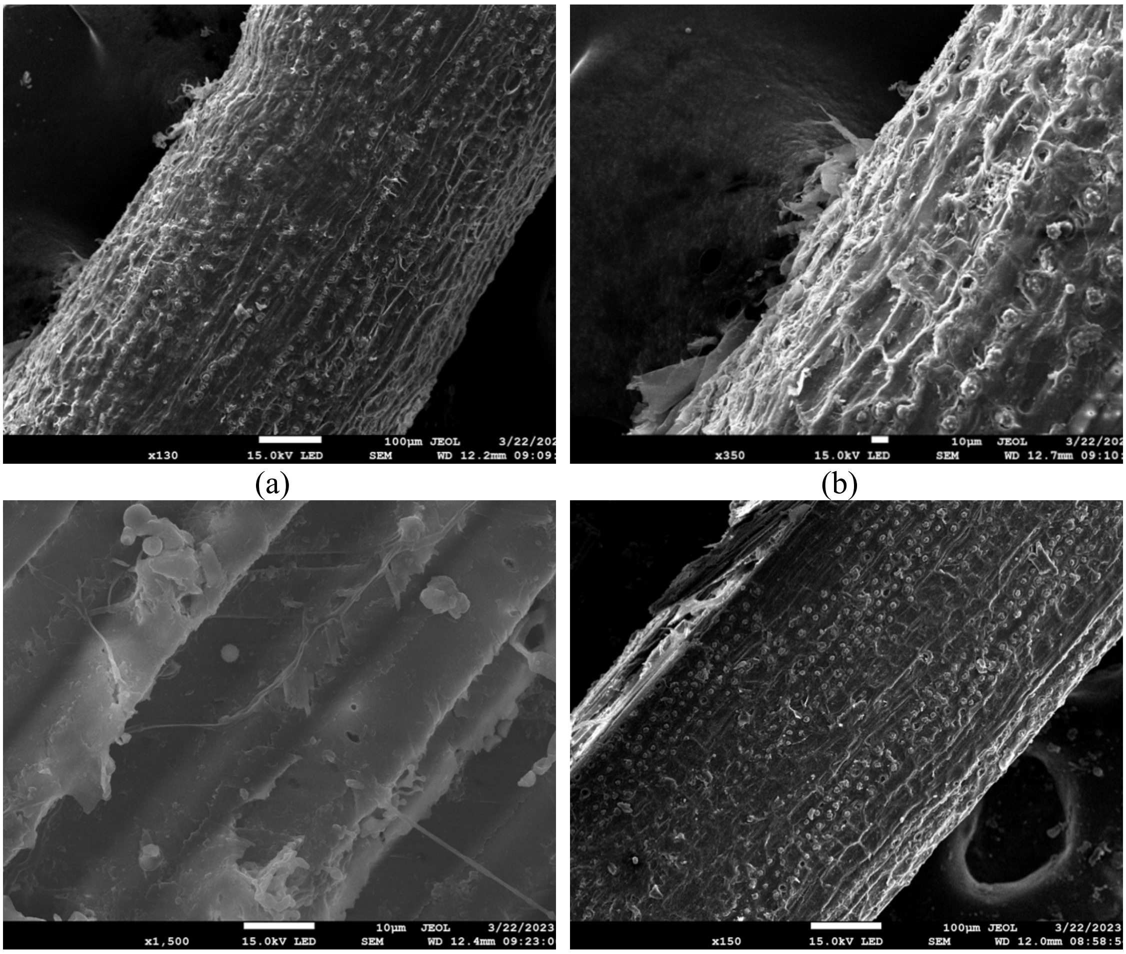
(a) (b)

(c) (d)

Source: Mylena Uhlig Siqueira

In the SEM of the natural coconut fiber, it is possible to visualize greater dirtiness, it is hypothesized that through analysis the deposited material is organic, of the choir itself as pectins already visualized in literature. Therefore, the retted fibers have a more rough and porous structure visually (**Figure 62**).

Figure 62. SEM images of the longitudinal section of green retted coconut fiber (*Cocos nucifera*) with magnification and scale



(a) (b)

(c) (d)

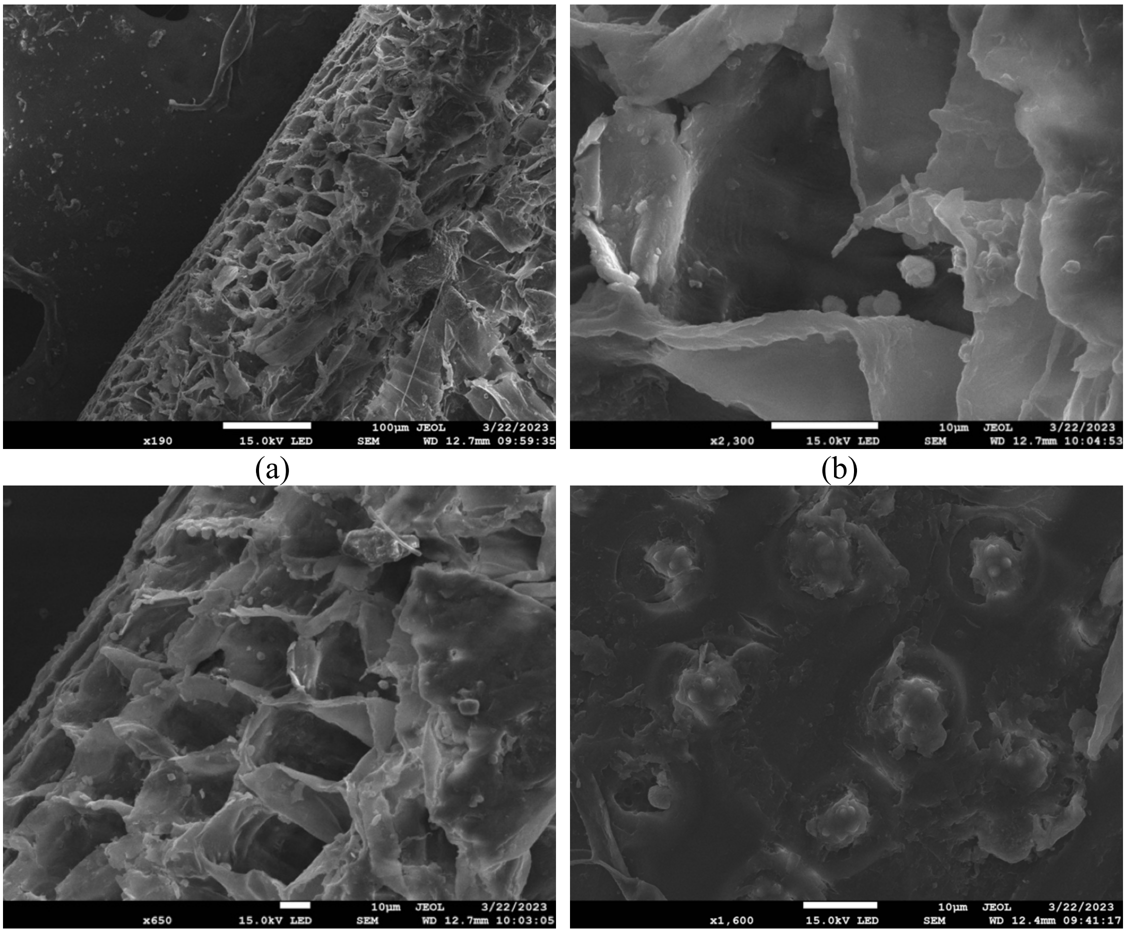
Source: Mylena Uhlig Siqueira

The grooves, porosities and bulges that were previously observed in the optical microscopy images could be seen more clearly here and identified as uniformly distributed formations along the entire surface of the fiber.

6.6.5.2.Cross-sectional view

The SEM reveals several remarkable aspects of the structure and composition of coconut fibers. The fibers have numerous pores and channels along their surface, which make them excellent at absorbing liquids and gases, useful in various applications such as carpet making and water purification. Additionally, the surface of the fibers has scales and grooves that enhance their grip and strength, making them suitable for products like ropes, nets, and baskets. Furthermore, SEMs show the internal structure of coconut fibers with a complex network of interwoven fibers that give them strength and durability. This matted structure also helps to hold the fibers together, even under extreme wear and tear, highlighting a highly functional and complex structure with absorption channels, adhesion scales and grooves, and interwoven fibers for durability and strength (**Figure 63**).

Figure 63. SEM images of the cross section of the green coconut fiber in natura (*Cocos nucifera*) with magnification and scale.

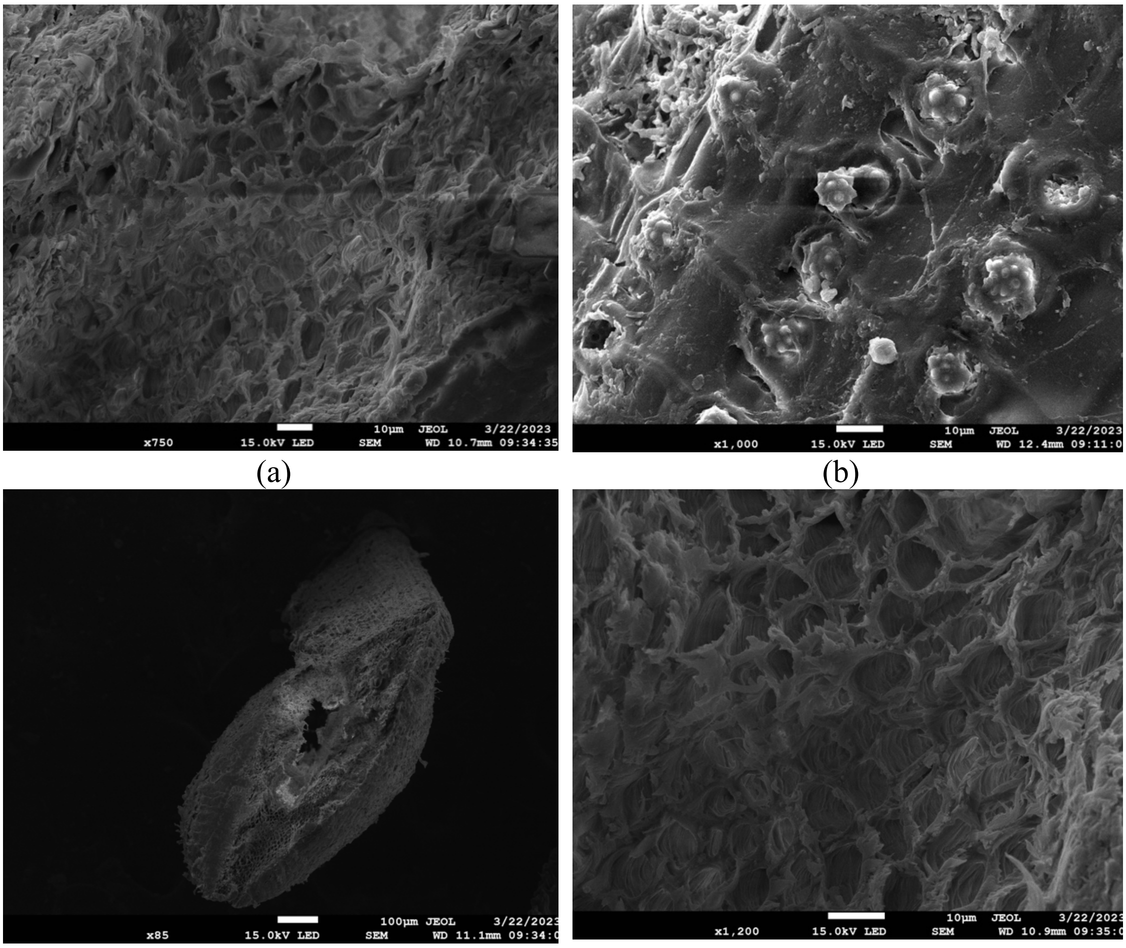


(a) (b)

(c) (d)

Source: Mylena Uhlig Siqueira

Figure 64. SEM images of the cross-section of green retted coconut fiber (*Cocos nucifera*) with magnification and scale.



(a) (b)

(c) (d)

Source: Mylena Uhlig Siqueira

The hypothesis that differs between the cross-sectional SEM images of fresh coconut fiber and retted coconut fiber is the more organized cell structure of the first compared to the second, which presents cells and tissues that are more separated and disorganized. In natura coconut fiber, the cell wall is thicker and the cells are arranged in concentric layers, while in retted coconut fiber, the cell wall is thinner and less organized, with possible irregularities and deformations. This difference can affect the physical and mechanical properties of the fiber, influencing its use in different applications (**Figure 64**). Observing the fiber, it is possible to notice the presence of different types of cells organized in a regular arrangement, presenting a large central gap. These cells are almost circular, similar to those found in coir fibers from other countries. However, unlike previously reported Brazilian fibers, this fiber has scanning electron micrographs that show the fiber's longitudinal section and tensile failure surfaces. Although some surface defects are visible, the fracture surfaces indicate a ductile fracture (SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b; TOMCZAK; SATYANARAYANA; SYDENSTRICKER, 2007; TOMCZAK; SYDENSTRICKER; SATYANARAYANA, 2007b).

6.6.6. Density

The main results of the coconut fiber density test are presented in **Table 14** and **15** the totality of measurements in **Appendix E.**

Table 14. Natural coconut fiber density.

	P1 (PSI)	P2 (PSI)	Vc (cm^3)	Vr (cm^3)	Vp Sample (cm^3)	Mass (g)	**Density** (g/cm^3)
Average	17.654	6.015	11.620	5.840	0.3199	0.3187	0.996423
Standard Deviation	0.180	0.060	0.000	0.000	0.0039	0.0000	0.012321

Source: Mylena Uhlig Siqueira.

According to Pickering (2008), all natural fibers have, in general, a cell wall density of about 1.5 g/cm^3 and, therefore, the density of coconut fibers is considered low compared to other plant fibers.

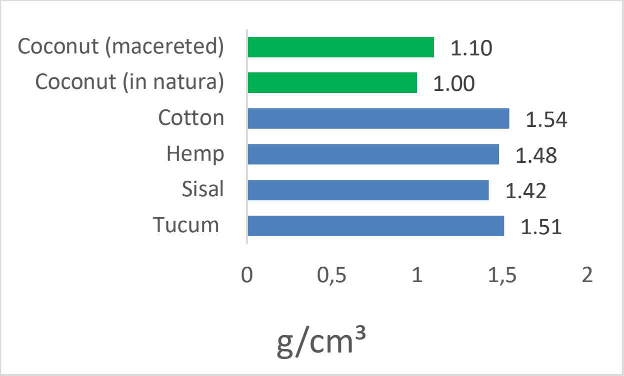
Table 15. Retted coconut fiber density.

	P1 (PSI)	P2 (PSI)	Vc (cm^3)	Vr (cm^3)	Vp Sample (cm^3)	Mass (g)	**Density** (g/cm^3)
Average	17.683	6.096	11.620	5.840	0.5199	0.5708	1.098476
Standard Deviation	0.216	0.073	0.000	0.000	0.0117	0.0000	0.024678

Source: Mylena Uhlig Siqueira.

Below, **Figure 65** presents density values of other fibers of recognized textile use (AL-OQLA; SALIT, 2017), by way of comparison.

Figure 65. Comparative graph of plant fiber densities.

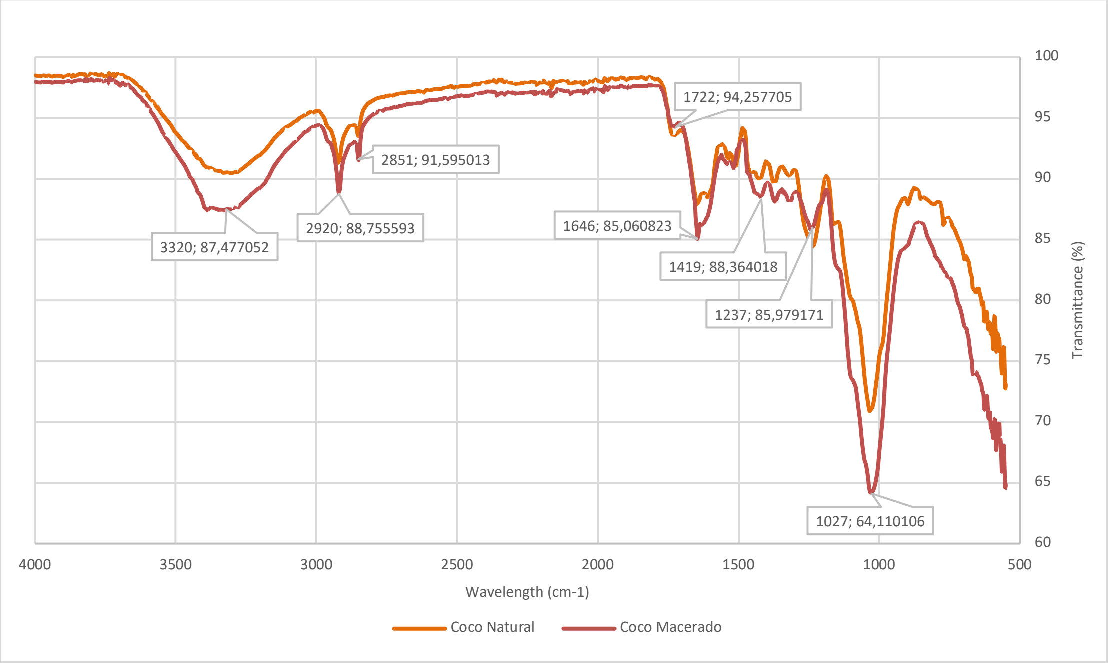


Source: Coconut- Mylena Uhlig Siqueira. Other Fibers-Adapted from PENNAS (2019).

6.7. FTIR

The spectra obtained in the FTIR test of the coconut fiber in natura, as well as the spectra of the retted coconut fibers can be seen in **Figure 66**.

Figure 66. FTIR of green in natura and retted coconut fiber (*Cocos nucifera*)**.**



Source: Mylena Uhlig Siqueira.

By analyzing the FTIR spectra of natural and retted coconut fibers, it is possible to identify the absorption bands corresponding to the chemical components present in the fibers, such as cellulose, hemicellulose and lignin. When comparing the spectra, differences in the absorption bands can be observed, which indicate chemical changes in the materials due to the steeping process. These differences can affect the physical and chemical properties of coconut fibers and their applications in different industry sectors. Analyzing the results and based on the literature, it is possible to perceive the similarity between the spectra of the compared fibers and, therefore, confirm the presence of cellulose, hemicellulose and lignin in the studied fiber (SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b; TOMCZAK; SATYANARAYANA; SYDENSTRICKER, 2007; TOMCZAK; SYDENSTRICKER; SATYANARAYANA, 2007b).

6.8. Regain Content (Percent Moisture Recovery)

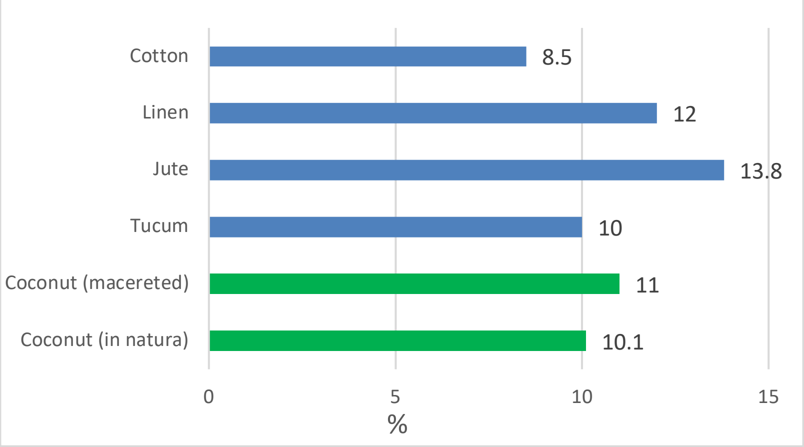
The Regain percentages obtained from coconut fibers are compatible with other cellulosic fibers of recognized textile use, as shown in **Figure 67** (KASWELL, 1963; MALUF; KOLBE, 2003).

