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Review

Amazon Natural Fibers for Application in Engineering Composites and Sustainable Actions: A Review

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Abstract: The Amazon rainforest, spanning multiple countries in South America, is the world's largest equatorial expanse, housing a vast array of relatively unknown plant and animal species. Encompassing the planet's greatest flora, the Amazon offers a tremendous variety of plants from which natural lignocellulosic fibers (NLFs) can be extracted. In this century, NLFs, which have long been utilized by indigenous populations of the Amazon, have garnered interest as potential reinforcements for composites, whether polymer- or cement-based, in various technical applications such as packaging, construction, automotive products, and ballistic armor. A comparison with synthetic materials like glass, carbon, and aramid fibers, as well as other established NLFs, highlights the cost and specific property advantages of Amazon natural fibers (ANFs). Notably, the sustainable cultivation and extraction of ANFs, as alternatives to deforestation and livestock pasture, contribute to the preservation of the Amazon rainforest. This review article provides a comprehensive examination of recent studies directly related to ANF-reinforced polymer matrix composites. The specific advantages, proposed applications, and reported challenges are highlighted, shedding light on the potential of these unique natural fibers.

Keywords: natural lignocellulosic fibers; NLFs; Amazon rainforest; composite materials; engineering applications; sustainability; properties

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1. Introduction

Nature has provided a comprehensive diversity of natural fibers throughout the ages. With a remarkably extensive history, these fibers have roots that date back to prehistoric times, unquestionably meeting human needs throughout history [1–3]. Vegetable fibers have been used for various purposes in different eras and regions of the world. Primitive humans used them to keep warm, protect themselves, and as materials for household utensils such as ropes and fishing nets [1,4–6].

The use of vegetable fibers for textiles dates back to the end of the Paleolithic period (12,000–8000 BC). Discoveries, like palm leaf fragments in a 10,000 BC Mexican cave and net bags in a Utah cave, reveal Native Americans' skills in processing vegetable fibers [1]. Table 1 outlines the history of natural fiber use in prehistoric eras.

Vegetable fibers played a crucial role in human history, influencing agricultural, fishing, artisanal, and commercial activities [7,8]. Civilizations aimed to enhance their quality of life, driving improvements in living standards, technology, economics, and societal strength [6,8]. Technological progress in vegetable fiber production surged after the 18th-century Industrial Revolution, fostering economic growth. However, it brought challenges like increased resource consumption and pollution, impacting global sustainability efforts [9,10].

Table 1. Timeline of natural fiber use in antiquity [1].

Period (Year)	Fact
20,000 BC	Humans making ropes and cords during the Paleolithic Age
12,000 BC	Evidence of the existence of cotton in Egypt
10,000 BC	First reports of the cultivation of wild plants and the manufacture of fabrics from natural fibers
9000 BC	The discovery of a net bag in Utah indicated that the American Indians had advanced skills in processing plant fibers in approximately 9000 BC.
8000 BC	The Swiss Lake Dwellers of the Stone Age cultivated flax and wove it into linen fabric.
6000 BC	Hemp, believed by some to be the oldest cultivated fiber plant, originated in Southeast Asia and spread to China
5700 BC	Evidence of cotton fabrics produced in Mexico during this period
5000 BC	The first evidence of weaving, through the manufacture of baskets using plant fibers, dates from this period. Cotton was cultivated and used in the Tehuacan Valley of Mexico.
3500 BC	Heavy, strong ropes were used to drag heavy objects in Egypt. The ropes were made by twisting strips cut from hides or fibers from papyrus reeds
3400 BC	The art of spinning and weaving linen was well developed in Egypt by 3400 BC, suggesting flax had been cultivated prior to that date
3000 BC	Spinning and weaving of cotton is practiced in Pakistan, evidenced by the discovery of cotton fabrics and string from excavations at Mohenjo-Daro
2900 BC	The Emperor Shen Nung encouraged the growth of hemp in China
2500 BC	Cotton and cotton textiles existed in Peru
2300 BC	Cotton was cultivated in the Indus Valley
1400 BC	A Hindu hymn describes the manufacture of cotton yarns and the weaving of cotton cloth
445 BC	Herodotus wrote of trees which grow wild in India, the fruit of which is a wool exceeding in beauty and goodness that of sheep and from which the natives make clothing
63 BC	Lentullus Spinther introduced cotton awnings in the theater at the Appolinarian games

The pursuit of a better quality of life is an important demand, as is the technological progress of a nation. This means that integrating technology and sustainability represents a low-environmental-impact option for fully viable engineering applications. Thus, in the face of growing environmental concerns and the possibility of depleting oil reserves, natural fibers can be an environmentally friendly alternative, in line with the principles of sustainable development. These materials are known to be renewable and biodegradable, and they have been widely used in various industrial and engineering applications [11–16]. According to the annual report of the Discover Natural Fibers Initiative (DNFI), shown in Table 2, in the year 2023, global production of natural fibers was estimated at 31.9 million tons, surpassing the production of the year 2020. The utilization of fibers in the industry may result in the global fiber production in 2023 being higher than that of the years 2021 and 2022 [17].

Given the exponential growth in the use of natural fibers, a promising class of engineering materials has emerged from the need to improve the properties of conventional materials. An example of this is the composite materials made from raw natural fibers and polymeric matrices, which, when combined, result in a new material with unique properties and an enhanced combination of characteristics compared to the individual materials that compose them. These materials have become one of the most investigated research topics in recent times [12,13,18]. This trend is not only due to environmental concerns but also to the favorable mechanical properties offered by the fibers at a lower cost, which has attracted the interest of the industry, seeking to introduce alternative materials into the market to replace synthetic components [19–21].

One of the industries that extensively uses natural fibers in the production of parts is the automotive sector. Manufacturers such as Audi, Volkswagen, Toyota, Mercedes-Benz, Volvo, and Ford utilize these composites with natural fibers. These materials are primarily employed in non-structural components of car bodies, such as door panels, package trays, hat trays, instrument panels, internal engine covers, sun visors, luggage liners, oil and air filters, and are even progressing towards more demanding structural parts like seat backs and external floor panels [22]. In addition to the automotive sector, these composites are also being applied in other areas such as maritime structures, military vest production, sports, and general engineering, with potential for use in aerospace, wind energy, and even space applications like satellites [11,19,23–27]. The applications of these composites are diverse, and there is a variety of new industrial applications that can be fully realized using the concept of sustainability, including recycling [19,25].

Table 2. Global production of natural fibers estimated by DNFI—Discover Natural Fibers Initiative in the period 2020–2023. Updated on 9 November 2023 [17].