Table 16. Determination of Regain content of green coconut fibers.

	Original mass (g)	Dry mass (g)	Regain (%)
Natural coconut	0.8637	0.7845	**10. 1%**
Retted coconut	1.0823	0.9748	**11.0 %**

Source: Mylena Uhlig Siqueira.

Figure 67. Comparison chart of Regain values.



Source: Coconut- Mylena Uhlig Siqueira. Other fibers –Adapted from PENNAS (2019).

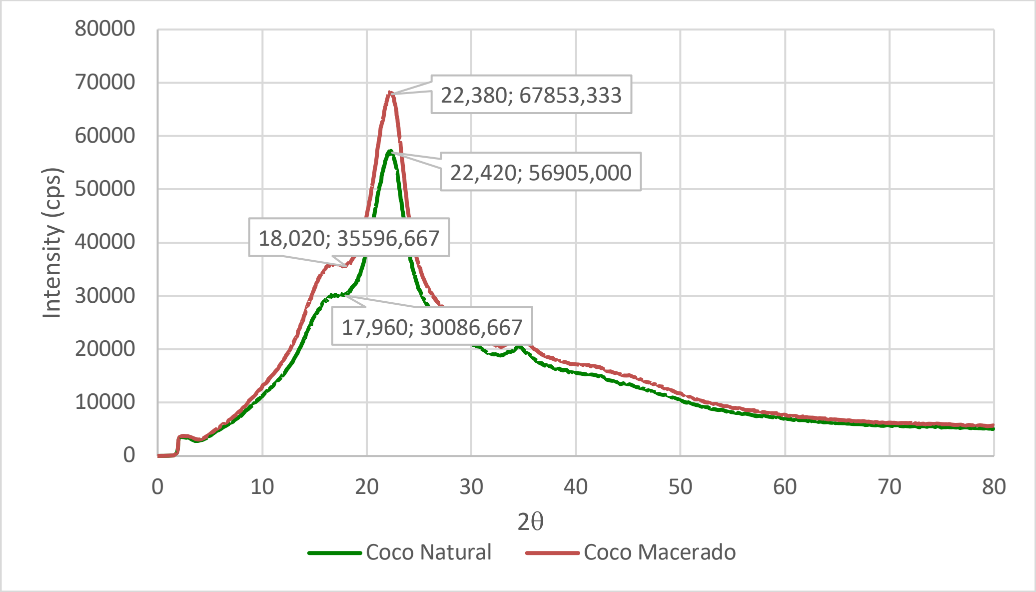
Fibers with greater moisture recovery capacity (regain), as a rule, owe this characteristic to the lower crystallinity of the cellulose. However, coconut fiber demonstrates a high degree of cellulose with amorphous orientation. Although flax and jute have a relatively high degree of crystallinity, their high regain results from the presence of non-cellulosic substances, especially hemicellulose and pectin, which are hydrophilic (**Table 16**) (REDDY; YANG, 2005a, 2005b, 2009).

6.9. X-Ray Diffraction (XRD)

With the data obtained by the diffractogram, the crystallinity index was calculated from DRX shown equation, resulting in a value of 47.1% for in natura coconut fibers and 47.5% for retted coconut.

The two calculated crystallinity indices are lower than the crystallinity percentage of cotton (60%). The crystallinity index is a measure of the structural order in a material, and when applied to textile fibers such as cotton, it indicates the proportion of crystalline (more ordered) regions in relation to amorphous (less ordered) regions in the fiber, which represents that coconut fibers have cellulose regions and have fewer crystalline regions than amorphous ones in their structure. This can affect its physical and chemical properties, such as strength, rigidity and transparency, for example. Textile fibers with a higher crystallinity index tend to have greater strength and stiffness, while fibers with a lower crystallinity index tend to be more flexible and absorbent. Other factors such as fiber purity, the length of the fibers and the way they are processed are also important in determining the quality and suitability of a textile fiber for different uses (**Figure 68**).

Figure 68. Comparative chart of Crystallinity Index values of coconut fiber



Source: Mylena Uhlig Siqueira

In item X, it was mentioned that fibers with high moisture recovery capacity (regain) may be related to lower crystallinity and size of cellulose crystals. However, the previous item demonstrated that the crystallinity index of coconut is lower than that of cotton, despite its percentage of regain being higher. This can be attributed to the presence of non-cellulosic substances, such as hemicellulose and pectin, in coconut fibers, which are hydrophilic and therefore increase the fiber's affinity for water. In addition, the scales in its structure can facilitate the absorption of water (REDDY; YANG, 2005a, 2005b, 2009).

The crystalline cellulose (microfibrils) considered as reinforcement, are helically wound in an amorphous matrix (lignin). The amount of cellulose and lignin and the helical angle of various fibers depend on their place of origin, maturity and species, as mentioned earlier. The X-ray diffraction spectrum of the coconut fibers used in the referenced studies demonstrates the peak associated with the crystalline part at 2h = 22°. The crystallinity index of coconut fibers calculated using this spectrum is 57%, compared to 44%, being similar to the results of analyzes carried out for both fiber arrangements (SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b; TOMCZAK; SATYANARAYANA; SYDENSTRICKER, 2007; TOMCZAK; SYDENSTRICKER; SATYANARAYANA, 2007b).

6.10. Thermogravimetric Analysis (TGA)

According to the methodology developed by Bouchard, Léger and Chornet (1986) for lignocellulosic materials, the events (peaks characterized by inflection points) in the DTG curves can be associated with processes that occur to the different constituents of the analyzed material. Thus, in many cases, the approximate composition of the analyzed lignocellulosic material can be estimated by comparing the TGA curves.

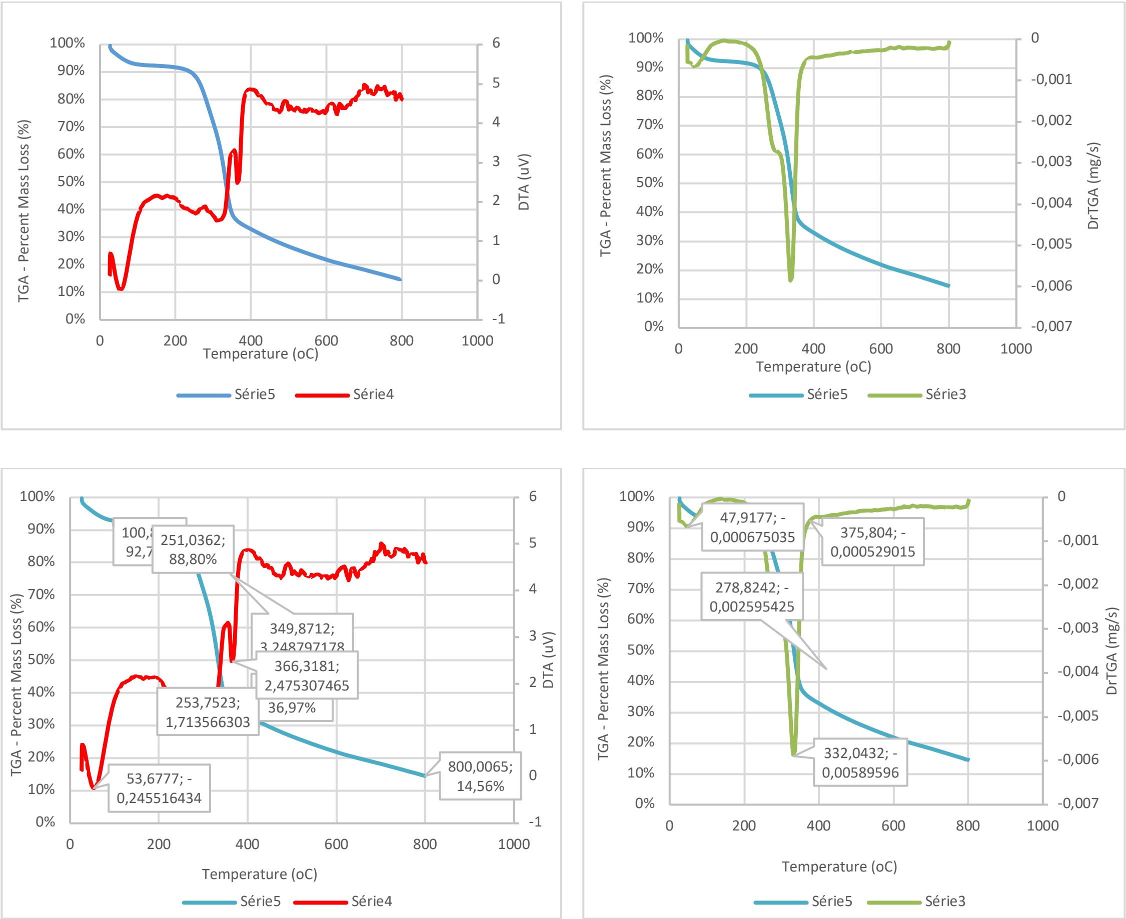
The analyzes are carried out by evaluating the moisture content, weight loss, time, temperature in the TGA graphs, as well as in its derivative (Derivative Thermogravimetry - DTG). In the DSC graphs, the initial and final temperatures of the peaks are analyzed and whether they are endothermic or exothermic (SOULTANIDIS; BARRON, 2009).

Analyzing all the curves, three events can be observed. The first event occurs between ambient temperature and 100°C and can be attributed to moisture loss. The second event can be observed between approximately 100°C and 200°C and can be attributed to the loss of hemicellulose + alpha cellulose. The third event takes place from 200°C to 360°C, total cellulose degradation. Subsequent events up to the stipulated temperature of 800°C correspond to the degradation of lignin, such as mineral material, remaining extractives.

Thus, from this analysis, relating the events at certain temperatures with the corresponding mass loss, it was possible to obtain the approximate amounts of these constituents of the natural and retted coconut fiber, shown in **Figure 69**.

For Natural coconut, in the range from 0 to 100C, only moisture loss close to regain values (10.5%) is expected. Experimentally, an approximate loss of 7.0% was estimated, a very consistent value since the sample was placed in the equipment under ambient conditions and not the standard conditions for determination of regain. The estimated value for hemicellulose was 4.0%. The estimated value for alpha-cellulose was 52.0%. The estimated value for lignin was 37.0%. It is observed that at 800oC there was still no decomposition of 14.5% of the sample. Possibly, these are fractions of lignin that are more resistant to thermal decomposition and/or ash (inorganic part of the sample). No "artifact" was observed, that is, any contamination of the sample with any element foreign to the analysis, such as, for example, a grain of dust or an insect that entered the analysis crucible. Visible in **Figure 69**:

Figure 69. TGA results for green in natura coconut fiber.

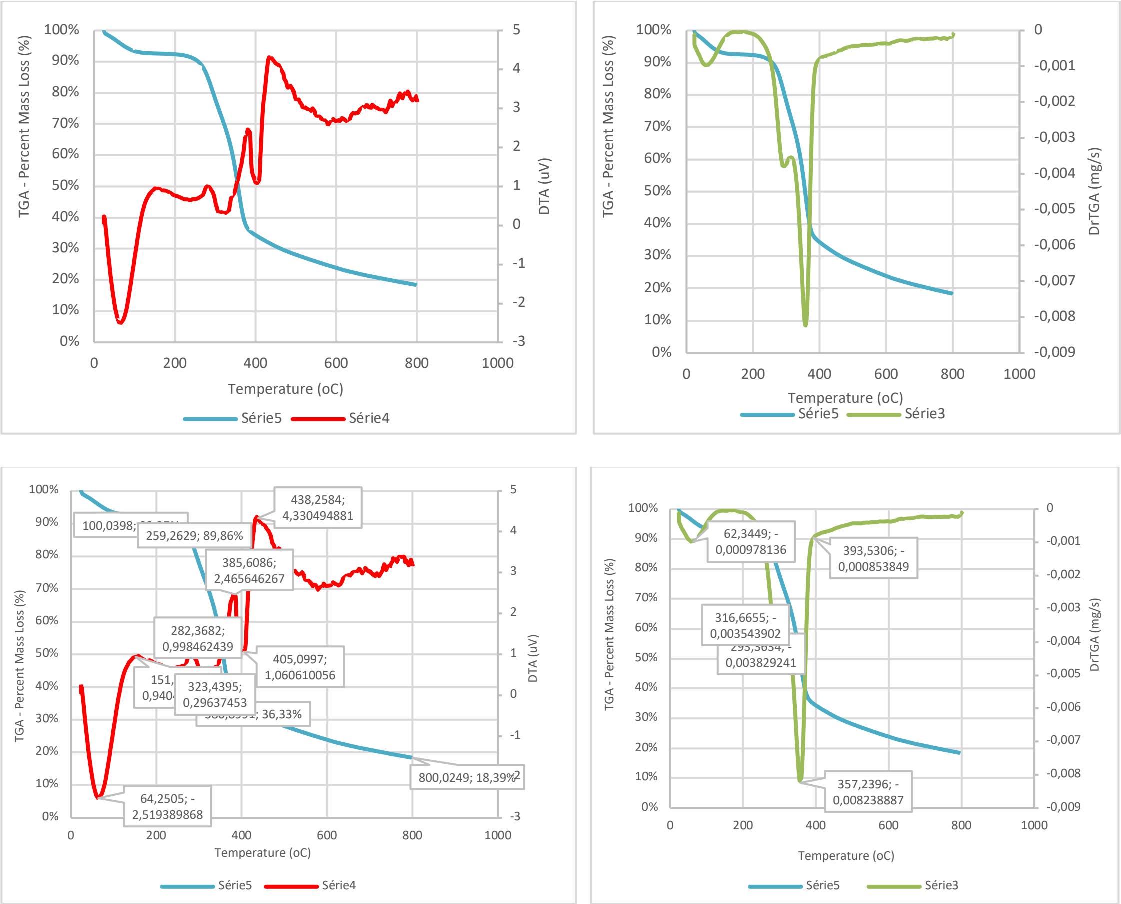


Source: Mylena Uhlig Siqueira.

In the range from 0 to 100oC, only moisture loss close to regain values (10.5%) is expected. Experimentally, an approximate loss of 6.5% was estimated, a very consistent value since the sample was placed in the equipment under ambient conditions and not the standard conditions for determination of regain. The estimated value for hemicellulose was 3.5%. The estimated value for alpha-cellulose was 53.5%. The estimated value for lignin was 36.5%. It is observed that at 800oC there was still no decomposition of 18.4% of the sample. Possibly, these are fractions of lignin that are more resistant to thermal decomposition and/or ash (inorganic part of the sample).

However, according to Satyanarayana et al. (2007), the carbonization of coconut fiber results in a greater mass loss when performed above 500 °C, and the residual mass obtained at the end of the process is around 16%. This residual mass can be attributed to the presence of silicon as confirmed in **Appendix G**, which is also present in other natural fibers. However, it is not possible to separate the different degradation processes of the fiber components (hemicellulose, cellulose and lignin) in the oxidative atmosphere, due to the complexity of the reactions that occur in this temperature range (220-350°C) (SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b; TOMCZAK; SATYANARAYANA; SYDENSTRICKER, 2007; TOMCZAK; SYDENSTRICKER; SATYANARAYANA, 2007b).

Figure 70. TGA results for retted coconut fiber



Source: Mylena Uhlig Siqueira

There are no significant differences in the values of the components of green coconut fiber in natura and retted fiber (**Figure 70**).

Table 17. Comparison of estimated concentrations of hemicellulose, α-cellulose and lignin in other lignocellulosic fibers.

Fiber	**Holocellulose (%)**		**Lignin (%)**
	Cellulose/alpha-cellulose (%)	Hemicellulose (%)	
Green Coconut in natura	**52.0**	**4.0**	**37.0**
Green Retted coconut	**53.5**	**3.5**	**36.5**
Bagasse (sugar cane)	54.3–55.2	16.8–29.7	25.3–24.3
Tucum	68.4		21.7
Buriti	65–71		21–27
Tururi	74.1	12	31.1
Sisal	65–67	12	9.9
Curauá	71-74	9.9-21	7.5-11

Source: Coconut- Mylena Uhlig Siqueira. Other Fibers-Adapted from PENNAS (2019) and (SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b).

Compared to other fibers, including three other palm fibers (Tucum - Astrocaryum chambira Burret; Buriti -Mauritia flexuosa Mart and Tururi - Manicaria saccifera Gaertn) and two other leaf fibers (sisal - Agave sisalana and curauá - Ananas erictifolius), the percentages of the constituents show variation among themselves, demonstrating greater similarity with the bagasse/sugarcane bark fiber (**Table 17**)

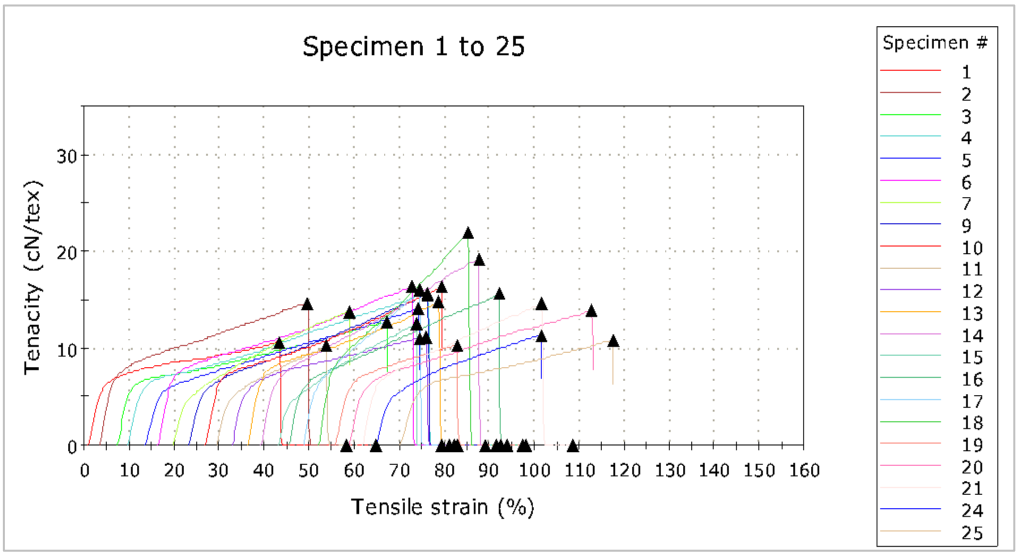
6.11. Breaking Load (N) and Elongation (%)

The dynamometer test generates the graphs shown **in Figures 71 and 72** Tenacity x Elongation, where each line represents a tested fiber and its peak, marked by a triangle sign, represents where the fiber broke, as shown in the example below (**Figure 71 and 72**).

The table with Maximum load values (N); Breaking Load (N); Breaking toughness (cN/Tex); Maximum elongation (mm); Elongation at break (mm); Percent elongation at break (%) and Young's Modulus (N/Tex), also generated by the software, is complete in **Appendix F**, and summarized (mean, standard deviation and CV%), in **Tables 18 and 19**.

A total of 114 fibers were tested for each sample (in natura fiber and for retted fiber) and the graphs are divided into 4 (from 25 to 25) (**Figure 71 and 72**).