Fiber	Global Production (Ton)			
	2020	**2021**	**2022**	**2023**
Abaca	75,889	83,501	72,000	66,000
Agave Fibers	40,625	40,743	41,000	41,000
Coir	1,101,498	1,115,349	1,145,000	1,175,000
Cotton	23,989,000	25,176,000	25,314,609	24,515,567
Other fiber crops	739,145	755,326	733,000	742,000
Flax, processed but not spun	974,806	896,636	851,805	851,805
True hemp, raw or retted	251,062	302,318	272,000	272,000
Jute, Kenaf and Allied fibers	2,874,000	3,175,600	3,095,000	2,700,000
Kapok	78,674	82,150	80,000	80,000
Ramie, raw or retted	62,228	10,138	10,000	10,000
Sisal, Henequen and similar hard fibers	280,800	281,400	273,000	278,000
Silk, raw	91,765	86,311	91,221	90,000
Total Natural Fibers	**31,606,868**	**33,069,866**	**33,100,000**	**31,900,000**

Since 2015, the United Nations has established a technical document signed by more than 190 countries, based on the sustainable development of their societies: the 2030 Agenda. One of the Sustainable Development Goals (SDGs) is dedicated to recyclable plastic (goal 12) and the elimination of the use of plastic bags (goal 14). Therefore, one of the greatest solutions to minimize the global problem of plastic pollution is to use sustainable, biodegradable, and recyclable plastics and composites [28]. Recycling plays a crucial role within a circular economy, an economic model that aims to minimize waste and optimize the use of resources [29]. Unlike the traditional linear model (production, use, and disposal), the circular economy seeks to keep materials and products in use for as long as possible, promoting reuse, repair, and recycling at the end of their life cycle [30,31]. Reuse and recycling contribute to environmental sustainability because the reduction in the extraction of new resources decreases pressure on the environment and, at the same time, reduces the amount of waste that can cause negative impacts associated with production [25]. Thus, the incorporation of recyclable and/or bio-based polymer matrices in composites can allow for recyclability, non-toxicity, and lower environmental impacts [19]. In addition to the use of recyclable matrices, the use of natural fibers allows for greater recyclability of the composite, as well as easier degradation in nature. Therefore, new sustainable industrial applications can be fully realized using the concept of sustainability design for Natural Fiber-Reinforced Polymer Composites (NFRPCs) [32], as shown in Figure 1.

Additionally, unused fiber residues from composite production can also be utilized. These lignocellulosic residues emerge as a promising option to serve as an alternative source of energy, being repurposed as raw materials in a differentiated manner. For instance, they can be used for heat or electricity generation, or for the production of materials and chemicals, following the principles of green chemistry that advocate for the use of renewable raw materials [33]. Another alternative to address the excessive accumulation of plant residues is the utilization of these residues as fillers in polymeric composites and other conventional engineering materials. Within this context, waste management brings benefits to both organizations and society, promoting the commercialization of these materials and generating income through recycling and sustainability practices [16]. This is highly advantageous, considering that Brazil is currently one of the main producers of various natural fibers, thanks to the great diversity of these materials in the country, especially those originating from the Amazon [34–36].

Figure 1. Diagram presenting the sustainable process of natural fiber-reinforced plastic composites. Reprinted with permission from ref. [32]. Copyright 2022, MDPI AG. Licensed under CC BY 4.0.

Considering the context of Brazil in the production of natural lignocellulosic fibers, the country is home to the Amazon region. The Amazon rainforest boasts the highest biodiversity on the planet, housing a wide variety of plant species. This region's biome stands out as the largest preserved forest in the world and the largest biome in Brazil, covering approximately 49.29% of the national territory and about 40% of the South American continent. With over 13,000 tree species, including 2956 endemic species, it is an incredibly rich ecosystem that contributes to a unique and unparalleled diversity in this region [37,38].

Encompassing all this diversity, Brazil demonstrates considerable potential to position itself as a global leader in the production of lignocellulosic fibers for use in composite materials [39]. This is already evident in the production of certain fibers, such as sisal, in which the country is the largest global producer, accounting for 44.7% of the world's total production of this fiber [35]. In addition to sisal, the country also stands out as one of the main global producers of cotton fiber.

Based on the information presented in this introduction, it can be inferred that lignocellulosic natural fibers are an attractive option for use in composite materials as substitutes for synthetic fibers. The objective of this article is to conduct a review on natural fibers from the Amazon region, highlighting some of the various fibers of Brazilian origin, describing their main characteristics and areas of occurrence, as well as providing an overview of the current use of these fibers in engineering applications. In this way, the aim is to promote knowledge and utilization of these Amazon fibers, with the intention of encouraging further studies in this field.

2. Characteristics and Properties of Natural Lignocellulosic Fibers

In this section, the concepts related to lignocellulosic natural fibers will be addressed in order to provide a better understanding to the reader. Definitions, classifications, characteristics, and properties of these fibers will be presented.

Fibers can be classified into natural or artificial fibers. In recent decades, there has been an increase in the use of natural fibers as a replacement for artificial fibers due to advantages such as low cost, low density, and reduced tool wear. Additionally, natural fibers exhibit similar or even superior properties in various applications [40,41]. The extensive utilization of natural fibers as reinforcement in composites has driven research in a wide range of fibers. There are three main types of natural fibers based on their origins: plant fibers, mineral fibers, and animal fibers. However, animal fibers such as hair and silk [42–44] and mineral fibers like asbestos and basalt [45–49] are not as widely used as reinforcement compared to plant fibers [50–52]. On the other hand, several plant fibers have been extensively employed in biocomposites for automotive, maritime, aerospace, and construction applications [53–61]. Plant fibers can also be classified based on the region of the plant from which they are extracted, categorized as bast, fruit, grass, seed, leaf, stalk, and wood fibers [62,63]. Figure 2 illustrates the classification of plant fibers according to their extraction source.

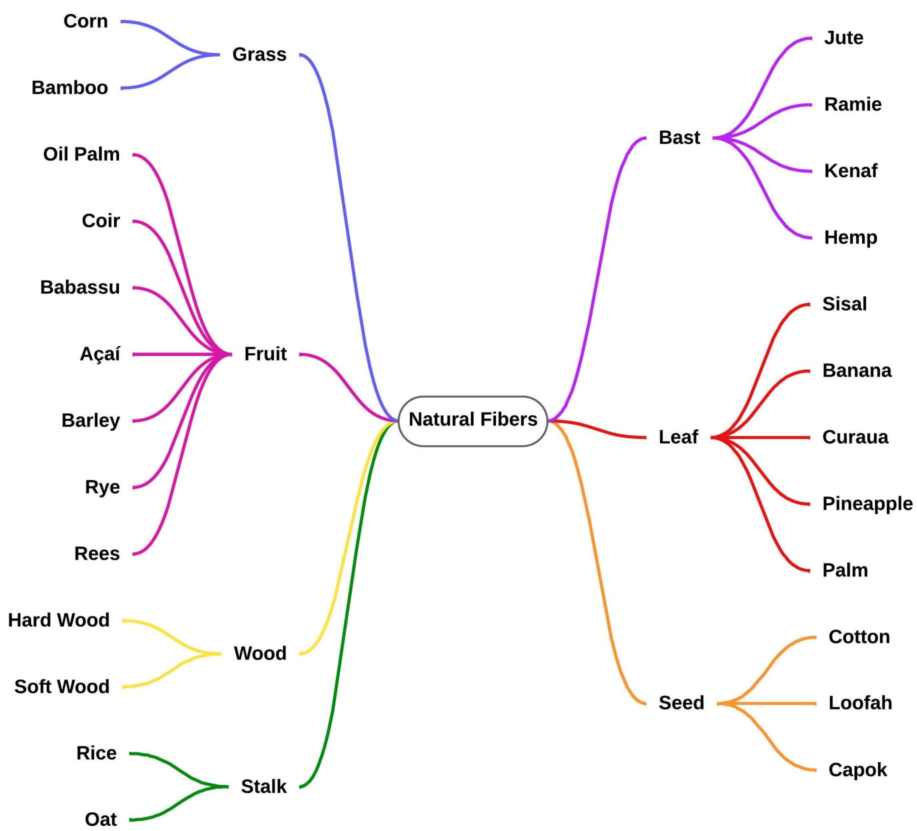

Figure 2. Classification of natural fibers based on the part of the plant of origin.

Natural fibers have satisfactory mechanical performance when used as reinforcement agents in composite materials [64]. Although they have lower tensile strength compared to synthetic fibers, they offer several significant advantages. Additionally, natural fibers are typically rigid and do not fracture during processing, exhibiting specific strength and stiffness comparable to glass fibers []. They also have lower density and competitive Young's modulus or elasticity [65]. The performance of polymer composites reinforced with natural fibers depends on various factors, including chemical composition, cell dimensions, microfibril angle, defects, structure, and the physical and mechanical properties of the fiber, as well as the interaction between the fiber and the polymer [66].

Natural fibers can be considered as natural composites, primarily composed of crystalline cellulose fibrils incorporated in an amorphous lignin matrix. These cellulose fibrils are aligned along the length of the fiber, and the effectiveness of natural fiber as reinforcement is related to the nature of cellulose and its crystallinity [67]. Figure 3, illustrated below, depicts the structure of a natural fiber.

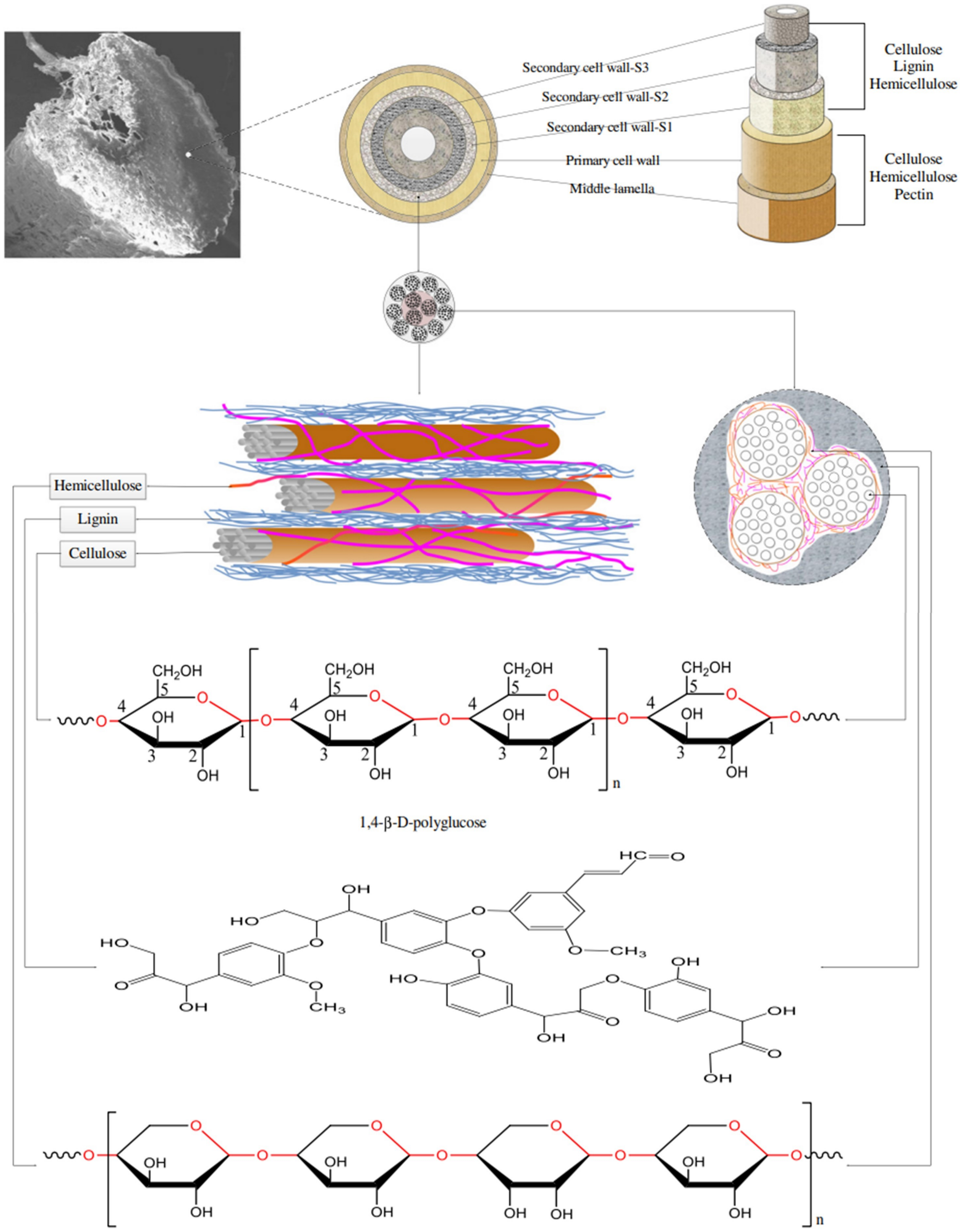

Figure 3. Schematic diagram of the natural fiber cell wall and its molecular structure. Reprinted with permission of ref. [68]. Copyright 2022, Elsevier.

Natural fibers, as shown in Figure 3, are composed of hollow cellulose fibrils interconnected by a matrix of lignin and hemicellulose [69]. The cell wall of a fiber is not uniform and consists of a complex layered structure. Each fibril has a thin primary wall, which is the first layer deposited during cell growth, surrounding a secondary wall. The secondary wall is composed of three layers, with the thick middle layer determining the mechanical properties of the fiber. This middle layer is formed by a series of helically twisted cellulose microfibrils, composed of long cellulose molecules [67].

These fibrils have a diameter ranging from 10 to 30 nm and are composed of 30 to 100 cellulose molecules in an extended chain conformation, providing mechanical strength to the fiber. The amorphous phase in a cell wall consists of hemicellulose, lignin, and in some cases, pectin. Hemicellulose molecules are linked by hydrogen bonds to cellulose and act as a cement matrix between cellulose microfibrils, forming the cellulose–hemicellulose network, which is considered the main structural component of the fiber cell. The hydrophobic network of lignin affects the properties of other networks, acting as a coupling agent and increasing the stiffness of the cellulose/hemicellulose composite [70].