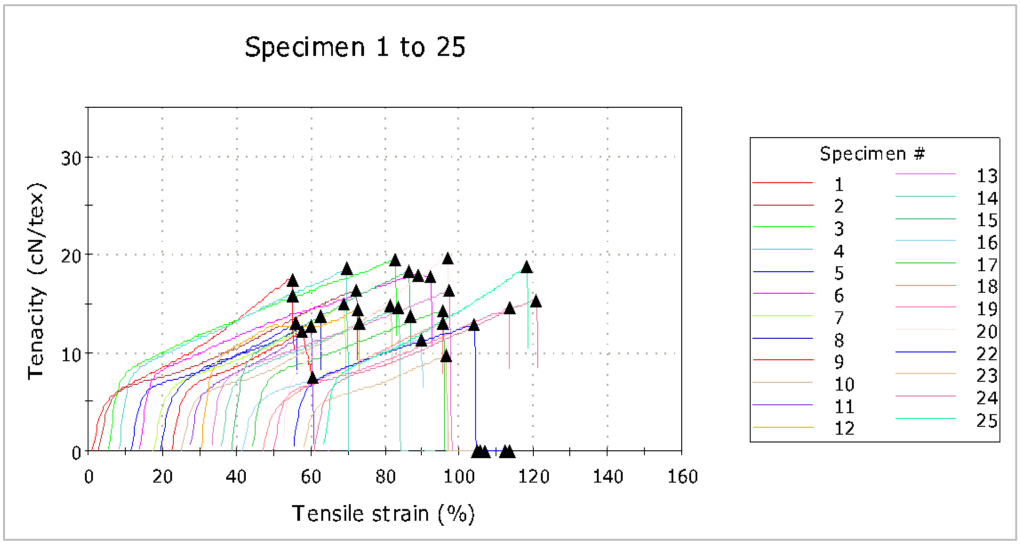
Figure 71. Tenacity x Elongation curve - Natural coconut fibers (from 1 to 114/51-75)



(51 – 75)

Source: Mylena Uhlig Siqueira

Figure 72. Tenacity x Elongation curve – Retted coconut fibers (from 1 to 114/1-25)



(1 – 25)

Source: Mylena Uhlig Siqueira

Table 18. Mechanical properties of natural coconut fiber.

	Maximum Force (N)	Tenacity at Maximum Force (cN/tex)	Extension at Maximum Force (mm)	Elongation (%)	Young's Modulus (N/tex)
Average	9.28	14.40	11.39	45.55	0.865
Standard deviation	5.397	3.405	3.144	12.577	0.3079
CV%	58.2%	23.6%	27.6%	27.6%	35.6%

Source: Mylena Uhlig Siqueira.

Table 19. Mechanical properties of retted coconut fiber.

	Maximum Force (N)	Tenacity at Maximum Force (cN/tex)	Extension at Maximum Force (mm)	Elongation (%)	Young's Modulus (N/tex)
Average	11.19	14.16	13.19	52.75	0.721
Standard deviation	4.948	3.938	2.926	11.703	0.2800
CV%	44.2%	27.8%	22.2%	22.2%	38.8%

Source: Mylena Uhlig Siqueira.

The main values obtained (Toughness, % elongation and Young Modulus) were compared with results from fibers of recognized textile employability. This comparison is shown in **Table 18 and 19**.

lignocellulosic fibers, when subjected to mechanical tests, such as coconut, present elastic behavior at high test speeds, with the crystalline region supporting most of the applied load, resulting in greater tensile strength and Young's modulus. At lower test speeds, the fiber behaves like a viscous liquid, with the amorphous region carrying the load, resulting in a low modulus. Tensile strength is more sensitive to velocity than Young's modulus, and the increase in strength can be explained by the increase in velocity. Furthermore, the tensile strength and Young's modulus may not change with increasing speed, as the crystallinity index of coconut fibers approaches 50%, similar to the results demonstrated in **Table 20** (SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b; TOMCZAK; SATYANARAYANA; SYDENSTRICKER, 2007; TOMCZAK; SYDENSTRICKER; SATYANARAYANA, 2007b).

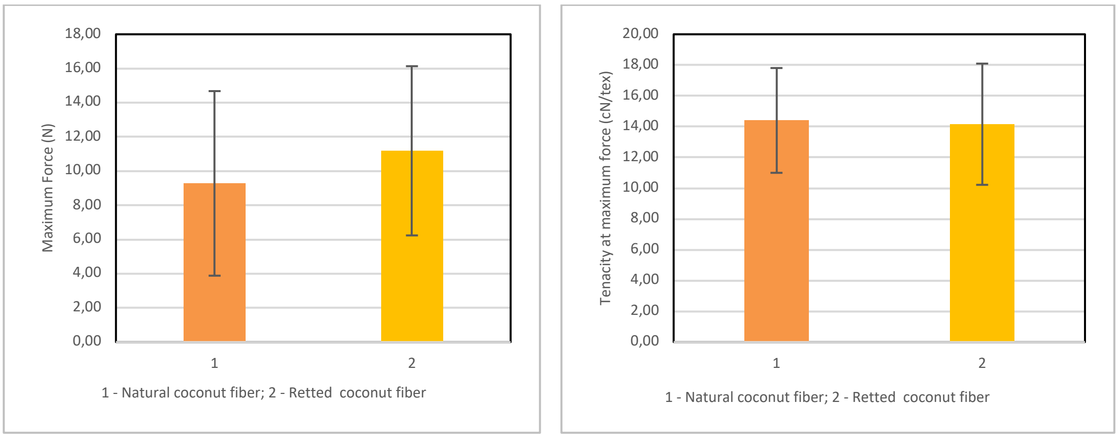
Table 20. Comparison with other fibers - Tenacity/Elongation/Young Modulus

	Tenacity (cN/Tex)	**Elongation (%)**	**Young Modulus (N/Tex)**
Green Natural Coconut	14.40	45.55	0.865
Green Retted Coconut	14.16	52.75	0.721
Tucum	37.44	6.57	8.254
Cotton	26.5 - 43.4	3 -- 7	5.3 - 6.2
Linen	23.0 - 68.0	2.7 - 3.3	15.5
Hemp	51.2 - 60.0	1.8	19.4
Jute	26.5 - 51.2	1.7 - 2	17.9
Sisal	35.3 - 44.1	2 --3	12.4
Polyester	38.8 - 44.1	14 - 25	1.6 - 3.2

Source: Coconut – Mylena Uhlig Siqueira. Other Fibers – PENNAS (2019)

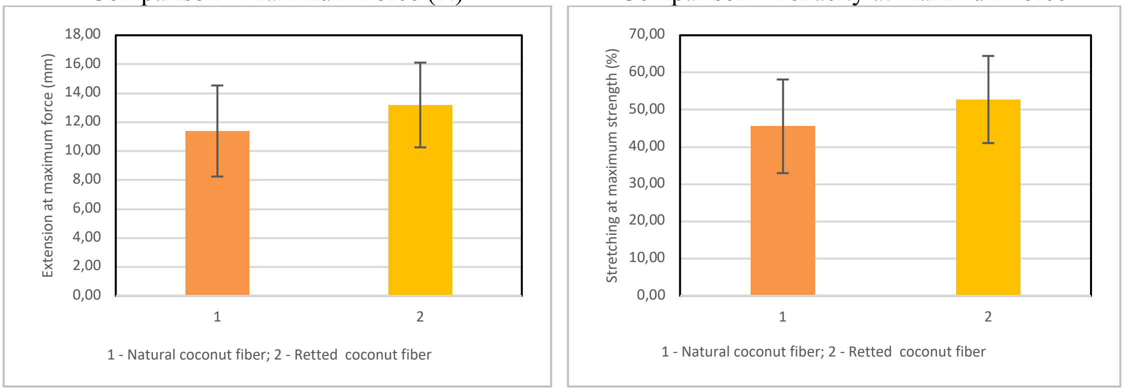
Elongation is far superior to all, including that of sisal, a leaf fiber that has been showing characteristics very similar to tucum, such as tenacity, crystallinity index, percentage of constituents and regain. Polyester fiber was placed only as a representative of synthetic fibers (**Figure 73**). Coir fiber has good resistance to moisture and chemicals, making it suitable for use in humid environments. Abrasion resistance is average compared to other natural fibers. In general, coir fiber is a viable option for use in fabrics and textiles, especially in applications where moisture and chemical resistance is important.

Figure 73. Comparative tensile Graphics



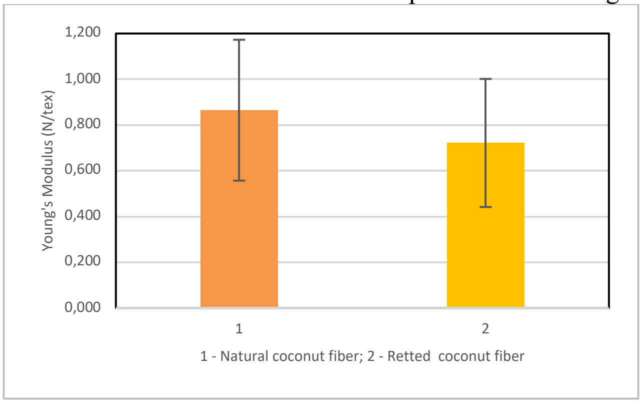
Comparison - Maximum Force (N)

Comparison - Tenacity at maximum force



Comparison - Extension at maximum force

Comparison - Stretching at maximum strength



Comparison - Young's Modulus

Source: Mylena Uhlig Siqueira

By analyzing the mean plus or minus standard deviation graph, it is observed that there is no statistically significant difference between the values of maximum strength; mean tenacity at maximum strength; extension at maximum force; elongation at maximum force and the mean Young's Modulus between natural coconut fibers and retted coconut fibers.

According to other studies of tests and different authors, it was verified that a hypothesis to be discussed is that the tensile strength (TS) and the Young's modulus (YM) of these coconut fibers may tend to decrease, while the percentage (% strain at break remained constant as fiber diameter increased. Those lignocellulosic fibers exhibit viscoelastic behavior when subjected to deformation under load, and the applied load is initially shared by the crystalline region (represented by the spring) and by the amorphous regions (represented by the trace) of the fiber. The resistance to deformation in the low-tension region is determined by the microfibrillar angle and is called the initial modulus of the fiber, which varies according to the age, origin, extraction method and fiber maturity. in the module values can be explained by the test conditions used in different studies (SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b; TOMCZAK; SYDENSTRICKER; SATYANARAYANA, 2007b).

6.12. Summary of Results

The textile fiber characterization parameters are summarized in **Table 21,** in order to facilitate visualization.

Table 21. Characterization of coconut fibers *(Cocos nucifera)*

Characterization of Green coconut fibers (Cocos nucifera)	**In Natura**	**Retted**
Length (cm)	11.7	12.3
Count number (Text)	65.1	80.3
Density (g/cm³)	1.00	1.10
Cell diameter (µm)	15.5	16.6- 18.7
% Regain	10.1	11.0
Crystallinity index (%)	47.1	47.5
% Cellulose	56.0	57.0
% lignin	37.0	36.5
Tenacity (cN/Tex)	14.4	14.1
% Stretching	45.5	52.7
Young Module (N/Tex)	0.865	0.721

Source: Mylena Uhlig Siqueira

7. FINAL CONSIDERATIONS

In view of the development of the research, some perceptions regarding the study were understood, such as its subjectivities and technical issues. It is important to relate them to the study of the materials and their characterizations due to all the social aspects that involve the historical cultivation, management of the coconut and families involved in its agriculture and maintenance.

In order to cover subjective aspects of the relationship between agro-industrial waste and the object of study, it is understood that agribusiness must be strengthened with the use of the best market knowledge, the collection and democratization of statistical data, in addition to strategic alliances with external capital to improve the raw material. Investments in science, technology, materials development, technology transference should be made to create and maintain a large number of jobs in all fiber producing areas, ensuring the livelihood of many families in both rural and urban areas which depends on the creation of new business opportunities and technological options. Especially for the development of the main natural fiber producing areas, such as the North and Northeast of Brazil.

The development of the necessary infrastructure for the transport of fibers and their products, in addition to the involvement of projects and organizations to guide small producers and agricultural companies, discover markets, offer new technological options and value the dimension of natural products with sufficient funds are important aspects to consider. The demand is not equated with the effective deployment of agricultural/industrial units, due to the lack of technological support units at an appropriate scale, leading to risks for entrepreneurs. If these problems are properly addressed, lignocellulosic materials can cause drastic changes in the socioeconomic development of countries as Brazil (CARDONA ALZATE; ORTIZ-SANCHEZ; SOLARTE-TORO, 2023; SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b; TOMCZAK; SYDENSTRICKER; SATYANARAYANA, 2007b).

As large amounts of these fibers become available, it is important to systematically characterize all types of properties, including chemical, physical, mechanical and textile properties, using available and accessible technology and multidisciplinary tools. This exercise would allow the use of fibers in both the textile and non-textile sectors. There is a needed market to gain the attention, including entrepreneurial skills, which make these fibers the best options for agriculture - economic diversification in developing countries.

When it comes to the technical qualities shown below, the physical and chemical characteristics of coconut fiber are essential for the development of any product from it, but they are not the only aspects to be taken into account when an application is sought/studied. Cultural aspects are inseparable and the way in which traditional people deal with the species and with this fiber must be respected, valued and maintained, and added to the research in question as used in companies such as AMAFIBRA.

The wide variety of studies point to coconut fiber as a bio sorbent material and energy generator, as its application is not vast in the textile industry. However, its best receptivity as a material so far in the area of Design has been from reinforcement and aesthetically designer composites. In areas where the fiber itself is not used, its compositions such as cellulose and lignin are used as binders and in various forms and functions in the sector. In this way, it can be understood that coconut fibers have specific characteristics comparable to fibers that make them ideal for the development of composite materials and, consequently, for an expansion of their use.

From the results of the irregular normal, it becomes more evident the different populations of fibers existing in the coconut, which influence the total result of its analysis. The different fiber locations influence the length and structure and the results when analyzed individually. However, this difference is greater when it comes to retted fibers due to the greater ease of taking samples after the retting process, which influences the difference in tenacity between both, due to the greater variability of fibers, the tenacity of the retted fiber is lower than the fiber in natura, despite its greater elongation. All these characteristics influence how the results can be analyzed an applicated in materials and engineering design.

Although comparative results between the retting processes are not significantly distant, it is noted in the literature, the need for more studies related to the practice of extraction and removal of the fiber in Brazil, the information obtained from reference countries such as India, and available methods are intended for small communities and social projects. To exemplify the issue, while the fibers used in this work were extracted manually after a period of 1 month, the fibers of other important studies were extracted in different ways, such as mechanically using green coconuts in the three days following their collection on the beaches where they had been used for its water (Private Communication with EMBRAPA), those used by other researchers, were from similar barks, but extracted after retting in water for 4 months (TOMCZAK; SATYANARAYANA; SYDENSTRICKER, 2007). Despite the great literary and research benefit that the divergent forms add to the subject, there is a difficulty in the process of standardizing comparative analyzes in terms of performance and performance with other authors (SATYANARAYANA; GUIMARÃES; WYPYCH, 2007b)

It is important to point out that since it is a Brazilian lignocellulosic fiber, it has mechanical values that are within the range reported for various natural fibers in other locations, differing from whose nature the fiber is the main explanation for the difference.

The transdisciplinary look contributed to the first researches on the fiber of coco, which is based on the first contributions made by renowned Brazilian researchers, who observe that there is the possibility of using the regional raw materials, close to processing sites, such as waste agro-industrial sectors, in order to contribute to stimulate an environmental, social and regional economic, in which the benefits are intangible, propagating significant systemic changes of these actors allied to environmental preservation and . This research was of great value for a better understanding of the value of the relationships of this Brazilian residual material and its performance. It is understood that transdisciplinary research can contribute and improve relations between these actors.

Future contributions should be directed towards connecting institutions academic institutions, researchers, private organizations and the textile sector with the aim of creating truly effective solutions with less impact on the environment and its actors, with thorough investigation of the facts.

As suggestions for future work, this author proposes:

- Research the origins and how this knowledge is formed in different countries, and how the relationships of its actors with the local environment, with the broader traditional market, and what are their possible barriers and challenges faced. Also research what it would take to preserve its values, improve its internal and external relations, and contribute for a unified value, respecting the characteristics of this environment;

- Mapping of partner companies in the distribution of coconut waste and Coconut Institutions/Cooperatives existing in Brazil and their potential for use (environmental, food, technical, biotechnological, textile, etc.);
- Comparisons between other industrial textile processes for non-woven fibers conventional (such as jute, sisal) and verify the possibility of adapting these processes applied to coconut fiber in terms of processing and other possibilities;
- Thoroughly investigate the fiber extraction and removal processes carried out in Brazil
- Use characterizations and tests for each fiber population with the most in-depth study of its applicability in the design and textile sector.

8. CONCLUSION

The employment of fibers from residual agricultural biomass is a cheap, accessible, and widely available alternative, constituting a model for adding economic value to the agro-industrial chains of the Brazilian main crops. The analysis of the scientific literature database reveals that research on the recovery and relocation of agro-industrial materials in the textile industry still shows incipient advances in Brazil. The main areas identified address materials such as dye bio sorbents from industrial effluents and reinforcement material in composites. In general, researches on natural fibers represents further advances in sugarcane, coconut, banana and pineapple, which are already employed as fibers in these studies. Materials such as açai, rice, wheat and corn are highlighted for obtaining the raw fiber of the material, especially for reinforcing composites. Furthermore, all other agro-industrial materials are investigated to obtain cellulose nanofibers.

Coconut fibers stand out due to their intense abundance of residues, and their physicochemical properties of high quality, low cost, low density and biodegradability Despite being well known fibers, the industrial applicability of fibers in Brazil is small, almost null in the textile sector, while availability is growing. Alternative technologies are generally not introduced to the domestic fiber industry, such as coconut, so far, neglecting their potential to expand an effective research structure, at a possible technological disadvantage compared to other cultures in the country. The coconut crop has great potential for adapting to different crops (as cocoa and coffee) and climate and soil conditions, an important characteristic for small farmers with limited area.

The researches directed to the textile industry presents a larger incidence focused on treating effluents than applied to new materials, constituting scientific opportunities. Thus, scientific investment in researches on materials and technology development are necessary to provide applications that could meet current and future demands and expand the scope of new materials for sustainability.

The main values found from the characterization of green in natura coconut fibers were: length: 11.7 ± 1.5 cm; regain: 10.1%; Crystallinity index: 47.1%; tenacity: 14.4 ± 3.4 cN/tex; elongation: 45.6 ± 12.6%; Young Modulus: 0.865±0.308 N/tex; from the TGA analyses, the estimated values of the percentage of the constituents were 56.0% cellulose and 37.0% lignin. For values found from the characterization of green retted coconut fibers were: length: 12.3 ± 1.6 cm; regain: 11.0%; Crystallinity index: 47.5%; tenacity: 14.2 ± 3.9 cN/tex; elongation: 52.8 ± 11.7%; Young Modulus: 0.721 ± 0.280 N/tex. From the TGA analyses, the estimated values for the percentage of constituents were 57.0% cellulose and 36.5% lignin. These results are in line with other clinical and mechanical data on coconut fiber found in the literature.

In the long EDS analysis of green coconut fiber, in Appendix G, it was possible to identify the granules deposited on the surface were silicon . According to the literature, the presence of pectinases, silicons are mainly suggested. Silicon is not a rare element in plants like palm trees, it has already been found in the leaves of the *Oenocarpus Mart*. palm tree (Arecaceae), for example.

The retting process was effective in facilitating the process of removing the fibers in manual extraction, however, there were no significant comparative results between both fibers in the time and conditions of the experiment used. However, in SEM analyzes on the longitudinal surface and cross-section, an aspect of greater roughness in the fibers after the submitted process is noticed. In its mechanical properties, it is possible to observe the influence of the grinding process and ease of removal of the fibers when the normality of the fibers in their tenacity and tex in their final applicability. In future projects, it is appropriate to apply them in composite materials or subject them to new tests to measure adhesion and adaptability.

Of the fiber producing countries, Brazil appears with great development in the area of technological research and production. Despite the development of the study of fiber, there is no transfer of technology at its maximum potential for the elaboration and distribution of products in the Design sector, such as the textile industry. Initiatives by researchers in terms of Design were observed, but the commercial use of fiber on a large scale and in material processing cooperatives does not cover its use in its entirety. The fiber products sold are aimed at the area of geotextiles, upholstery and gardening. The way to highlight the use of the fiber in the textile and clothing industry is Woocoa, patent for the production of coconut fiber with hemp in the production of a vegan wool.