The structure, microfibril angle, cell dimensions, defects, and chemical composition of the fibers are the most important variables determining their properties [71]. Typically, the tensile strength and Young's modulus of the fibers increase with increasing cellulose content. The microfibril angle determines the stiffness of the fibers. Vegetable fibers are more ductile when the microfibrils have a spiral orientation relative to the fiber axis. If the microfibrils are oriented parallel to the fiber axis, the fibers will be rigid, inflexible, and have high tensile strength [67]. Cellulose has a positive relationship with the tensile strength and Young's modulus of natural fibers, while lignin impairs these properties. In addition to cellulose, hemicellulose and wax contents have shown a positive correlation with the Young's modulus, while lignin and pectin reduce the values of the Young's modulus. Moisture absorption is affected by hemicellulose and lignin, where higher contents of these two components result in increased absorption [72,73]. Table 3 presents the relationship of each component in the natural fiber composition to their main characteristics and properties.

Table 3. The influence of chemical composition on the mechanical and physical properties of natural fibers. The (+) symbol represents a positive correlation and (-) symbol represents a negative correlation [73].

Chemical Component of Natural Fibers	Parameters of Mechanical Properties				Parameter of Physical Properties		
	Tensile Strength	Specific Young's Modulus	Failure Strain	Microfibril Angle (MFA)	Diameter	Density	Moisture Gain
Cellulose	+++	++	-	-	+	+++	-
Hemicellulose	-	+++	++	-	+	-	++
Lignin	-	-	+++	+++	-	-	++
Pectin	-	-	++	+++	-	+++	-
Wax	-	++	-	-	-	-	+

The properties of fibers are influenced by the microfibril angle and the arrangement within the cell wall [74]. Although plants are composed of lignocellulosic material, there are significant differences between different types of plants that affect how different plant materials can be used in the manufacturing process [75]. Figure 3 illustrates the position of the chemical components, while Table 4 presents the chemical properties of some natural fibers. The amount of cellulose increases from the primary layer (S1) to the secondary (S2) and tertiary (S3) layers, while the hemicellulose content remains constant in each layer and the lignin content decreases proportionally to cellulose. Hemicellulose binds to cellulose and together they form a network with lignin and pectin, providing adhesive quality. The S2 layer is responsible for the physical and mechanical strength of the fibers. Additionally, better strength properties are achieved with high cellulose content and lower microfibril angle [76,77].

Table 4. Composition of some fibers reported in literature.

Fiber	Cellulose (wt.%)	Lignin (wt.%)	Hemicellulose (wt.%)	Pectin (wt.%)	Wax (wt.%)	Reference
Flax	60–81	2	14–21	2–5	1–2	[78,79]
Hemp	57–78	3–13	11–22	1	0–3	[80–82]
Ramie	68–75	0.8–1.5	13–16	4–5	1–2	[83,84]
Kenaf	45–66	14–20	12–20	0.4–2.7	0.3–3	[40,85]
Guaruman	39–40	10–12	40–41	-	-	[86]
Jute	61–72	12–13	13–20	0.2	-	[87]
Sisal	67–78	8–12	10–14	10	2	[88,89]
Cabuya	48–84	8.3–17	0.5–11	-	2	[90,91]
Abacca	56–66	7–13	21–30	1–3	-	[91,92]
Betelnut	53	7	33	-	0.6	[93,94]
Banana	64–82	5–8.5	19	-	-	[95,96]
Coir	32–50	30–45	0.15–15	1.8–4	-	[97,98]
Bamboo	26–75	10–31	12–16	0.37	-	[99,100]
Bagasse	32–55	19–25	27–32	-	-	[101,102]
Sponge gourd	62	11.2	20	-	-	[102,103]
Rice husk	35–57	21	12–33	-	-	[104]
Wheat Straw	47–63	5.5–18.5	12–32	-	-	[105]
Oat	31–48	16–19	-	-	-	[91]
Napier Grass	45–59	20–24	20–33	-	-	[106]
Curaua	73.6	9.9	5.5	-	-	[107,108]
Henequen	60	8	25	-	2	[109]
Cotton	77–96	2–5	3	0.8–2.5	0.6	[91,110,111]
Nettle	72–84	2.2–7.5	6–12	-	-	[112,113]
Pineapple	49–82	5–31	6–13	-	-	[88,114,115]
Hard Wood	70–74	2.6–5.2	0.5–0.7	-	-	[116]
Soft Wood	40–45	25–34	20–30	-	-	[117,118]
Piassava	28–32	45–48	25–26	-	-	[119–121]
Açai	45–47	31–34	10–15	-	-	[122]
Phormium tenax	67	11	30	-	-	[123]
Sansevieria ehrenberg	80	3.8	10	-	0.1	[124]
Sea Grass	40–77	5–11	14–38	10	-	[91,125]
Isora	71–75	21–23	3.1	-	-	[126,127]
Oil Palm	60	11	-	-	-	[128]
Rachis	43–45	26	28–31	-	-	[129]
Rachilla	42	16	-	-	-	[91,130]
Coconut	26–50	49–53	6–43	-	-	[131,132]
Barley	31–45	14–15	-	-	-	[91]
Pigeon Pea	55	18	-	2.4	-	[133]
Arundo donax L.	75.3	4.3	-	-	-	[134]
Rye	33–50	16–31	16	-	-	[91,135]
Esparto	42–44.5	12–17	25.6–27.5	-	-	[136]
Sabai	43–67	14–18	13–21	-	-	[137]
Phragmites communis	43–48	10–11	33–36	-	-	[138]
Coniferous	40–45	26–34	-	-	-	[91]
Deciduous	38–49	23–30	-	-	-	[91]
Cytostachys renda	42–49	17–22	19–23	-	-	[139]
Phychosperma macarthurii	39	18.2	19.1	-	-	[91]
Petiole bark	29–48	23–42	-	-	-	[140]
Kudzu	43–78	18–42	1–18	-	-	[141]

Based on the data presented in Table 4, a variation in the composition of different species of natural fibers can be observed, as reported in previous studies in the literature. Although there are sometimes significant differences in fiber composition, one factor that remains constant is the high cellulose content, always higher than the content of other fiber components. However, it is important to note that the cellulose level alone is not the sole determinant of the properties of natural fibers, but rather a series of interconnected factors.

These factors include environmental growth conditions, extraction methods, harvesting timing, and harvesting methods [142]. Plant age, harvesting method, and fiber extraction method are crucial in determining fiber quality and, consequently, the quality of composites produced with these fibers.

Natural fibers with a relatively high cellulose content include jute, pineapple, flax, and ramie. Basically, a high cellulose content and a lower amount of lignin provide high tensile strength, as can be observed in the example of these fibers in Table 5. However, the correlation is not always linear due to various factors that affect tensile strength. Cellulose, especially in its crystalline parts, exerts a significant influence on the tensile strength value, as higher cellulose crystallinity leads to greater fiber strength. The position of lignin in the biomass also affects tensile strength, making it lower, as lignin is located between cellulose and hemicellulose and exhibits lower resistance.