The researches directed to the textile industry presents a larger incidence focused on treating effluents than applied to new materials, constituting scientific opportunities. Thus, scientific investment in researches on materials and technology development are necessary to provide applications that could meet current and future demands and expand the scope of new materials for sustainability.

After comparing green coconut fiber with other textile fibers of recognized use can provide directions for possible applications of coconut fiber. However, additional issues were addressed, such as the residual agro-industrial origin, future perspectives and technical parameters associated with coconut fibers. This allows coconut fiber to be considered an alternative raw material to conventional ones for various purposes, with the aim of providing a solid basis for future studies and development of new applications.

Lastly, efficient management, based on sustainable criteria, of agro-industry wastes, requires urgent programs to evaluate methods and new possibilities in the short and long term. The development of appropriate technologies for these processes reduces the sector's negative impacts and increases its eco-efficiency, generating ecological benefits on several fronts, from land use and waste, as well as greater management of the extraction of non-renewable resources. All reported results contributed to understanding of the potential use of agro-industrial waste in the generation of industrial textile products in agreement with other industries.

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APPENDICES

APPENDIX A - COCONUT FIBER LENGTH DATA

	Natural Length (cm)	Retted Length (cm)
1.	12.4	14.5
2.	15.0	14.5
3.	10.7	15.0
4.	11.4	14.2
5.	12.5	11.5
6.	13.0	13.9
7.	11.3	12.0
8.	12.6	14.3
9.	11.5	15.1
10.	12.2	11.7
11.	11.5	11.9
12.	11.6	15.3
13.	12.4	15.0
14.	11.5	13.8
15.	12.0	13.0
16.	12.7	10.5
17.	10.5	14.3
18.	10.0	12.8
19.	10.9	13.5
20.	11.5	13.9
21.	11.0	13.0
22.	11.0	13.0
23.	12.0	12.9
24.	14.3	12.2
25.	10.9	13.0
26.	14.7	14.0
27.	13.5	13.5
28.	14.2	13.9

29.	10.8	14.0
30.	13.0	14.4
31.	9.8	11.5
32.	15.0	11.4
33.	12.2	14.4
34.	9.5	13.1
35.	10.5	12.2
36.	12.3	9.8
37.	12.0	11.5
38.	11.7	11.8
39.	11.6	11.6
40.	14.2	11.7
41.	10.5	13.7
42.	12.2	13.0
43.	12.5	11.8
44.	12.6	11.9
45.	10.6	16.0
46.	10.7	11.8
47.	10.1	12.8
48.	9.1	13.3
49.	12.8	11.4
50.	11.9	14.0
51.	12.4	10.9
52.	11.6	12.3
53.	13.3	12.3
54.	11.1	11.5
55.	10.4	12.9
56.	11.5	15.0
57.	14.6	12.4
58.	9.9	12.3
59.	9.8	13.5
60.	14.0	16.0
61.	11.3	11.0

62.	11.5	12.5
63.	13.5	11.3
64.	11.2	15.4
65.	11.8	12.7
66.	12.5	11.3
67.	13.2	13.0
68.	13.0	14.0
69.	11.8	12.9
70.	14.9	10.7
71.	12.8	12.9
72.	12.0	13.8
73.	12.4	11.1
74.	11.4	12.0
75.	12.0	11.7
76.	12.2	11.8
77.	14.8	9.6
78.	13.5	11.0
79.	11.7	11.6
80.	10.2	12.1
81.	13.3	12.4
82.	8.5	11.9
83.	10.5	14.2
84.	11.7	10.4
85.	11.9	11.5
86.	11.8	13.5
87.	12.0	10.2
88.	11.0	9.5
89.	10.2	11.0
90.	9.6	10.0
91.	11.3	11.7
92.	11.5	12.5
93.	9.3	12.0
94.	8.5	10.5

95.	8.7	12.4
96.	11.1	10.2
97.	11.2	10.4
98.	11.9	12.5
99.	13.5	10.0
100.	12.1	11.7
101.	11.2	12.8
102.	13.5	11.5
103.	8.5	11.5
104.	10.8	11.5
105.	11.5	10.4
106.	10.5	13.0
107.	10.3	10.8
108.	9.8	9.7
109.	12.0	10.9
110.	11.1	9.2
111.	12.3	11.3
112.	12.5	11.0
113.	9.6	8.5
114.	10.2	10.5
Average	**11.7**	**12.3**
Standard deviation	**1.45**	**1.55**
CV (%)	**12.4%**	**12.6%**

APPENDIX B - TEX COUNT NUMBER CALCULATION DATA

APPENDIX B .1- COCONUT FIBERS IN NATURA

	Sample Number	**Weight (g)**	**Length (cm)**	**TEX (g per 1000 m)**
	1	0.0061	12.4	**49.2**
	2	0.0132	15,0	**88,0**
	3	0,0069	10,7	**64,5**
	4	0,0041	11,4	**36,0**
	5	0,0034	12,5	**27,2**
	6	0,0044	13,0	**33,8**
	7	0,0080	11,3	**70,8**
	8	0,0025	12,6	**19,8**
	9	0,0069	11,5	**60,0**
	10	0,0132	12,2	**108,2**
	11	0,0108	11,5	**93,9**
	12	0,0115	11,6	**99,1**
	13	0,0082	12,4	**66,1**
	14	0,0029	11,5	**25,2**
	15	0,0131	12,0	**109,2**
	16	0,0103	12,7	**81,1**
	17	0,0062	10,5	**59,0**
	18	0,0043	10,0	**43,0**
	19	0,0107	10,9	**98,2**
	20	0,0091	11,5	**79,1**
	21	0,0070	11,0	**63,6**
	22	0,0132	11,0	**120,0**
	23	0,0109	12,0	**90,8**
	24	0,0118	14,3	**82,5**
	25	0,0038	10,9	**34,9**
	26	0,0209	14,7	**142,2**
	27	0,0087	13,5	**64,4**
	28	0,0154	14,2	**108,5**
	29	0,0055	10,8	**50,9**
	30	0,0053	13,0	**40,8**
	31	0,0072	9,8	**73,5**
	32	0,0268	15,0	**178,7**
	33	0,0062	12,2	**50,8**
	34	0,0044	9,5	**46,3**
	35	0,0059	10,5	**56,2**
	36	0,0043	12,3	**35,0**
	37	0,0135	12,0	**112,5**
	38	0,0042	11,7	**35,9**

	39	0,0070	11,6	**60,3**
	40	0,0103	14,2	**72,5**
	41	0,0021	10,5	**20,0**
	42	0,0120	12,2	**98,4**
	43	0,0027	12,5	**21,6**
	44	0,0154	12,6	**122,2**
	45	0,0027	10,6	**25,5**
	46	0,0030	10,7	**28,0**
	47	0,0032	10,1	**31,7**
	48	0,0050	9,1	**54,9**
	49	0,0069	12,8	**53,9**
	50	0,0122	11,9	**102,5**
	51	0,0105	12,4	**84,7**
	52	0,0046	11,6	**39,7**
	53	0,0166	13,3	**124,8**
	54	0,0062	11,1	**55,9**
	55	0,0088	10,4	**84,6**
	56	0,0062	11,5	**53,9**
	57	0,0135	14,6	**92,5**
	58	0,0057	9,9	**57,6**
	59	0,0034	9,8	**34,7**
	60	0,0089	14,0	**63,6**
	61	0,0025	11,3	**22,1**
	62	0,0075	11,5	**65,2**
	63	0,0064	13,5	**47,4**
	64	0,0023	11,2	**20,5**
	65	0,0074	11,8	**62,7**
	66	0,0029	12,5	**23,2**
	67	0,0015	13,2	**11,4**
	68	0,0023	13,0	**17,7**
	69	0,0098	11,8	**83,1**
	70	0,0157	14,9	**105,4**
	71	0,0060	12,8	**46,9**
	72	0,0131	12,0	**109,2**
	73	0,0110	12,4	**88,7**
	74	0,0125	11,4	**109,6**
	75	0,0082	12,0	**68,3**
	76	0,0030	12,2	**24,6**
	77	0,0123	14,8	**83,1**
	78	0,0090	13,5	**66,7**
	79	0,0041	11,7	**35,0**
	80	0,0060	10,2	**58,8**

	81	0,0115	13,3	**86,5**
	82	0,0060	8,5	**70,6**
	83	0,0065	10,5	**61,9**
	84	0,0055	11,7	**47,0**
	85	0,0213	11,9	**179,0**
	86	0,0080	11,8	**67,8**
	87	0,0050	12,0	**41,7**
	88	0,0063	11,0	**57,3**
	89	0,0061	10,2	**59,8**
	90	0,0055	9,6	**57,3**
	91	0,0080	11,3	**70,8**
	92	0,0083	11,5	**72,2**
	93	0,0063	9,3	**67,7**
	94	0,0051	8,5	**60,0**
	95	0,0042	8,7	**48,3**
	96	0,0089	11,1	**80,2**
	97	0,0084	11,2	**75,0**
	98	0,0033	11,9	**27,7**
	99	0,0200	13,5	**148,1**
	100	0,0117	12,1	**96,7**
	101	0,0085	11,2	**75,9**
	102	0,0037	13,5	**27,4**
	103	0,0050	8,5	**58,8**
	104	0,0050	10,8	**46,3**
	105	0,0082	11,5	**71,3**
	106	0,0076	10,5	**72,4**
	107	0,0049	10,3	**47,6**
	108	0,0081	9,8	**82,7**
	109	0,0085	12,0	**70,8**
	110	0,0046	11,1	**41,4**
	111	0,0039	12,3	**31,7**
	112	0,0049	12,5	**39,2**
	113	0,0028	9,6	**29,2**
	114	0,0019	10,2	**18,6**
Average	**-----**	**0,0078**	**11,7**	**65,1**
Sample Standard Deviation	**-----**	**1,45**	**1,45**	**32,78**
CV (%)	**-----**	**12,4**	**12,4**	**50,4**

APPENDIX B .2- RETTED COCONUT FIBERS

	Sample Number	**Weight (g)**	**Length (cm)**	**TEX (g per 1000 m)**
	1	0,0227	14,5	**156,6**
	2	0,0195	14,5	**134,5**
	3	0,0086	15,0	**57,3**
	4	0,0070	14,2	**49,3**
	5	0,0100	11,5	**87,0**
	6	0,0083	13,9	**59,7**
	7	0,0100	12,0	**83,3**
	8	0,0161	14,3	**112,6**
	9	0,0245	15,1	**162,3**
	10	0,0185	11,7	**158,1**
	11	0,0043	11,9	**36,1**
	12	0,0123	15,3	**80,4**
	13	0,0067	15,0	**44,7**
	14	0,0075	13,8	**54,3**
	15	0,0077	13,0	**59,2**
	16	0,0159	10,5	**151,4**
	17	0,0076	14,3	**53,1**
	18	0,0154	12,8	**120,3**
	19	0,0134	13,5	**99,3**
	20	0,0047	13,9	**33,8**
	21	0,0073	13,0	**56,2**
	22	0,0090	13,0	**69,2**
	23	0,0119	12,9	**92,2**
	24	0,0118	12,2	**96,7**
	25	0,0080	13,0	**61,5**
	26	0,0131	14,0	**93,6**
	27	0,0103	13,5	**76,3**
	28	0,0185	13,9	**133,1**
	29	0,0089	14,0	**63,6**
	30	0,0041	14,4	**28,5**
	31	0,0076	11,5	**66,1**
	32	0,0061	11,4	**53,5**
	33	0,0105	14,4	**72,9**
	34	0,0208	13,1	**158,8**
	35	0,0055	12,2	**45,1**
	36	0,0041	9,8	**41,8**
	37	0,0064	11,5	**55,7**
	38	0,0054	11,8	**45,8**

	39	0,0122	11,6	**105,2**
	40	0,0107	11,7	**91,5**
	41	0,0070	13,7	**51,1**
	42	0,0128	13,0	**98,5**
	43	0,0083	11,8	**70,3**
	44	0,0105	11,9	**88,2**
	45	0,0057	16,0	**35,6**
	46	0,0156	11,8	**132,2**
	47	0,0201	12,8	**157,0**
	48	0,0073	13,3	**54,9**
	49	0,0176	11,4	**154,4**
	50	0,0080	14,0	**57,1**
	51	0,0122	10,9	**111,9**
	52	0,0070	12,3	**56,9**
	53	0,0083	12,3	**67,5**
	54	0,0063	11,5	**54,8**
	55	0,0132	12,9	**102,3**
	56	0,0108	15,0	**72,0**
	57	0,0092	12,4	**74,2**
	58	0,0081	12,3	**65,9**
	59	0,0060	13,5	**44,4**
	60	0,0110	16,0	**68,8**
	61	0,0078	11,0	**70,9**
	62	0,0073	12,5	**58,4**
	63	0,0079	11,3	**69,9**
	64	0,0046	15,4	**29,9**
	65	0,0149	12,7	**117,3**
	66	0,0140	11,3	**123,9**
	67	0,0071	13,0	**54,6**
	68	0,0182	14,0	**130,0**
	69	0,0157	12,9	**121,7**
	70	0,0073	10,7	**68,2**
	71	0,0075	12,9	**58,1**
	72	0,0116	13,8	**84,1**
	73	0,0042	11,1	**37,8**
	74	0,0094	12,0	**78,3**
	75	0,0091	11,7	**77,8**
	76	0,0108	11,8	**91,5**
	77	0,0094	9,6	**97,9**
	78	0,0110	11,0	**100,0**
	79	0,0072	11,6	**62,1**
	80	0,0173	12,1	**143,0**
	81	0,0075	12,4	**60,5**

	82	0,0095	11,9	**79,8**
	83	0,0030	14,2	**21,1**
	84	0,0081	10,4	**77,9**
	85	0,0067	11,5	**58,3**
	86	0,0125	13,5	**92,6**
	87	0,0103	10,2	**101,0**
	88	0,0066	9,5	**69,5**
	89	0,0065	11,0	**59,1**
	90	0,0109	10,0	**109,0**
	91	0,0068	11,7	**58,1**
	92	0,0084	12,5	**67,2**
	93	0,0054	12,0	**45,0**
	94	0,0054	10,5	**51,4**
	95	0,0096	12,4	**77,4**
	96	0,0055	10,2	**53,9**
	97	0,0076	10,4	**73,1**
	98	0,0064	12,5	**51,2**
	99	0,0059	10,0	**59,0**
	100	0,0060	11,7	**51,3**
	101	0,0118	12,8	**92,2**
	102	0,0071	11,5	**61,7**
	103	0,0054	11,5	**47,0**
	104	0,0107	11,5	**93,0**
	105	0,0058	10,4	**55,8**
	106	0,0056	13,0	**43,1**
	107	0,0076	10,8	**70,4**
	108	0,0154	9,7	**158,8**
	109	0,0074	10,9	**67,9**
	110	0,0076	9,2	**82,6**
	111	0,0113	11,3	**100,0**
	112	0,0076	11,0	**69,1**
	113	0,0096	8,5	**112,9**
	114	0,0200	10,5	**190,5**
Average	-----	**0,0098**	**12,3**	**80,3**
Sample Standard Deviation	-----	**0,00440**	**1,55**	**34,76**
Average	-----	**44,7**	**12,6**	**43,3**

APPENDIX C - COCONUT FIBER DIAMETER DATA

APPENDIX C.1 - COCONUT FIBER IN NATURA

Sample Number	**Diameter 1**	**Diameter 2**	**Diameter 3**	**Average**	**Mean Standard Deviation**	**Sample Coefficient of Variation (%)**
1	326,40	334,37	336,70	332,49	5,40	1,6
2	507,96	490,23	506,38	501,52	9,81	2,0
3	385,71	401,77	392,26	393,25	8,08	2,1
4	266,47	284,86	278,39	276,57	9,33	3,4
5	224,69	243,07	234,04	233,93	9,19	3,9
6	230,08	227,48	232,77	230,11	2,65	1,1
7	503,05	501,01	523,24	509,10	12,29	2,4
8	194,99	203,03	201,42	199,81	4,25	2,1
9	340,33	352,45	350,10	347,63	6,43	1,8
10	447,60	471,44	455,55	458,20	12,14	2,6
11	542,87	513,48	522,39	526,25	15,07	2,9
12	662,05	626,44	598,46	628,98	31,87	5,1
13	377,82	373,89	379,73	377,15	2,98	0,8
14	248,71	244,73	221,11	238,18	14,92	6,3
15	664,88	611,63	624,87	633,79	27,72	4,4
16	576,88	596,42	576,66	583,32	11,35	1,9
17	362,03	394,04	378,16	378,08	16,01	4,2
18	409,12	416,72	406,39	410,74	5,35	1,3
19	362,27	358,30	358,12	359,56	2,35	0,7
20	575,26	600,02	563,01	579,43	18,85	3,3
21	395,95	400,10	413,82	403,29	9,35	2,3
22	779,05	782,25	794,45	785,25	8,13	1,0
23	529,24	505,84	503,23	512,77	14,32	2,8
24	310,50	306,58	303,09	306,72	3,71	1,2
25	330,74	307,09	307,43	315,09	13,56	4,3
26	514,62	492,66	475,76	494,35	19,48	3,9
27	286,90	313,97	301,90	300,92	13,56	4,5
28	653,43	656,94	661,26	657,21	3,92	0,6
29	309,41	307,81	296,65	304,62	6,95	2,3
30	272,26	295,95	289,03	285,75	12,18	4,3
31	575,81	560,28	560,86	565,65	8,80	1,6
32	975,25	956,16	956,26	962,56	10,99	1,1
33	408,63	419,16	433,82	420,54	12,65	3,0
34	387,86	383,99	369,90	380,58	9,45	2,5
35	295,37	286,72	287,63	289,91	4,75	1,6

36	297,18	295,74	299,70	297,54	2,00	0,7
37	745,95	770,03	783,78	766,59	19,15	2,5
38	299,43	295,80	303,65	299,63	3,93	1,3
39	372,30	354,08	356,06	360,81	10,00	2,8
40	370,62	380,03	399,60	383,42	14,78	3,9
41	131,23	139,29	169,93	146,82	20,42	13,9
42	599,52	555,27	536,58	563,79	32,32	5,7
43	183,98	175,13	181,08	180,06	4,51	2,5
44	503,17	525,09	513,02	513,76	10,98	2,1
45	197,63	211,07	210,27	206,32	7,54	3,7
46	245,51	255,41	260,92	253,95	7,81	3,1
47	304,34	290,27	298,22	297,61	7,05	2,4
48	365,37	342,78	351,73	353,29	11,38	3,2
49	350,18	348,37	343,25	347,27	3,59	1,0
50	417,97	403,89	421,85	414,57	9,45	2,3
51	529,91	508,81	510,01	516,24	11,85	2,3
52	322,46	318,25	312,13	317,61	5,19	1,6
53	607,30	593,41	577,05	592,59	15,14	2,6
54	375,08	354,43	372,00	367,17	11,14	3,0
55	447,10	444,84	427,92	439,95	10,48	2,4
56	418,77	421,73	438,04	426,18	10,38	2,4
57	369,80	360,24	348,05	359,36	10,90	3,0
58	487,34	483,69	481,13	484,05	3,12	0,6
59	211,33	215,04	210,89	212,42	2,28	1,1
60	413,69	395,63	423,48	410,93	14,13	3,4
61	218,70	239,10	212,73	223,51	13,83	6,2
62	526,93	519,13	511,07	519,04	7,93	1,5
63	539,44	447,53	409,55	465,51	66,78	14,3
64	204,86	232,68	230,92	222,82	15,58	7,0
65	402,70	401,91	419,78	408,13	10,10	2,5
66	247,87	235,13	246,59	243,20	7,02	2,9
67	121,42	125,50	127,24	124,72	2,99	2,4
68	161,08	175,13	173,14	169,78	7,60	4,5
69	491,96	481,70	509,39	494,35	14,00	2,8
70	654,32	704,12	731,74	696,73	39,24	5,6
71	351,91	346,90	347,21	348,67	2,81	0,8
72	559,08	540,77	552,77	550,87	9,30	1,7
73	648,26	658,13	667,99	658,13	9,87	1,5
74	403,58	365,83	358,17	375,86	24,31	6,5
75	378,16	371,79	375,75	375,23	3,22	0,9
76	266,67	286,31	290,37	281,12	12,67	4,5
77	637,08	647,47	636,49	640,35	6,18	1,0

78	322,09	304,18	314,14	313,47	8,97	2,9
79	292,92	295,37	291,41	293,23	2,00	0,7
80	415,58	425,49	411,53	417,53	7,18	1,7
81	610,42	604,64	602,50	605,85	4,10	0,7
82	461,24	463,37	481,45	468,69	11,10	2,4
83	461,30	445,44	458,36	455,03	8,44	1,9
84	431,58	441,39	446,20	439,72	7,45	1,7
85	878,73	860,84	793,33	844,30	45,04	5,3
86	375,75	361,85	365,85	367,82	7,16	1,9
87	377,86	361,83	389,84	376,51	14,05	3,7
88	354,08	368,06	352,34	358,16	8,62	2,4
89	461,27	479,23	487,18	475,89	13,27	2,8
90	262,79	269,28	264,46	265,51	3,37	1,3
91	540,81	495,07	507,27	514,38	23,69	4,6
92	399,60	401,63	393,96	398,40	3,97	1,0
93	495,17	512,94	476,98	495,03	17,98	3,6
94	520,73	510,07	473,83	501,54	24,59	4,9
95	507,96	507,62	524,99	513,52	9,93	1,9
96	475,22	449,30	435,43	453,32	20,20	4,5
97	497,03	469,45	465,25	477,24	17,26	3,6
98	413,64	422,15	433,95	423,25	10,20	2,4
99	844,97	884,75	882,70	870,81	22,40	2,6
100	644,18	636,19	626,25	635,54	8,98	1,4
101	392,38	392,38	376,17	386,98	9,36	2,4
102	294,34	294,26	280,57	289,72	7,93	2,7
103	408,14	418,35	408,14	411,54	5,89	1,4
104	324,06	318,12	310,15	317,44	6,98	2,2
105	461,27	447,39	473,18	460,61	12,91	2,8
106	491,73	524,28	511,49	509,17	16,40	3,2
107	419,48	449,74	407,60	425,61	21,73	5,1
108	518,92	520,85	491,15	510,31	16,62	3,3
109	397,63	387,68	425,61	403,64	19,67	4,9
110	330,02	318,12	342,09	330,08	11,99	3,6
111	165,06	175,00	199,44	179,83	17,69	9,8
112	196,98	212,87	212,76	207,54	9,14	4,4
113	254,47	264,41	260,63	259,84	5,02	1,9
114	197,63	199,29	205,55	200,82	4,18	2,1

APPENDIX C.2 - RETTED COCONUT FIBER

Sample Number	**Diameter 1**	**Diameter 2**	**Diameter 3**	**Average**	**Mean Standard Deviation**	**Sample Coefficient of Variation (%)**
1	992,25	980,25	992,06	988,19	6,87	0,7
2	783,42	791,50	881,55	818,82	54,47	6,7
3	421,49	393,88	409,56	408,31	13,85	3,4
4	379,72	419,48	385,71	394,97	21,44	5,4
5	564,70	555,37	589,68	569,92	17,74	3,1
6	471,18	479,31	473,18	474,56	4,24	0,9
7	604,46	610,39	629,25	614,70	12,94	2,1
8	1099,41	1097,53	1097,53	1098,16	1,09	0,1
9	1000,03	972,17	986,16	986,12	13,93	1,4
10	558,78	562,68	552,77	558,08	4,99	0,9
11	280,77	298,63	290,91	290,10	8,96	3,1
12	409,66	427,99	409,62	415,76	10,59	2,5
13	436,70	412,92	397,24	415,62	19,87	4,8
14	614,52	569,98	534,92	573,14	39,89	7,0
15	580,52	590,67	590,73	587,31	5,88	1,0
16	1007,53	1046,33	1102,69	1052,18	47,85	4,5
17	467,26	467,26	481,18	471,90	8,04	1,7
18	691,95	670,09	672,32	678,12	12,03	1,8
19	473,18	447,32	435,39	451,96	19,32	4,3
20	371,82	363,84	371,77	369,14	4,59	1,2
21	483,17	497,16	499,40	493,24	8,80	1,8
22	409,93	416,19	435,55	420,56	13,36	3,2
23	467,21	459,26	455,42	460,63	6,01	1,3
24	570,63	576,55	560,67	569,28	8,03	1,4
25	519,63	516,66	490,37	508,89	16,10	3,2
26	447,36	436,55	445,69	443,20	5,82	1,3
27	561,43	539,46	547,16	549,35	11,15	2,0
28	590,46	586,65	580,67	585,93	4,93	0,8
29	521,25	559,55	531,12	537,31	19,89	3,7
30	357,86	360,50	312,15	343,50	27,18	7,9
31	343,94	365,83	375,93	361,90	16,35	4,5
32	457,36	457,26	437,38	450,67	11,51	2,6
33	541,81	527,92	561,91	543,88	17,09	3,1
34	976,15	958,28	986,21	973,55	14,15	1,5
35	328,06	302,61	330,31	320,33	15,38	4,8
36	377,73	369,80	381,73	376,42	6,07	1,6
37	312,23	312,23	304,82	309,76	4,28	1,4

38	534,88	534,82	552,74	540,81	10,33	1,9
39	791,34	775,42	781,34	782,70	8,05	1,0
40	472,68	484,02	476,08	477,59	5,82	1,2
41	443,34	447,60	405,57	432,17	23,13	5,4
42	550,01	521,60	518,75	530,12	17,28	3,3
43	497,27	512,98	495,05	501,77	9,77	1,9
44	590,74	555,48	562,50	569,57	18,66	3,3
45	415,58	415,58	417,54	416,23	1,13	0,3
46	729,84	745,62	723,66	733,04	11,32	1,5
47	775,47	767,07	746,39	762,98	14,97	2,0
48	238,57	232,64	250,50	240,57	9,10	3,8
49	1045,73	1045,79	1053,80	1048,44	4,64	0,4
50	447,53	439,37	471,18	452,69	16,52	3,6
51	485,13	475,17	479,23	479,84	5,01	1,0
52	374,29	374,65	371,15	373,36	1,93	0,5
53	439,44	435,43	419,53	431,47	10,53	2,4
54	383,88	373,68	378,26	378,61	5,11	1,3
55	548,88	535,03	542,92	542,28	6,95	1,3
56	449,94	430,09	445,57	441,87	10,43	2,4
57	380,35	378,49	379,81	379,55	0,96	0,3
58	475,25	461,24	467,91	468,13	7,01	1,5
59	451,57	471,18	489,26	470,67	18,85	4,0
60	503,05	497,02	493,14	497,74	4,99	1,0
61	451,51	436,41	445,86	444,59	7,63	1,7
62	463,29	477,20	479,27	473,25	8,69	1,8
63	509,60	529,46	523,00	520,69	10,13	1,9
64	300,23	320,18	300,21	306,87	11,52	3,8
65	745,59	741,65	739,66	742,30	3,02	0,4
66	666,08	668,00	662,17	665,42	2,97	0,4
67	395,65	407,57	405,59	402,94	6,39	1,6
68	866,80	868,22	861,42	865,48	3,59	0,4
69	952,64	956,43	964,29	957,79	5,94	0,6
70	532,82	530,87	536,84	533,51	3,04	0,6
71	501,03	499,26	501,01	500,43	1,02	0,2
72	614,57	614,78	612,38	613,91	1,33	0,2
73	310,30	326,48	298,32	311,70	14,13	4,5
74	546,65	564,62	562,66	557,98	9,86	1,8
75	574,64	584,90	593,30	584,28	9,35	1,6
76	582,52	572,60	574,61	576,58	5,24	0,9
77	604,38	572,60	588,88	588,62	15,89	2,7
78	212,96	212,97	224,73	216,89	6,79	3,1
79	458,10	463,74	449,41	457,08	7,22	1,6
80	845,12	854,91	846,94	848,99	5,21	0,6

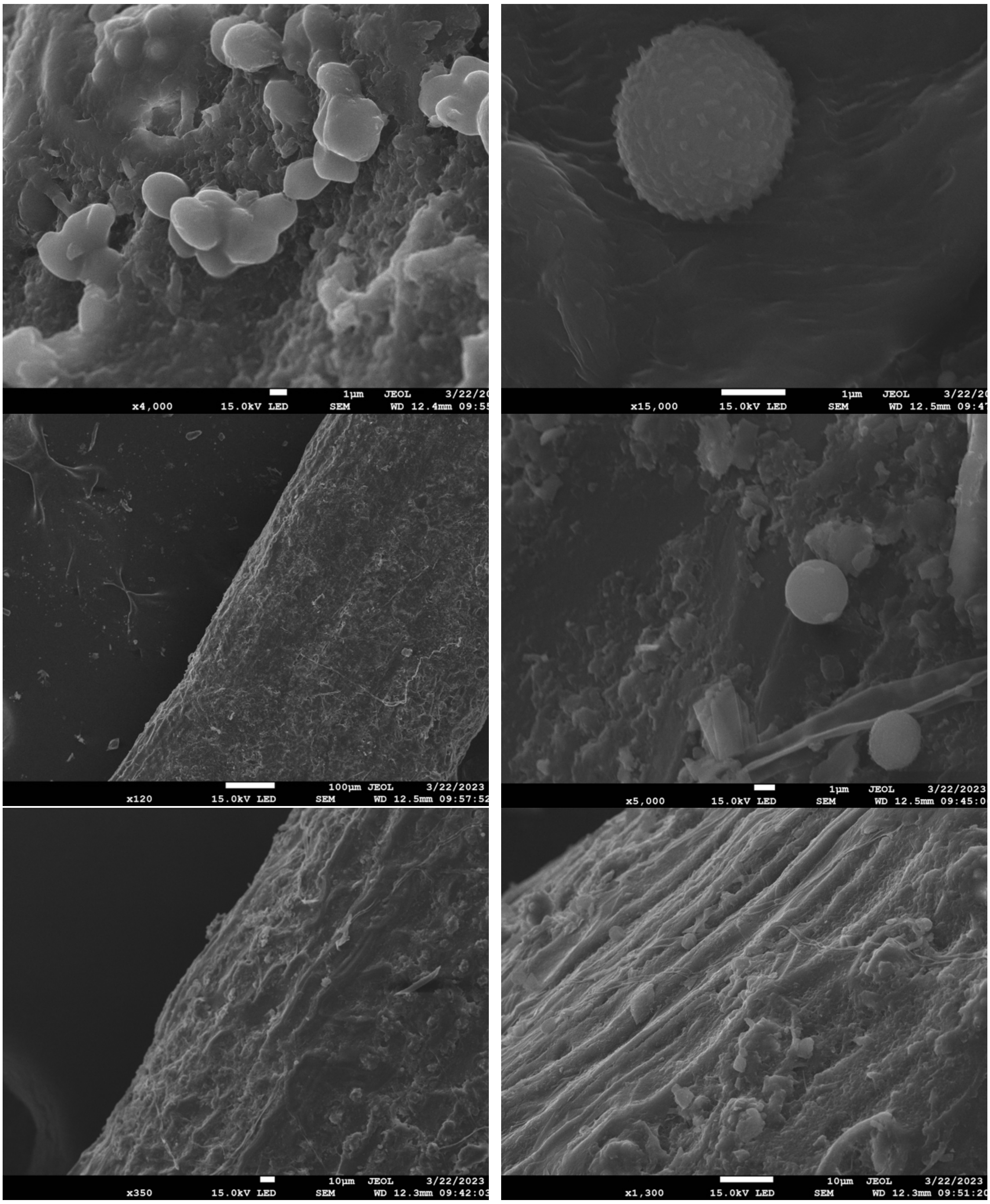
81	379,74	375,79	361,85	372,46	9,40	2,5
82	487,11	497,02	485,11	489,75	6,38	1,3
83	284,30	286,31	282,33	284,31	1,99	0,7
84	449,31	445,35	435,46	443,37	7,13	1,6
85	528,89	521,01	526,90	525,60	4,10	0,8
86	598,41	612,33	598,42	603,05	8,03	1,3
87	797,64	808,14	768,23	791,34	20,69	2,6
88	459,67	463,49	463,28	462,15	2,15	0,5
89	542,74	544,82	557,26	548,27	7,85	1,4
90	722,29	709,23	707,98	713,17	7,93	1,1
91	467,35	485,58	488,86	480,60	11,59	2,4
92	397,61	405,57	389,74	397,64	7,92	2,0
93	397,66	403,28	403,60	401,51	3,34	0,8
94	364,08	361,97	373,76	366,60	6,29	1,7
95	433,51	425,74	413,82	424,36	9,92	2,3
96	437,49	441,57	444,21	441,09	3,39	0,8
97	487,09	467,23	453,39	469,24	16,94	3,6
98	403,66	407,73	418,07	409,82	7,43	1,8
99	413,56	419,60	439,40	424,19	13,52	3,2
100	489,21	475,30	479,19	481,23	7,18	1,5
101	648,49	662,05	622,27	644,27	20,22	3,1
102	481,22	479,23	491,38	483,94	6,52	1,3
103	427,81	414,33	418,71	420,28	6,88	1,6
104	523,17	538,80	530,82	530,93	7,82	1,5
105	451,51	453,44	447,53	450,83	3,01	0,7
106	513,02	499,01	493,08	501,70	10,24	2,0
107	497,02	485,09	493,44	491,85	6,12	1,2
108	691,92	693,91	693,86	693,23	1,13	0,2
109	384,32	382,58	370,21	379,04	7,69	2,0
110	475,65	475,35	463,29	471,43	7,05	1,5
111	554,68	550,71	550,83	552,07	2,26	0,4
112	461,25	449,34	435,41	448,67	12,93	2,9
113	634,20	632,21	604,46	623,62	16,63	2,7
114	912,54	916,54	916,52	915,20	2,30	0,3

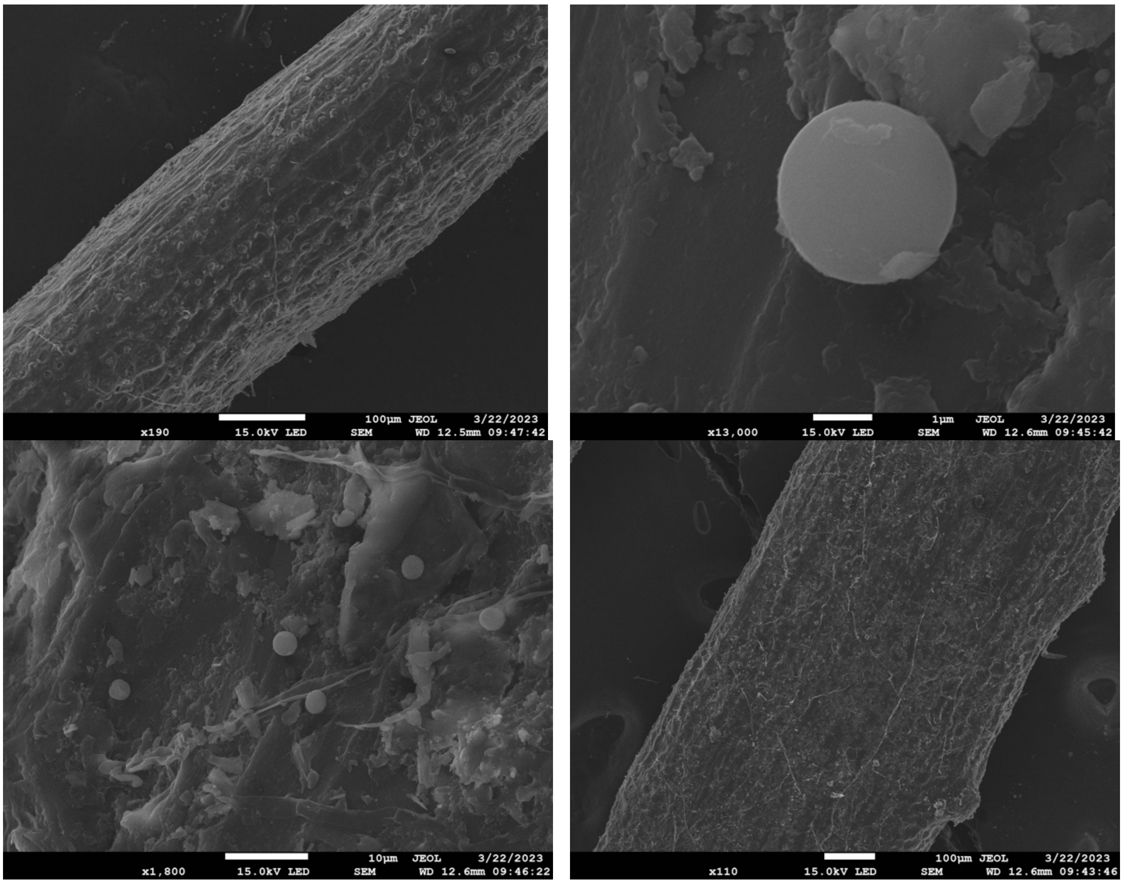
APPENDIX C.3 - MEASUREMENTS OBTAINED FROM MICROSCOPIES OF CROSS-SECTIONS OF FIBERS

	Natural Coconut	**Retted Coconut 1st sample**	**Retted Coconut 2st sample**
	16,995	16,055	16,142
	16,055	17,324	20,203
	15,885	22,186	18,14
	15,495	19,618	14,458
	15,149	21,424	15,126
	16,68	12,119	23,075
	14,384	21,424	15,219
	13,287	19,015	14,31
	13,576	15,449	12,605
	17,486	22,058	16,807
Average	15,5	18,7	16,6
StdDev	1,4	3,4	3,1
CV(%)	9,1%	18,0%	18,8%