As noted in Table 5, most natural fibers have a maximum density close to 1.60 g/cm^3, making them heavier than water. Although some natural fibers, such as vakka, bamboo, and rachila abaca, among others, are hollow and have low densities in their natural state, they are often densified during processing. Thus, the density of natural fibers is considerably lower than that of synthetic fibers such as glass and carbon fibers.

The low density of natural fibers makes them attractive as reinforcements in engineering applications, as weight is a crucial factor in certain applications. Natural fibers are added to matrices, usually plastics, to improve mechanical performance, such as stiffness and strength, without significantly increasing density [143]. The generally lower impact performance of natural fiber composites compared to synthetic fiber composites tends to limit their use, and addressing this issue is an active area of research. The low density of natural fibers offers more flexibility in composite structure design [,[144]]. Thus, low density plays a significant role in reducing the weight of biocomposites, making them competitive in terms of mechanical properties [145]. In general, the use of natural fibers allows for a reduction in composite weight between 40 and 50%, while maintaining good tensile strength and modulus values [146].

To enhance the properties of natural fibers, interfacial adhesion with composites, and consequently, the properties of the composites, natural fibers undergo treatments, either physical or chemical, that improve their properties [147]. Natural fibers typically exhibit poor hydrophilic properties, resulting in low chemical resistance, inferior mechanical properties, and a porous structure, limiting their engineering applications [148,149]. The hydrophilic nature also reduces the applicability of textile products, especially in transportation and packaging [150]. Therefore, various treatments are applied to the fibers, generally leading to improvements in their properties. Among the physical treatments used to improve the properties of fibers, Corona Discharge, Plasma Treatment, Ultraviolet (UV) Treatment, Fiber Beating, and Heat Treatment are notable. Corona Discharge is particularly effective in surface oxidation of fibers, resulting in a change in the surface energy of cellulose fibers and improving compatibility with hydrophobic matrices [151]. Plasma treatment, on the other hand, has proven to be an efficient option for removing impurities and dust particles from fibers, leading to an enhanced fiber surface. Precise control of gas type, pressure, and concentration is crucial for effective processing [152]. Regarding UV treatment, this relatively new approach stands out for its ability to remove dust particles from the surface of plant fibers. However, it is important to note that certain factors, such as flow and gas type, are not controlled during this treatment [148,153].

Table 5. Comparison of the tensile properties of various natural fibers with synthetic fibers [154].

Fiber	Density (g/cm^3)	Diameter (μm)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation (%)
Jute	1.46	-	393–800	10–30	1.5–1.8
Sisal	1.45	30–300	227–400	9–20	2–14
Pineapple	1.44	20–80	413–1627	345–825	0.8–1
Kenaf	1.40	81	250	4.3	-
Red Banana	-	-	482–567	-	30.6
Nendranbanana	-	-	407–505	-	28.3
Rasthalybanana	-	-	304–388	-	27.8
Morrisbanana	-	-	222–282	-	24.2
Poovanbanana	-	-	144–206	-	21.8
Vakka	0.81	175–230	549	1.5–8.5	3.46
Abaca	0.83	114–130	418–486	12–13.8	-
Alfa	0.89	-	35	22	5.8
Softwood kraft pulp	1.5	-	1000	40	4.4
Viscose	-	-	593	11	11.4
Wool	-	-	120–174	2.3–3.4	25–35
Nettle	-	-	650	38	1.7
Flax	1.50	-	345–1500	27.6–80	1.2–3.2
Hemp	1.48	-	550–900	70	1.6
Banana	1.35	80–250	529–759	8–20	1–3.5
Coir	1.15	100–460	108–252	4–6	15–40
Root	1.15	100–650	157	6.2	3
Palymyrah	1.09	70–1300	180–215	7.4–604	7–15
Date	0.99	-	309	11.3	2.7
Bamboo	0.91	-	503	35–91	1.4
Talipot	0.89	200–700	143–294	9.3–13	3.2–5
Snake Grass	0.88	45–250	279	9.7	2.9
Elephant Grass	0.81	70–400	185	7.4	2.5
Petiole Bark	0.69	250–650	185	15	2.1
Spatha	0.69	150–400	75.6	3.1	6
Rachila	0.65	200–400	61	2.8	8.1
Rachis	0.61	350–408	73	2.5	13.5
Coconut tree leafs heath	-	-	119.8	18	5.5
Sansevieria ehrenbergii	0.88	20–250	50–585	1.5–7.7	2.8–21.7
Sanseveria rifasciata	0.89	83–93	526–598	13.5–15.3	-
Sanseveria cylindrica	0.91	230–280	585–676	0.2–11.2	11–14
Palm	1.03	400–490	377	2.75	13.7
Agave	1.20	126–344	-	-	-
Henequen	1.20	-	430–470	11.1–16.3	3.7–5.9
Bagasse	1.25	200–400	290	11	-
Curaua	1.40	170	158–729	-	5
Sea Grass	1.50	5	453–692	3.1–3.7	13–26.6
Oil Palm	0.70–1.55	150–500	80–248	0.5–3.2	17–25
Piassava	1.4	-	134–143	1.07–4.59	7.8–21.9
PALF	0.80–1.60	20–80	180–1627	1.44–82.5	1.6–14.5
Ramie	1.00–1.55	20–80	400–1000	24.5–128	1.2–4.0
Isora	1.20–1.30	-	500–600	-	5–6
Hivernal	-	12.9 ± 3.3	1111 ± 544	71.7 ± 23.3	1.7 ± 0.6
Alaska	-	15.8 ± 4.1	733 ± 271	49.5 ± 3.2	1.7 ± 0.6
Niagara	-	15.6 ± 2.3	741 ± 400	45.6 ± 16.7	1.7 ± 0.6
Oliver	-	13.7 ± 3.7	899 ± 461	55.5 ± 20.9	1.7 ± 0.8
Cotton	1.60	-	287–597	5.5–12.6	3–10
E—glass	2.55	17	3400	73	3.4
S—glass	2.50	-	4580	85	4.6
Aramid	1.4	11.9	300	124	2.5
HS Carbon	1.82	8.2	2550	200	1.3
Carbon (Std. PAN-based)	1.4	-	4000	230–240	1.4–1.8

During the UV treatment process, the fibers are placed in a chamber for surface oxidation. Additionally, UV treatment increases the polarity of the fiber surface, improving fiber wettability and resulting in higher strength of the NFRPCs [151,152].

Chemical treatments have a significant impact on the mechanical properties of NFRPCs [155–157]. This is due to the presence of hydroxyl groups in cellulose and lignin [158]. Chemical treatment strategies involve the use of reagents or active groups capable of interacting with the structures of natural fibers, removing non-cellulosic materials [159]. Additionally, the hydroxyl groups resulting from chemical treatments can form hydrogen bonds within the cellulose fibers, limiting their movement towards the matrix [78,155]. As a result, chemical modifications activate these groups or introduce new structures that effectively bond with the matrix, promoting good adhesion [160]. Table 6 provides a summary of the main chemical treatments and their primary effects on the natural fibers.