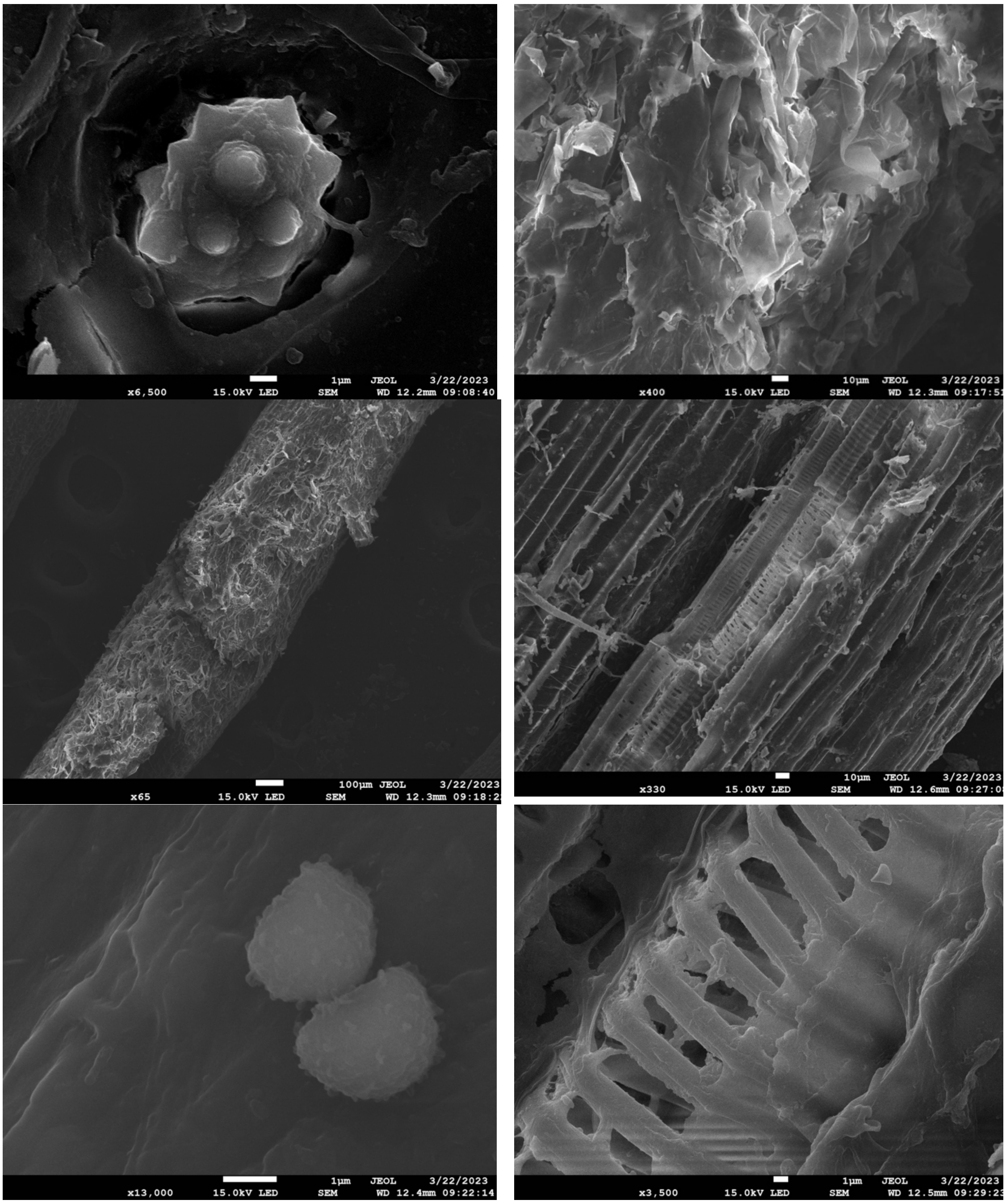
APPENDIX D - SCANNING ELECTRON MICROSCOPY IMAGES

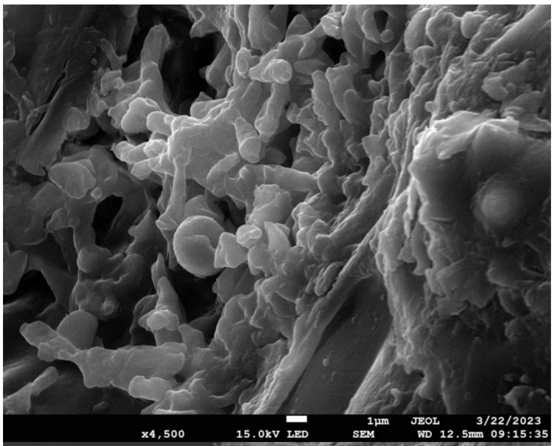
APÊNDICE D1.1 – IN NATURA COCONUT FIBER SEM

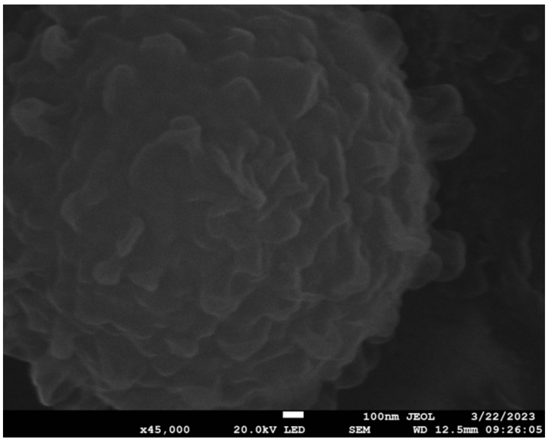


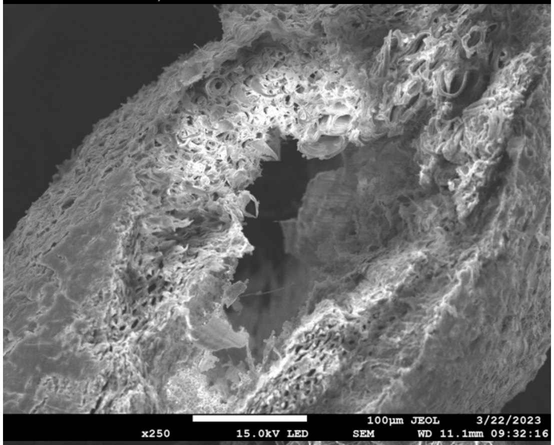

100µm JEOL 3/22/2023
x190 15.0kV LED SEM WD 12.5mm 09:47:42
1µm JEOL 3/22/2023
x13,000 15.0kV LED SEM WD 12.6mm 09:45:42
10µm JEOL 3/22/2023
x1,800 15.0kV LED SEM WD 12.6mm 09:46:22
100µm JEOL 3/22/2023
x110 15.0kV LED SEM WD 12.6mm 09:43:46

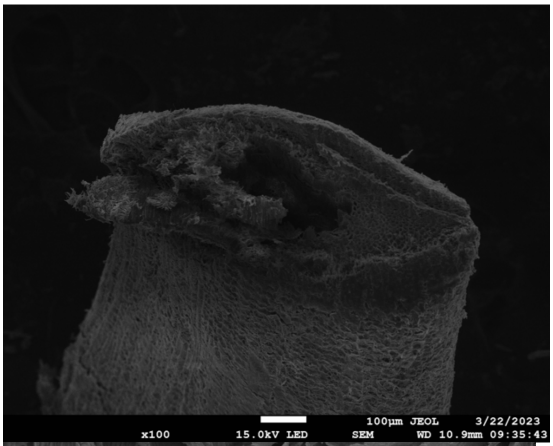
APÊNDICE D1.2 – RETTED COCONUT FIBER SEM

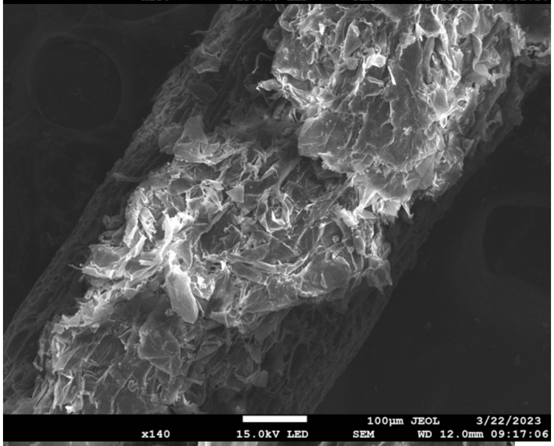


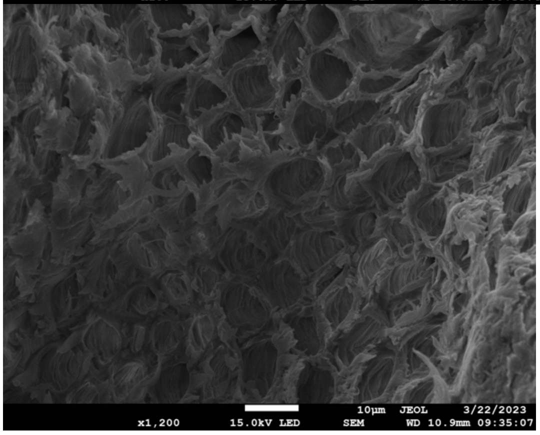

1µm JEOL 3/22/2023
x4,500 15.0kV LED SEM WD 12.5mm 09:15:35

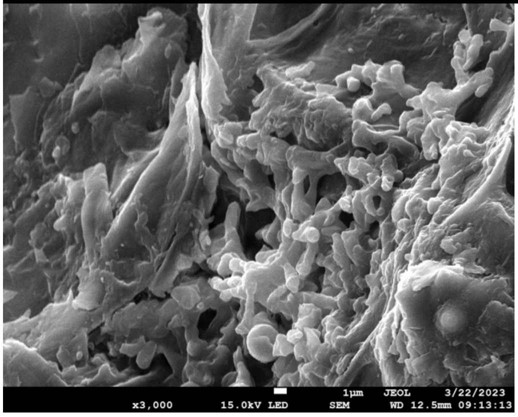

100nm JEOL 3/22/2023
x45,000 20.0kV LED SEM WD 12.5mm 09:26:05

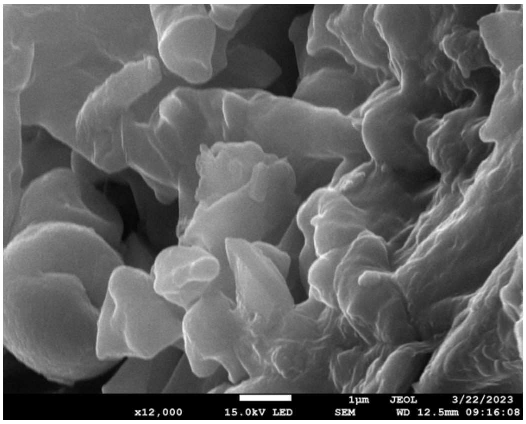

100µm JEOL 3/22/2023
x250 15.0kV LED SEM WD 11.1mm 09:32:16


100µm JEOL 3/22/2023
x100 15.0kV LED SEM WD 10.9mm 09:35:43


100µm JEOL 3/22/2023
x140 15.0kV LED SEM WD 12.0mm 09:17:06


10µm JEOL 3/22/2023
x1,200 15.0kV LED SEM WD 10.9mm 09:35:07


1µm JEOL 3/22/2023
x3,000 15.0kV LED SEM WD 12.5mm 09:13:13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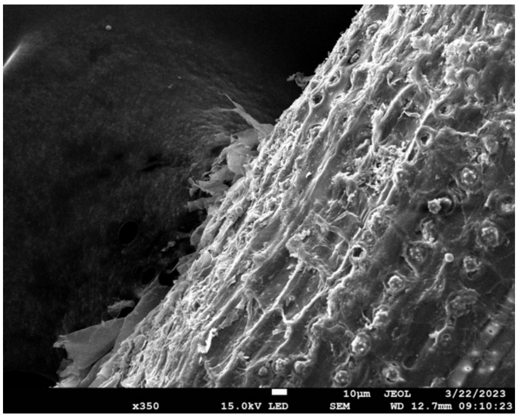
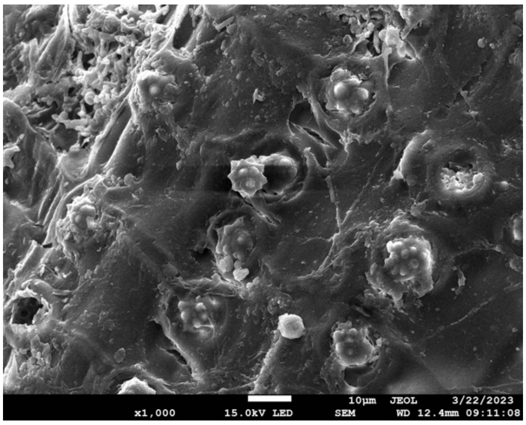
x12,000 15.0kV LED SEM WD 12.5mm 09:16:08


10µm JEOL 3/22/2023
x350 15.0kV LED SEM WD 12.7mm 09:10:23


10µm JEOL 3/22/2023
x1,000 15.0kV LED SEM WD 12.4mm 09:11:08

APPENDIX E - COCONUT FIBER DENSITY

APPENDIX E.1 - NATURAL COCONUT FIBER DENSITY

Sample Number	P1 (PSI)	P2 (PSI)	Vc (cm3)	Vr (cm3)	Vp Sample (cm3)	Mass (g)	Density (g/cm3)
01	17,396	5,928	11,62000	5,84000	0,3222	0,3187	0,989014
02	17,737	6,043	11,62000	5,84000	0,3188	0,3187	0,999587
03	17,599	5,997	11,62000	5,84000	0,3217	0,3187	0,990559
04	17,852	6,080	11,62000	5,84000	0,3127	0,3187	1,019239
05	17,704	6,033	11,62000	5,84000	0,3224	0,3187	0,988635
06	17,822	6,072	11,62000	5,84000	0,3189	0,3187	0,999229
07	17,384	5,925	11,62000	5,84000	0,3254	0,3187	0,979438
08	17,739	6,043	11,62000	5,84000	0,3169	0,3187	1,005684
Average	**17,654**	**6,015**	**11,620**	**5,840**	**0,3199**	**0,3187**	**0,996423**
Stan. P.	**0,180**	**0,060**	**0,000**	**0,000**	**0,0039**	**0,0000**	**0,012321**

APPENDIX E.1 - RETTED COCONUT FIBER DENSITY

Sample Number	P1 (PSI)	P2 (PSI)	Vc (cm3)	Vr (cm3)	Vp Sample (cm3)	Mass (g)	Density (g/cm3)
01	17,625	6,083	11,62000	5,84000	0,5391	0,5708	1,058855
02	17,888	6,170	11,62000	5,84000	0,5287	0,5708	1,079563
03	18,136	6,246	11,62000	5,84000	0,5029	0,5708	1,135087
04	17,579	6,058	11,62000	5,84000	0,5136	0,5708	1,111395
05	17,591	6,060	11,62000	5,84000	0,5076	0,5708	1,124469
06	17,563	6,055	11,62000	5,84000	0,5206	0,5708	1,096376
07	17,506	6,037	11,62000	5,84000	0,5253	0,5708	1,086705
08	17,577	6,060	11,62000	5,84000	0,5211	0,5708	1,095356
Average	**17,683**	**6,096**	**11,620**	**5,840**	**0,5199**	**0,5708**	**1,098476**
Stan. P.	**0,216**	**0,073**	**0,000**	**0,000**	**0,0117**	**0,0000**	**0,024678**

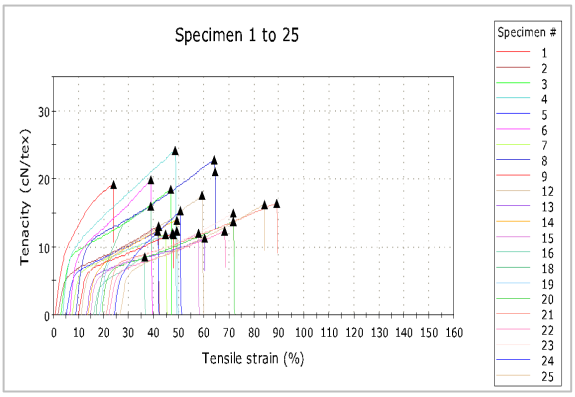
APPENDIX F - DYNAMOMETER TESTS WITH THE FIBER

APPENDIX F.1 - DYNAMOMETER IN NATURA COCONUT FIBER

	Maximum Load (N)	**Tenacity at Maximum Load (cN/tex)**	**Extension at Maximum Load (mm)**	**Tensile strain at Maximum Load (%)**	**Young Modulus (N/tex)**
	12,37	19,18	6,00	24,00	2,117
	4,72	13,11	10,17	40,67	0,777
	5,03	18,48	11,08	44,33	1,073
	8,19	24,24	11,25	45,00	1,217
	8,77	12,38	9,25	37,00	0,835
	3,94	19,92	8,25	33,00	1,612
	7,10	11,84	9,42	37,67	0,898
	24,66	22,79	13,92	55,67	1,058
	11,24	11,98	9,50	38,00	0,860
	4,42	17,56	12,17	48,67	0,703
	12,29	11,25	12,08	48,33	0,640
	11,35	13,99	9,00	36,00	1,056
	7,07	11,98	10,83	43,33	0,710
	3,67	8,55	5,17	20,67	1,103
	15,77	16,06	5,50	22,00	1,789
	9,75	12,33	7,83	31,33	1,405
	8,73	13,73	13,17	52,67	0,670
	19,66	16,38	17,17	68,67	0,489
	11,19	12,33	11,67	46,67	0,677
	12,32	14,94	12,25	49,00	0,811
	5,36	15,37	6,67	26,67	1,264
	23,03	16,20	14,75	59,00	0,604
	8,23	12,78	18,58	74,33	0,348
	14,47	13,34	14,58	58,33	0,535
	7,53	14,79	14,92	59,67	0,548
	5,95	14,58	15,75	63,00	0,481
	33,31	18,64	15,25	61,00	0,685
	6,78	13,34	11,25	45,00	0,720
	5,37	11,61	9,25	37,00	0,845
	6,29	11,19	10,25	41,00	0,901
	15,87	14,11	16,75	67,00	0,512
	5,11	14,22	9,42	37,67	0,996

	6,56	10,88	10,00	40,00	0,689
	11,50	15,86	16,50	66,00	0,443
	17,83	18,12	15,75	63,00	0,615
	3,85	17,84	9,67	38,67	0,877
	16,54	13,54	13,17	52,67	0,681
	3,82	14,99	9,42	37,67	0,861
	4,24	15,14	10,08	40,33	1,004
	4,24	13,36	8,25	33,00	1,282
	6,46	11,76	10,83	43,33	0,949
	7,51	13,94	7,50	30,00	1,342
	16,71	16,30	17,00	68,00	0,527
	9,01	10,63	10,83	43,33	0,780
	5,83	14,69	11,58	46,33	0,853
	15,90	12,74	15,17	60,67	0,538
	8,75	15,65	16,67	66,67	0,456
	11,89	14,05	15,33	61,33	0,515
	8,84	16,39	14,17	56,67	0,622
	12,80	13,84	9,83	39,33	0,757
	5,38	15,49	13,42	53,67	0,633
	10,40	16,36	13,33	53,33	0,676
	2,26	10,24	6,17	24,67	1,068
	7,26	11,13	10,92	43,67	0,828
	6,99	14,75	10,75	43,00	0,939
	3,92	19,12	12,17	48,67	0,744
	7,84	12,51	7,92	31,67	0,795
	3,62	15,62	11,67	46,67	0,762
	1,82	16,00	6,50	26,00	1,263
	3,88	21,95	8,33	33,33	1,317
	8,61	10,36	6,92	27,67	1,342
	14,70	13,95	13,58	54,33	0,604
	6,82	14,55	10,00	40,00	0,804
	10,08	11,37	9,17	36,67	0,807
	11,85	10,82	12,33	49,33	0,745
	10,49	12,63	10,25	41,00	0,943
	10,75	16,11	11,00	44,00	0,850
	7,44	12,66	10,67	42,67	0,744
	12,11	14,00	16,00	64,00	0,479
	11,30	16,00	16,00	64,00	0,784
	7,68	12,41	9,58	38,33	1,130
	6,61	14,07	13,00	52,00	0,870

	26,88	15,02	17,75	71,00	0,415
	10,22	15,07	20,25	81,00	0,376
	5,48	13,14	10,33	41,33	0,932
	6,18	10,79	7,25	29,00	1,195
	7,32	12,25	9,67	38,67	1,020
	6,31	11,02	13,75	55,00	0,439
	8,20	11,58	11,25	45,00	0,762
	9,60	13,29	12,75	51,00	0,709
	7,66	11,31	8,75	35,00	1,181
	8,26	13,76	9,58	38,33	1,012
	5,62	11,63	8,92	35,67	1,203
	11,95	14,90	12,67	50,67	0,672
	5,98	21,58	11,58	46,33	1,211
	22,78	15,38	10,42	41,67	0,953
	14,63	15,13	13,83	55,33	0,769
	9,52	12,55	9,17	36,67	0,979
	9,07	33,11	13,92	55,67	1,145
	7,05	11,98	10,42	41,67	0,803
	5,12	11,06	12,33	49,33	0,595
	9,01	12,64	12,67	50,67	0,696
	9,40	12,99	12,08	48,33	0,774
	5,78	12,14	9,75	39,00	1,043
	9,25	11,19	9,75	39,00	1,037
	10,53	14,87	13,33	53,33	0,563
	4,95	11,95	9,08	36,33	0,851
	4,38	13,81	5,33	21,33	1,542
	4,84	12,34	6,08	24,33	1,106
	4,26	14,59	12,75	51,00	0,664
	3,46	18,60	10,25	41,00	0,834
Mean	**9,28**	**14,40**	**11,39**	**45,55**	**0,865**
Standard Deviation	**5,397**	**3,405**	**3,144**	**12,577**	**0,3079**
Coefficient of Variation	**58,2%**	**23,6%**	**27,6%**	**27,6%**	**35,6%**