Table 6. Different chemical treatments and their effect on natural fibers [147].

Chemical Treatment	Improvement in Natural Fibers
Alkaline treatment	Adhesion
Silane treatment	Control Fiber Swelling
Acetylation treatment	Moisture absorption
Benzoylation treatment	Thermal stability
Peroxide treatment	Adhesion
Maleated coupling agents	Bonding between fibers and matrix
Sodium chlorite treatment	Moisture absorption
Acrylation and acrylonitrile grafting	Coupling
Isocyanate treatment	Bonding
Oleoyl chloride treatment	Wettability
Stearic acid treatment	Water resistance
Permanganate treatment	Adhesion
Fungal treatment	Remove lignin
Triazine treatment	Adhesion

In addition to characteristics such as recyclability, low density, mechanical properties, and treatments to improve fiber adhesion and properties, another important factor in choosing natural fibers is cost. Natural fibers have significantly lower purchasing costs compared to synthetic fibers [161,162]. However, a more accurate comparison of composite production costs should be performed specifically during the processing of each individual fiber and its use in a particular matrix. Factors such as the lifespan of the component can interfere with large-scale production costs, where logically, synthetic fibers would have an advantage due to their greater durability. However, each application will determine the requirements that need to be evaluated to determine the feasibility of raw material and production costs for NFRPCs. Huda et al. [163] investigated the costs of natural fibers and synthetic fibers for application in the automotive industry. According to the results obtained by the authors, natural fibers require much less energy to produce, which leads to advantages in terms of cost and energy compared to traditional reinforcement fibers such as fiberglass and carbon fiber. This comparison is shown in Table 7.

Table 7. Comparison of cost and energy expenditure for the production of natural and synthetic fibers [163].

Fibers	Cost (USD/Ton)	Energy (GJ/Ton)
Natural fibers	200–1000	4
Glass fiber	1200–1800	30
Carbon fiber	12,500	130

3. Amazon Natural Fibers

The Amazon region is globally recognized for its immense natural and cultural diversity. Located in South America, the Amazon spans eight countries: Brazil, Bolivia, Colombia, Ecuador, Guyana, Peru, Venezuela, and Suriname. However, the majority of its expanse is located in Brazil. The Amazon stands out for harboring the greatest fauna and flora on the planet, representing approximately 20% of the world's biodiversity [164]. Figure 4 illustrates a map of South America, highlighting the Brazilian Amazon region.

Figure 4. Map of South America, highlighting Brazil and its main biomes: Amazon, colored in green; Cerrado, colored in orange; Pantanal, colored in red; and the Legal Amazon Region, highlighted with green dashed lines. Reprinted with permission from ref. [165]. Copyright 2023, Nature. Licensed under CC BY 4.0.

The Amazon rainforest is rich in plant species that produce high-quality fibers used for a variety of purposes. Among the most well-known fibers are ubim, jute, buriti, piassava, and tucum. Each of these fibers has unique characteristics and interesting properties that make them valuable for different applications.

These natural fibers from the Amazon are widely used by local communities, both for traditional crafts such as baskets, mats, and nets, and for the construction of rural dwellings. Additionally, these fibers generate interest in the global market, being used in the textile industry, paper production, furniture manufacturing, and the creation of sustainable products.

In this section, we will discuss some plant fibers from the Amazon region that have applications in engineering composites. Among the countless plants from which fiber can be extracted, whether from leaves, stems, fruits, or roots, 10 fibers have been selected for this study. Throughout the review, we will address topics such as plant aspects, occurrence regions, fiber extraction characteristics, examples of fiber property characterization, and their application in composite materials, aiming for sustainability in the production of engineering materials with excellent properties.

3.1. Açaí

The açaí palm, scientifically known as *Euterpe oleraceae Mart.*, is a palm tree belonging to the Arecaceae family and is widely cultivated in the Brazilian Amazon region (Figure 5a). This plant is prominently featured due to its economic significance in regional fruit cultivation, particularly in the state of Pará, where the production and commercialization of açaí pulp generate a significant market [166]. The fruit holds considerable nutritional value and is a fundamental part of the diet in the states of Pará and Amapá. Its composition is characterized by high levels of lipids, proteins, fibers, and anthocyanins [167]. The primary cultivation areas for this species are located in the estuary region of the Amazon River, considered its center of origin. In this area, dense and diverse populations inhabit periodically flooded lands due to tides [168].

The mature fruit exhibits a color ranging from purple to almost black, as illustrated in Figure 5b. The pulp can be obtained through the pulping process, which can be performed manually or mechanically. This pulp is consumed fresh or used in the production of various products such as cream, liqueur, jelly, porridge, ice cream, and sweets [169–171].

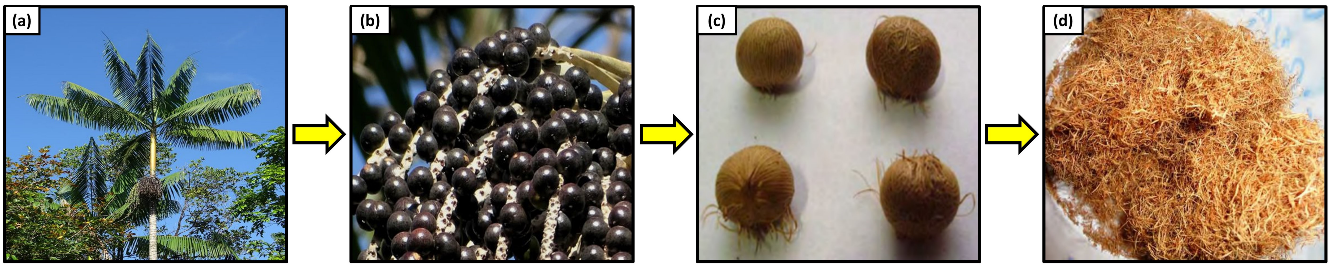

Figure 5. Açaí (*Euterpe oleraceae Mart.*): (**a**) palm tree; (**b**) açaí fruit; (**c**) fruit after drying; (**d**) fiber extracted from the fruit. Figures (**a**,**b**) reprinted with permission from ref. [172]. Licensed under CC BY-NC 4.0. Figures (**c**,**d**) reprinted from ref. [173].

The açaí fruit has a rounded shape, and approximately 70% of the fruit consists of residues, with only 3% of these residues being composed of lignocellulosic fibers. Although these residues can be used in bioenergy production, it is advisable to separate the fibers from the seeds since burning these components together can result in charcoal with varied chemical composition and thermal behavior, potentially altering the physical and mechanical properties of a specific material in which açaí fiber has been used [174].

The fibers from the açaí mesocarp are by-products of pulp extraction and adhere to the fruit's seed, as shown in Figure 5c,d [174]. These fibers are lignocellulosic in nature and have an elliptical shape with an average thickness of 130 μm and a length of about 18 mm. They have a slightly higher density than water, approximately 1.11 g/cm^3. Generally, açaí fibers are underutilized due to their toxic residues, leading to various environmental issues, and the extracted fiber yield is low [175–177].

Despite açaí being well-known, primarily for consumption, the properties of its fiber are relatively unexplored. Nevertheless, there are studies in the literature that examine the fiber's properties and its application in composite materials. Castro et al. [178] conducted a study on the production of composites using two distinct polymeric matrices, namely, polypropylene (PP) and high-impact polystyrene (HIPS), both derived from recycling processes. In this study, pressed açaí fibers were employed as reinforcement agents in the composites. The manufacturing of the composites took place through the hot compression method, and their properties were subsequently evaluated through tensile, compression, and impact tests. The tensile test results revealed significantly superior performance for the PP/açaí composite compared to the HIPS/açaí composite. Furthermore, the PP/açaí composite demonstrated higher impact resistance when contrasted with the HIPS/açaí composite. Notably, the HIPS/açaí composite exhibited superior properties only in terms of compression resistance, indicating an overall inferior mechanical behavior. This phenomenon is attributed to the low interfacial adhesion present in the HIPS/açaí composite. Thus, this study emphasizes the importance of the choice of polymeric matrix and the quality of the interface between components in determining the mechanical properties of composites.

Bastos et al. [179] conducted a study in which they developed panels made solely of pressed açaí fibers for sustainable application in the acoustic insulation of a classroom. The authors extracted the açaí fibers from the fruit and used a binder to keep the panels fixed during the cold compression process. Acoustic parameter measurements were taken, simulating the effects in a classroom. After simulating and testing the panels, the authors demonstrated that açaí fiber panels are a highly attractive solution for schools in the Northern Region of Brazil, as they combine low cost and good acoustic performance.

Martins et al. [180] analyzed the morphological characteristics and thermal stability of manually extracted açaí fiber from the fruit. Through thermogravimetric analysis conducted in a nitrogen (N_2) atmosphere and an oxidative atmosphere, the authors reported that the fiber exhibited good thermal stability when the test was conducted in a nitrogen atmosphere. However, thermal stability was compromised when heating was carried out in an oxidative atmosphere. The morphological analysis illustrated in Figure 6 showed that the fibers completely cover the açaí seed, and the fiber surface has numerous pores that may facilitate interfacial adhesion in a polymeric matrix.

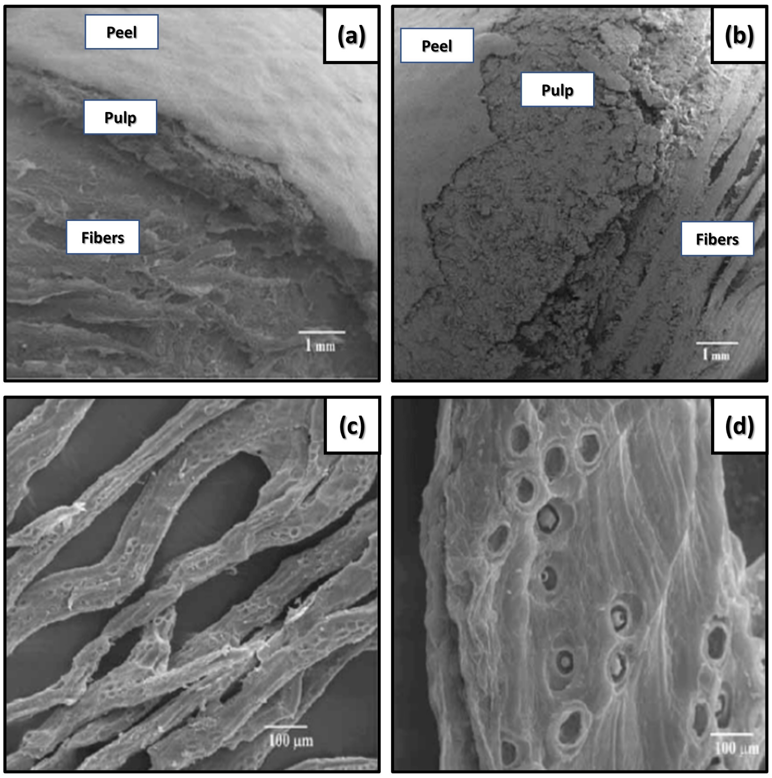

Figure 6. SEM micrographs of different regions of açaí: (**a**) fruit micrograph indicating the regions of peel, pulp, and fibers; (**b**) another region indicating the position of peel, pulp, and fibers; (**c**) micrograph of fine açaí fibers; (**d**) micrograph of a wider açaí fiber, showing the presence of pores and imperfections on the surface. Adapted with permission from ref. [180]. Licensed under CC BY 4.0.

3.2. Babassu

The babassu, belonging to the Arecaceae family and the Attalea genus, has the Brazilian species *Attalea speciosa*, a palm tree that can reach up to 20 m in height, as illustrated in Figure 7a. Its fruit contains oleaginous and edible seeds, with a high number of coconuts per cluster (between 150 and 250) and an average of four clusters per palm tree [181]. The fruits, as shown in Figure 7b, are ellipsoidal, measuring 8 to 15 cm in length and 5 to 7 cm in diameter, weighing between 90 and 280 g [182,183]. In Brazil, there are numerous babassu groves distributed from the southern Amazon region to the northeast, with occurrences also in Bolivia for the *Attalea speciosa* species [184].

In the states of Maranhão, Piauí, and Tocantins, the largest expanses of babassu forests in Brazil are found, forming homogeneous, dense, and naturally dark clusters due to the proximity of the large babassu palm trees [185]. This region is recognized as the world's largest concentration of oil-producing plants and the primary source of extractive plant production, known as the "Mata dos Cocais" [186].

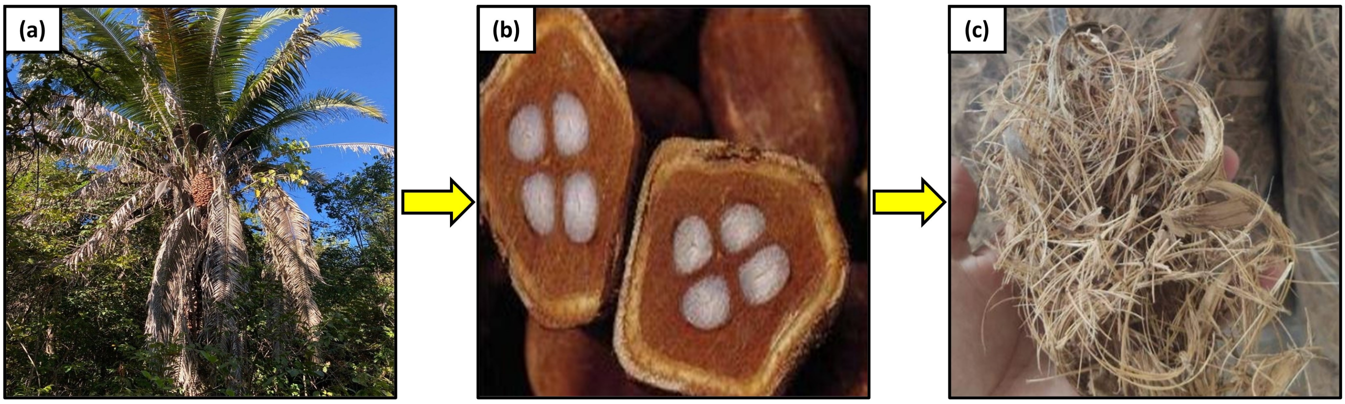

Figure 7. Babassu (*Attalea speciosa Mart ex Spreng.*): (**a**) palm tree; (**b**) babassu fruit; (**c**) fiber extracted from the fruit. Figures reprinted with permission from ref. [187]. Licensed under CC BY-NC 4.0.