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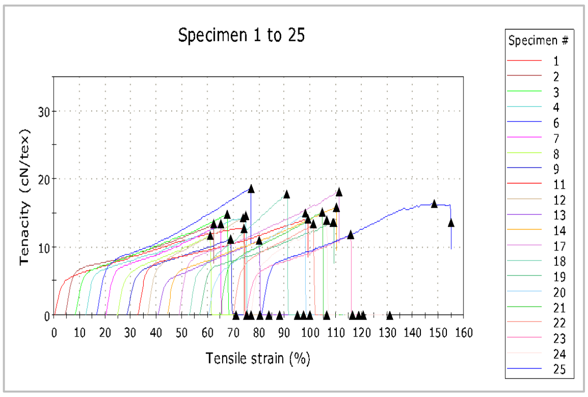

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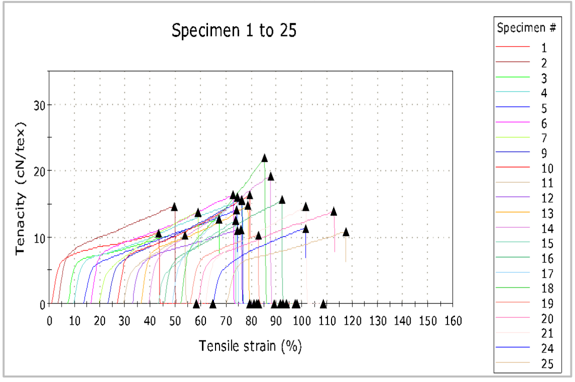

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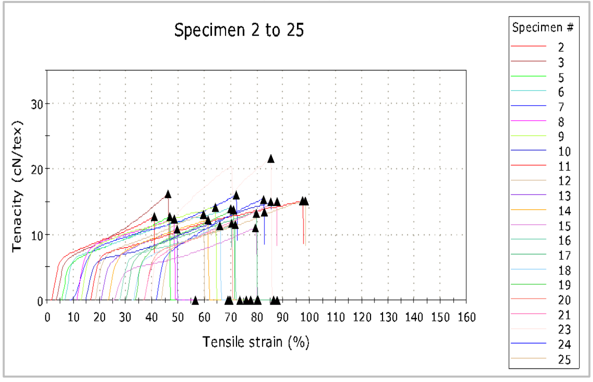

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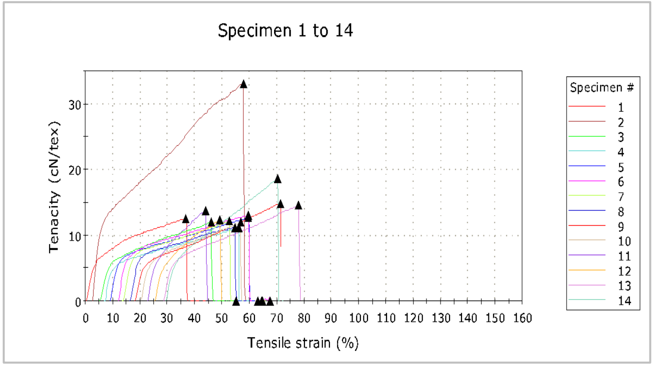


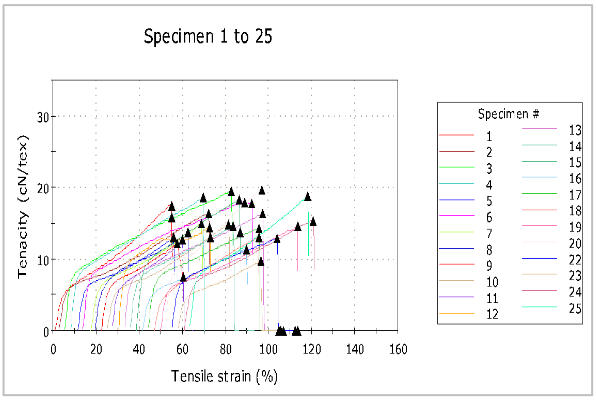
(101 – 114)

APPENDIX F.2 - DYNAMOMETER RETTED COCONUT FIBER

	Maximum Load (N)	Tenacity at Maximum Load (cN/tex)	Extension at Maximum Load (mm)	Tensile strain at Maximum Load (%)	Young Modulus (N/tex)
	27,39	17,49	13,75	55,00	0,602
	22,02	16,37	17,42	69,67	0,402
	11,18	19,51	19,33	77,33	0,492
	9,16	18,58	15,33	61,33	0,637
	11,30	12,99	11,25	45,00	0,684
	10,75	18,01	18,75	75,00	0,475
	12,44	14,93	13,08	52,33	0,698
	15,43	13,70	10,83	43,33	0,881
	19,66	12,11	8,92	35,67	1,010
	23,48	14,85	14,17	56,67	0,514
	4,60	12,75	8,17	32,67	1,006
	11,66	14,50	10,58	42,33	2,245
	7,29	16,31	16,08	64,33	0,582
	7,90	14,55	11,92	47,67	0,817
	10,84	18,31	11,92	47,67	1,016
	17,13	11,31	12,08	48,33	0,584
	7,59	14,30	12,83	51,33	0,773
	15,76	13,10	12,17	48,67	0,512
	14,47	14,58	15,92	63,67	0,470
	6,65	19,68	11,08	44,33	0,908
	8,87	12,82	12,17	48,67	0,759
	8,94	9,69	9,58	38,33	0,681
	14,89	15,40	14,92	59,67	0,546
	11,55	18,77	13,67	54,67	0,727
	13,08	13,98	11,92	47,67	0,797
	19,18	14,41	13,75	55,00	0,533
	10,51	16,52	9,83	39,33	1,134
	7,72	27,09	16,92	67,67	0,826
	7,28	11,01	9,58	38,33	0,845
	5,98	11,18	9,50	38,00	1,017
	10,12	13,88	12,17	48,67	0,729
	22,98	14,47	15,33	61,33	0,532

	5,41	12,00	9,08	36,33	0,921
	5,55	13,29	9,83	39,33	0,933
	6,90	12,38	12,42	49,67	0,701
	7,63	16,66	8,83	35,33	1,280
	8,14	7,73	8,58	34,33	0,868
	9,71	10,61	14,25	57,00	0,570
	7,78	15,22	12,17	48,67	0,871
	13,81	14,02	15,75	63,00	0,464
	9,93	14,12	14,33	57,33	0,589
	11,14	12,63	17,08	68,33	0,422
	7,75	21,76	14,33	57,33	0,774
	13,85	10,48	12,67	50,67	0,617
	27,21	17,33	16,58	66,33	0,480
	7,81	14,23	13,08	52,33	0,622
	13,40	23,47	16,58	66,33	0,603
	14,59	12,17	16,00	64,00	0,384
	9,64	14,29	15,83	63,33	0,513
	6,06	11,05	10,42	41,67	0,817
	11,60	11,34	10,42	41,67	0,834
	14,60	20,28	13,08	52,33	0,791
	9,72	13,10	17,25	69,00	0,427
	5,92	13,33	8,92	35,67	1,373
	18,48	26,86	16,00	64,00	0,985
	8,42	11,88	13,00	52,00	0,555
	9,12	13,05	15,67	62,67	0,492
	7,28	24,35	12,33	49,33	1,107
	16,57	14,13	13,67	54,67	0,619
	15,46	12,48	15,92	63,67	0,460
	7,61	13,93	19,42	77,67	0,421
	17,88	13,75	14,92	59,67	0,584
	14,62	12,02	12,42	49,67	0,710
	6,51	9,54	9,83	39,33	0,822
	7,67	9,79	15,08	60,33	0,378
	7,29	9,37	8,50	34,00	1,075
	10,09	11,02	14,42	57,67	0,530
	8,77	8,96	9,58	38,33	0,860
	7,39	11,90	12,58	50,33	0,681
	16,76	11,72	16,75	67,00	0,460
	11,88	14,89	16,42	65,67	0,505
	4,84	22,92	14,33	57,33	0,901

	11,60	19,90	18,92	75,67	0,507
	9,80	10,58	9,67	38,67	0,826
	16,72	16,55	15,92	63,67	0,647
	6,99	10,06	14,33	57,33	0,492
	7,52	12,72	14,17	56,67	0,625
	8,26	7,58	10,67	42,67	0,510
	10,16	17,48	18,25	73,00	0,472
	7,12	10,59	16,00	64,00	0,784
	7,76	10,03	13,50	54,00	0,430
	6,98	9,55	11,50	46,00	0,619
	5,58	10,90	9,00	36,00	0,990
	12,72	13,80	15,33	61,33	0,539
	6,28	10,19	9,33	37,33	0,957
	5,94	12,64	9,75	39,00	1,018
	8,97	9,64	11,58	46,33	0,639
	6,75	15,67	8,42	33,67	1,542
	18,98	11,95	13,08	52,33	0,550
	9,38	11,36	9,58	38,33	0,812
	16,98	16,98	14,50	58,00	0,537
	11,72	16,96	17,67	70,67	0,536
	11,46	10,15	11,92	47,67	0,628
Mean	**11,19**	**14,16**	**13,19**	**52,75**	**0,721**
Standard Deviation	**4,948**	**3,938**	**2,926**	**11,703**	**0,2800**
Coefficient of Variation	**44,2%**	**27,8%**	**22,2%**	**22,2%**	**38,8%**



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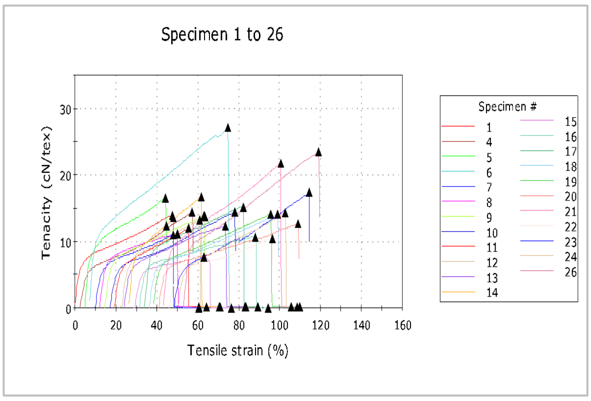

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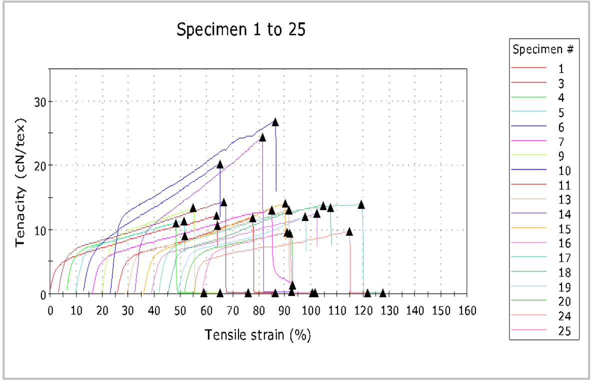
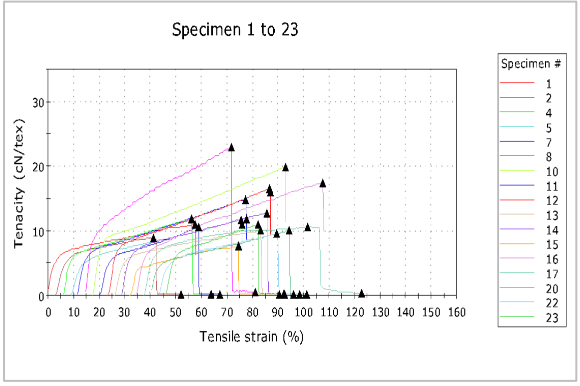
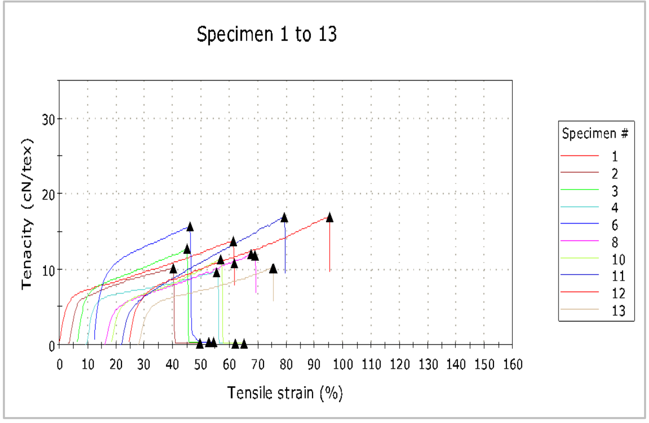


(52 – 76)

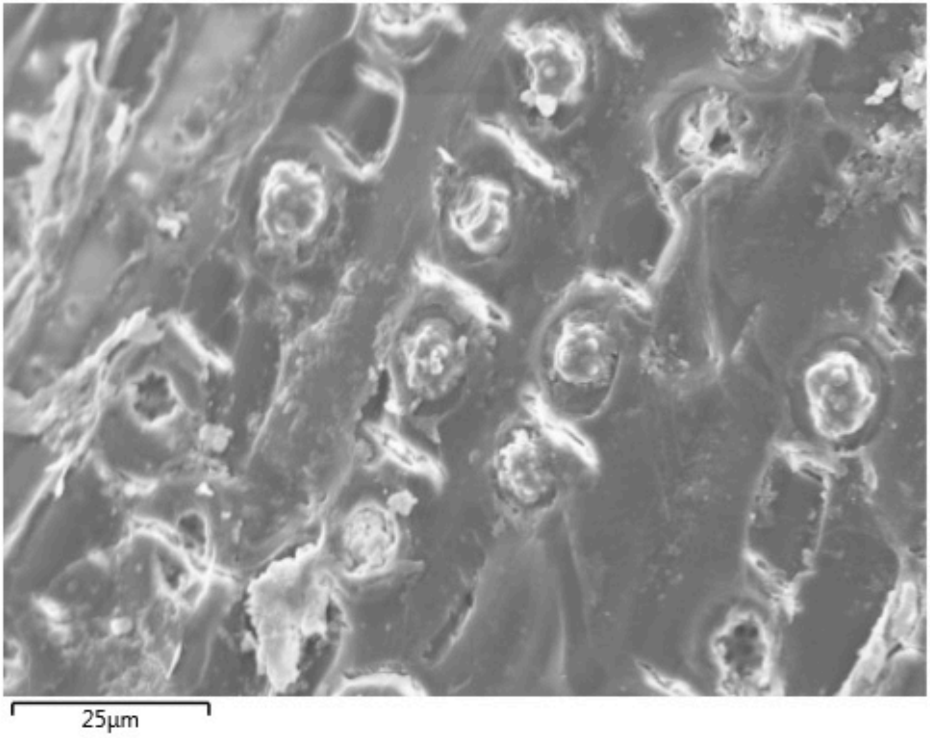


(77 – 100)

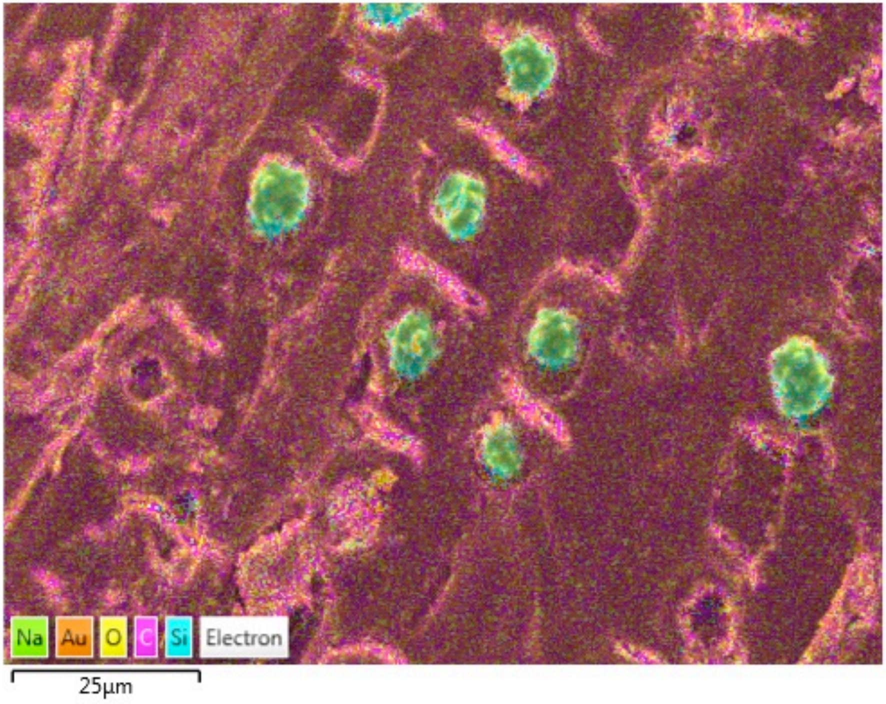


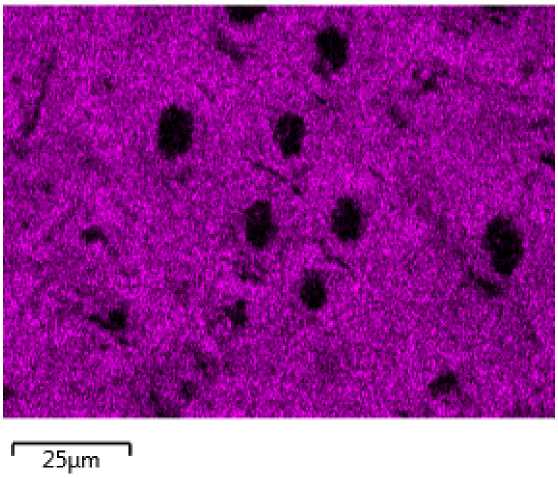
(101 – 114)

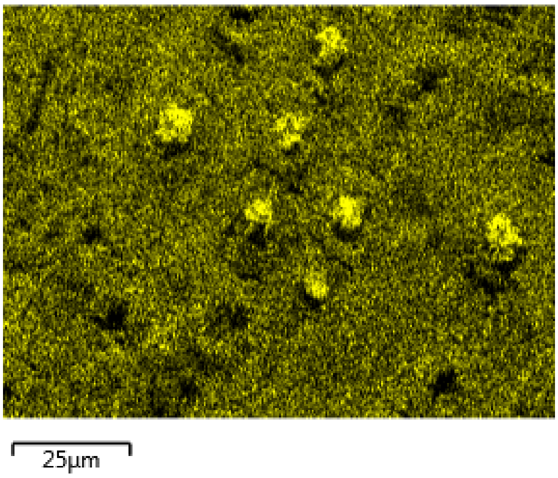
APPENDIX G - EDS ANALYSIS GREEN COCONUT FIBER

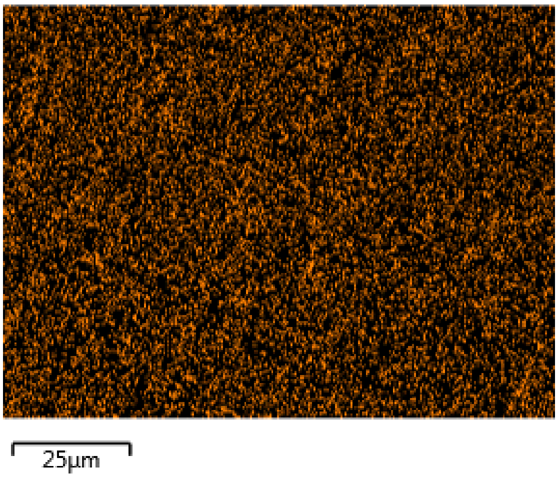

Electron Image 5

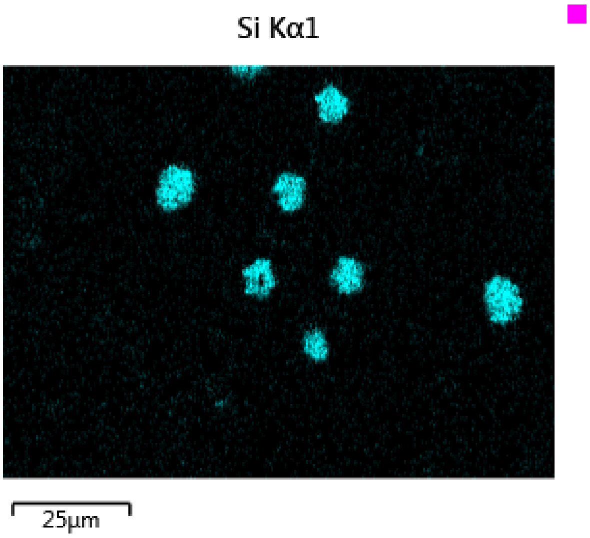
Settings
Phases for Acquisition

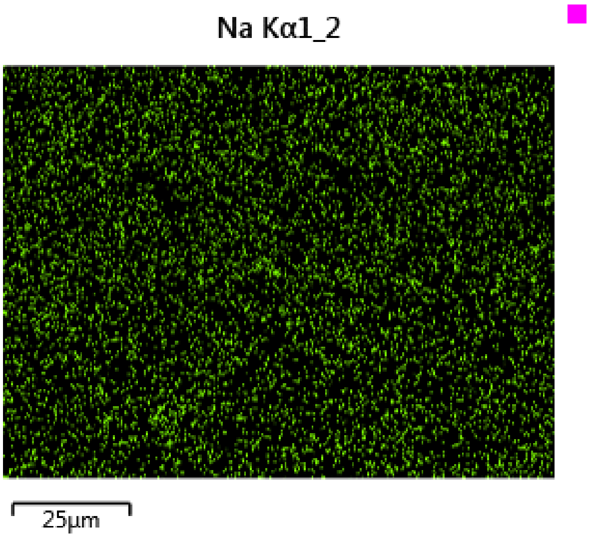

EDS Layered Image 2

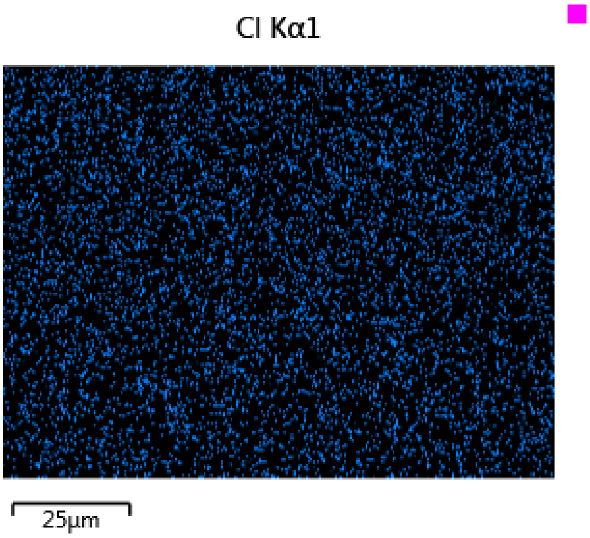

C Kα1_2

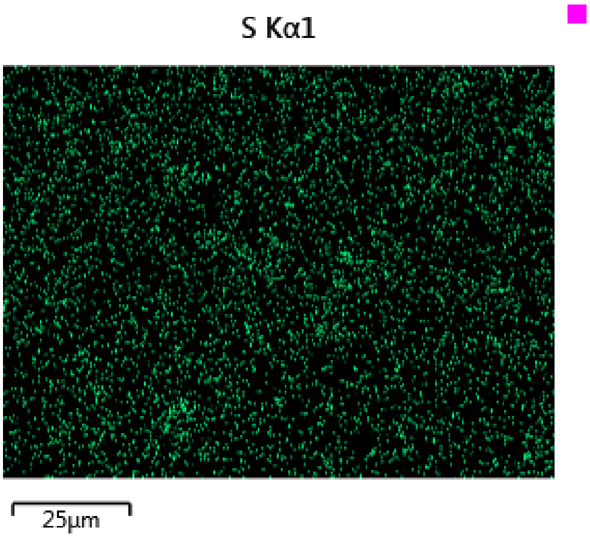

O Kα1

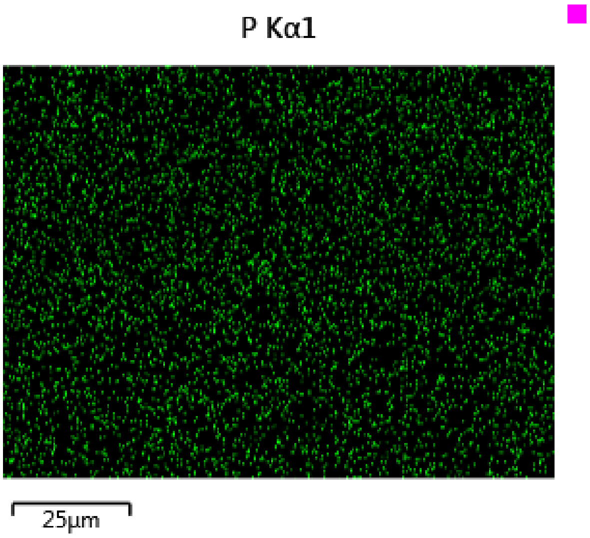

Au Mα1

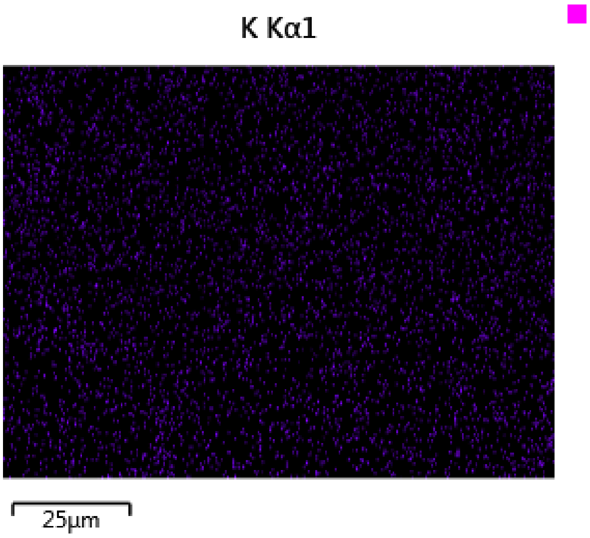

Si Kα1
25µm

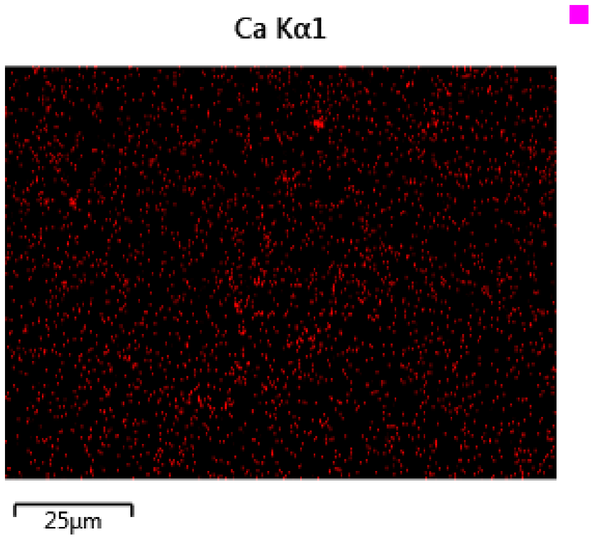

Na Kα1_2
25µm


Cl Kα1
25µm

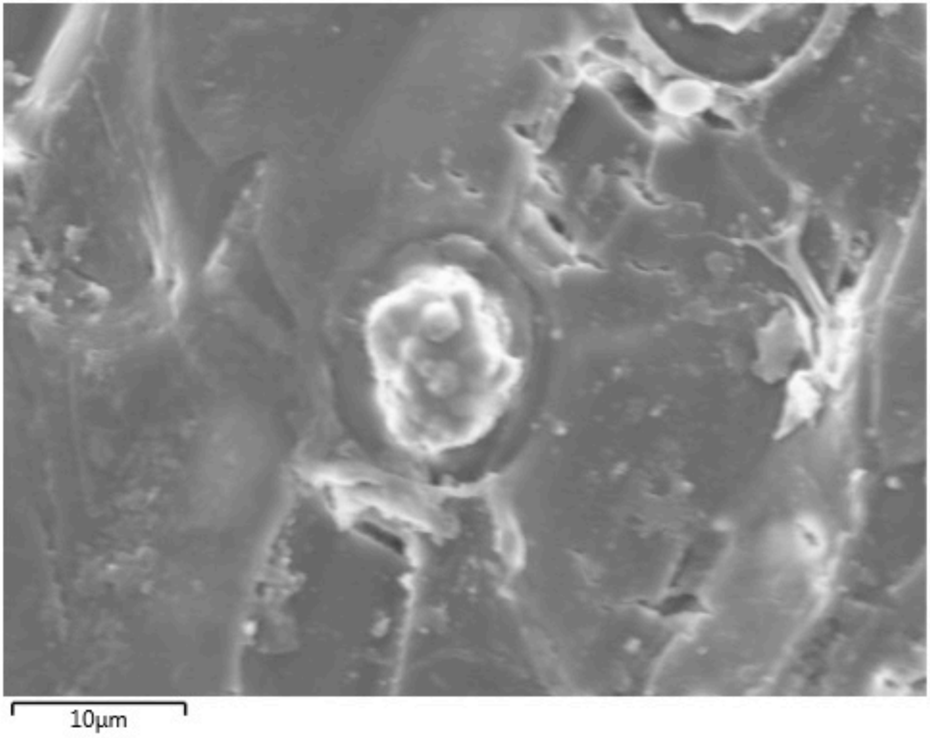

S Kα1
25µm


P Kα1
25µm

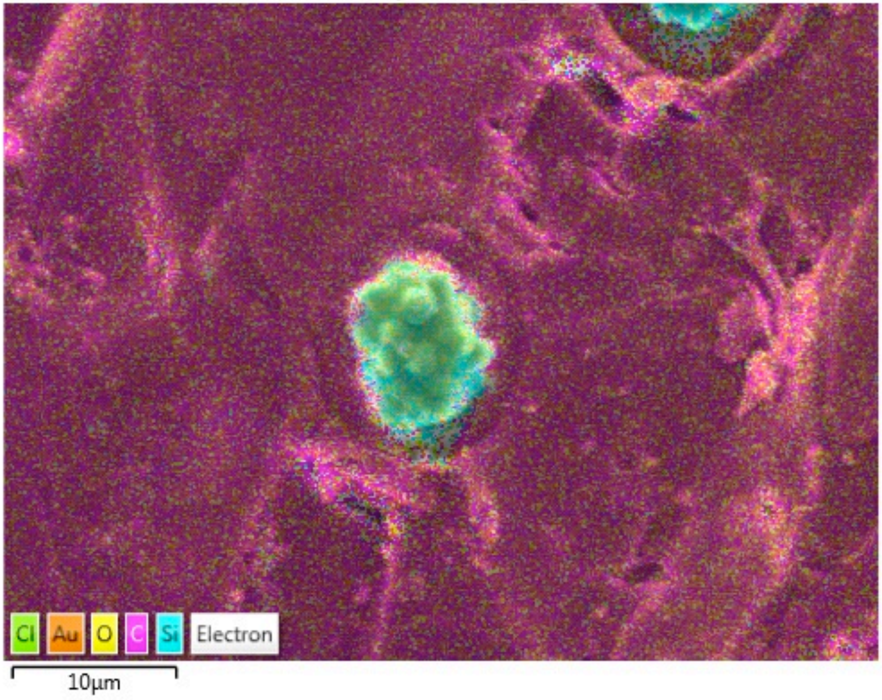

K Kα1
25µm



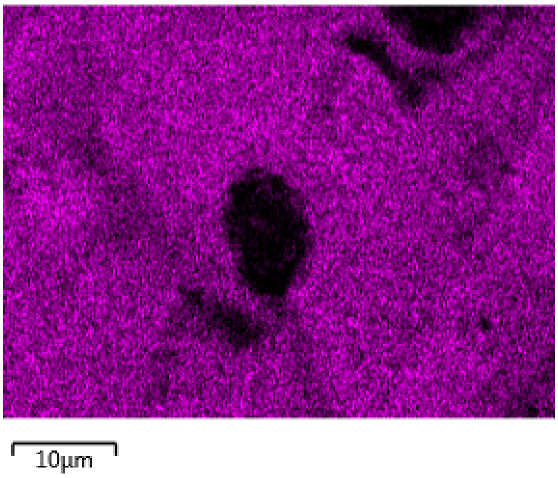
Phase Fraction


Electron Image 6

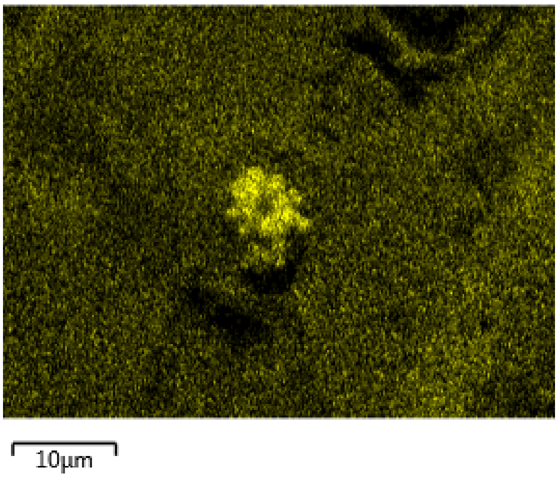
Settings
Phases for Acquisition


EDS Layered Image 3

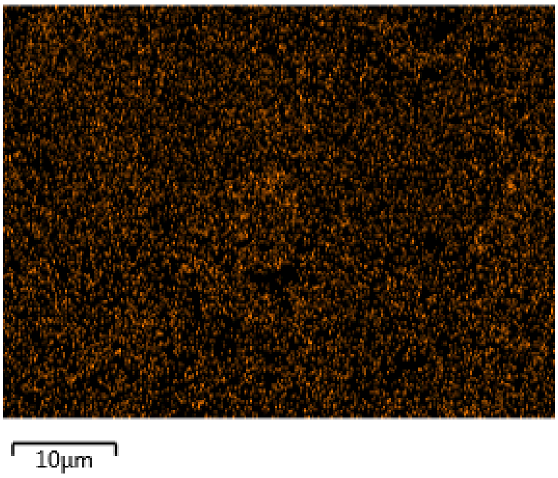
C Kα1_2

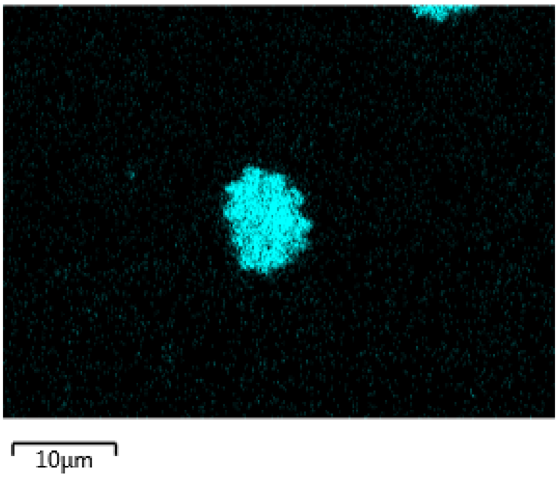


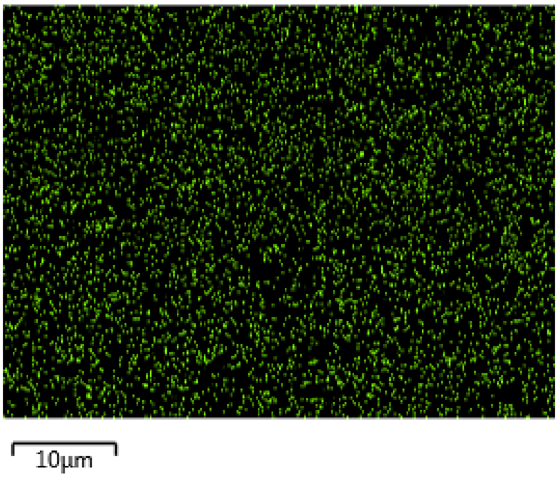
O Kα1

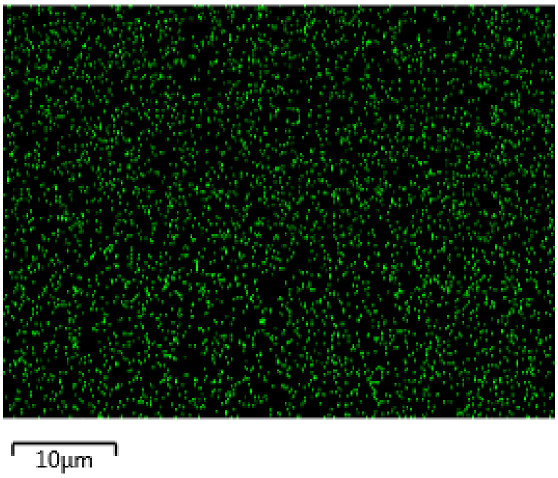


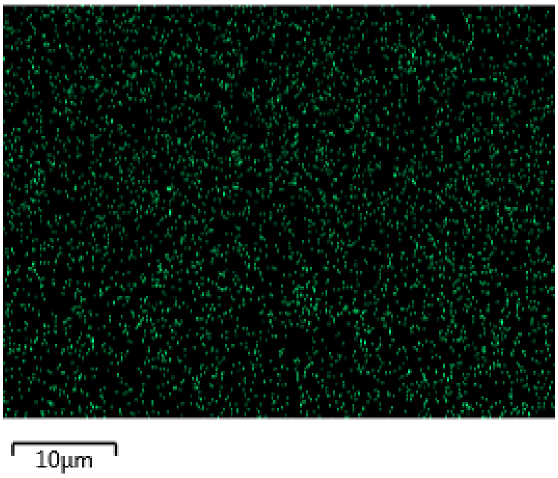
Au Mα1

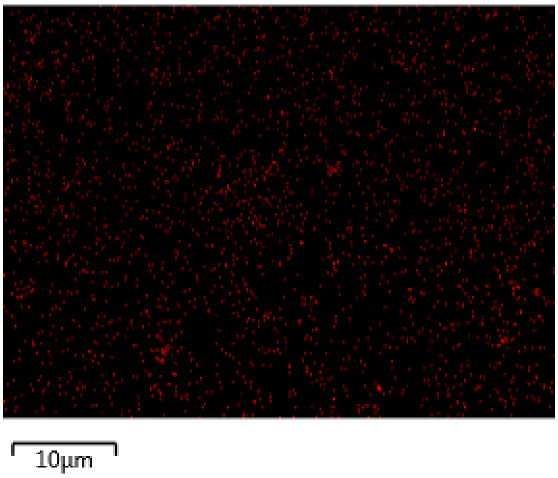



Si Kα1


Cl Kα1


P Kα1


K Kα1


Ca Kα1

Phase Fraction