The production of babassu nuts is of significant importance for generating income for thousands of families that rely on babassu nut harvesting, with estimates suggesting that over 300,000 women depend on this activity. After maturation, the babassu nut falls to the ground, where it is harvested by workers. It is also collected by climbing the palm tree. When collected, it is transported in straw baskets, typically on the backs of animals. When not possible, the nut cracking is carried out at the base of the palm tree. The fruits are broken in a rudimentary manner, usually by women, using a machete as a cutting tool and a wooden bar for mechanical action. The babassu nut is a fruit that can be fully utilized [188].

Unlike other plants that yield natural fibers, babassu has a distinctive characteristic: the practicality of utilizing almost all parts of the plant. Its trunk is used for structural support in the construction of houses in these regions, and the leaves are used for roofing houses, fences, and in the fabrication of small utensils such as baskets and fans. From the babassu nut, almonds are extracted and used in the production of oil known as "azeite". The mesocarp is used to prepare flour with medicinal properties, and the husk is employed in charcoal production. These products are used in the daily lives of families [189]. It is possible to obtain more than 60 products from babassu, many manufactured from the nut, such as oil, "azeite", milk, for both fresh consumption and industries like food, cleaning materials, personal hygiene, cosmetics, as well as charcoal, fertilizers, and other by-products [190–192].

Babaçu fibers are manually obtained, extracted from both the coconut and the palm tree trunk. However, the most common extraction method is from the coconut. Chaves et al. [193] conducted the extraction of babaçu fibers with the aim of characterizing their properties for potential application in composites. Throughout the study, the authors followed a sequence of steps to obtain the fibers. Initially, the babaçu coconut is left to dry for 48 h for dehydration. Subsequently, the coconut shell is placed in a container for washing, where it remains for a period of 7 days. This phase is crucial to facilitate the extraction of fibers in the subsequent defibration process. Figure 8 illustrates the steps of fiber extraction carried out by the authors.

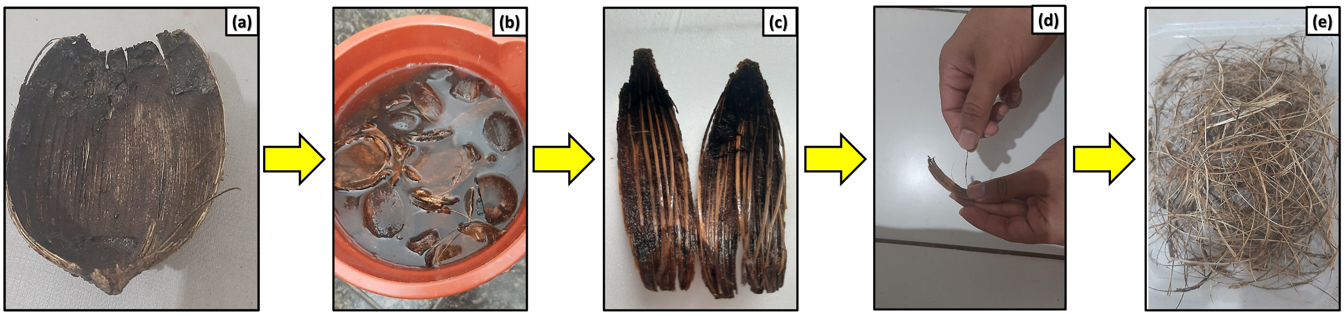

Figure 8. Steps of babassu fiber extraction: (**a**) babassu coconut in drying process for 48 h; (**b**) washing babassu; (**c**) babassu after washing, ready for defibrillation; (**d**) manual defibrillation process; (**e**) extracted babassu fibers. Reprinted with permission from ref. [193]. Licensed under CC BY-NC-ND 4.0.

The babassu palm already has a significant history of applications, as mentioned earlier, including the use of its fibers in composites for engineering applications. In addition to the analysis of the properties of the fiber in isolation [193–195], the investigation of composite materials using this fiber as a reinforcing agent enables its application in various engineering fields while maintaining a sustainable approach to plastic materials.

An example is highlighted in the work of Furtado et al. [196], in which the authors produced low-density polyethylene (LDPE) composites reinforced with babassu fibers at concentrations ranging from 5 to 20 wt.%. They conducted a comprehensive analysis of the mechanical and photodegradative properties, simulating solar and ultraviolet (UV) radiation conditions, aiming for potential use in biodegradable plastic bags. The results obtained by the authors were promising for the composites, revealing good interfacial adhesion between the fiber and the polymeric matrix. Additionally, photodegradation tests indicated degradation under exposure to sunlight and UV, without the release of CO_2 groups into the atmosphere. These results highlight babassu as a viable and highly potential option for the production of biodegradable and cost-effective plastic bags.

Dourado et al. [197] used babassu fibers as reinforcement in cementitious mortars, applying an alkaline treatment to the fibers to enhance the interfacial adhesion between the reinforcement phase and the matrix. Scanning Electron Microscopy images revealed the removal of a superficial layer, reducing the fiber's adhesion to the matrix. Consequently, through tensile tests, the authors observed that the treated fibers exhibited higher tensile strength compared to untreated fibers. Additionally, liquid absorption tests indicated that the treated fibers showed lower total absorption. The incorporation of fibers into the mortar significantly increased the compressive strength of the composites, coupled with a reduction in porosity and water absorption. Overall, the addition of babassu fibers resulted in enhanced strength of the cementitious composites, making this material attractive for the construction industry.

Marinho et al. [198] investigated the biodegradation properties of polyhydroxybutyrate (PHB) composites reinforced with 20 wt.% of babassu fibers and different types of stabilizers. The authors conducted soil biodegradation tests and observed that composites with various stabilizers exhibited a more significant mass variation, indicating a better biodegradation capacity, as illustrated in Figure 9. Figure 9b–d present the results of the modulus of elasticity, tensile strength, and elongation at break properties obtained through tensile tests for both biodegraded and non-biodegraded samples. The results indicated a drastic reduction in the properties of the composites after biodegradation, emphasizing the ease of degradation of these materials in the environment and their utility as eco-friendly materials.

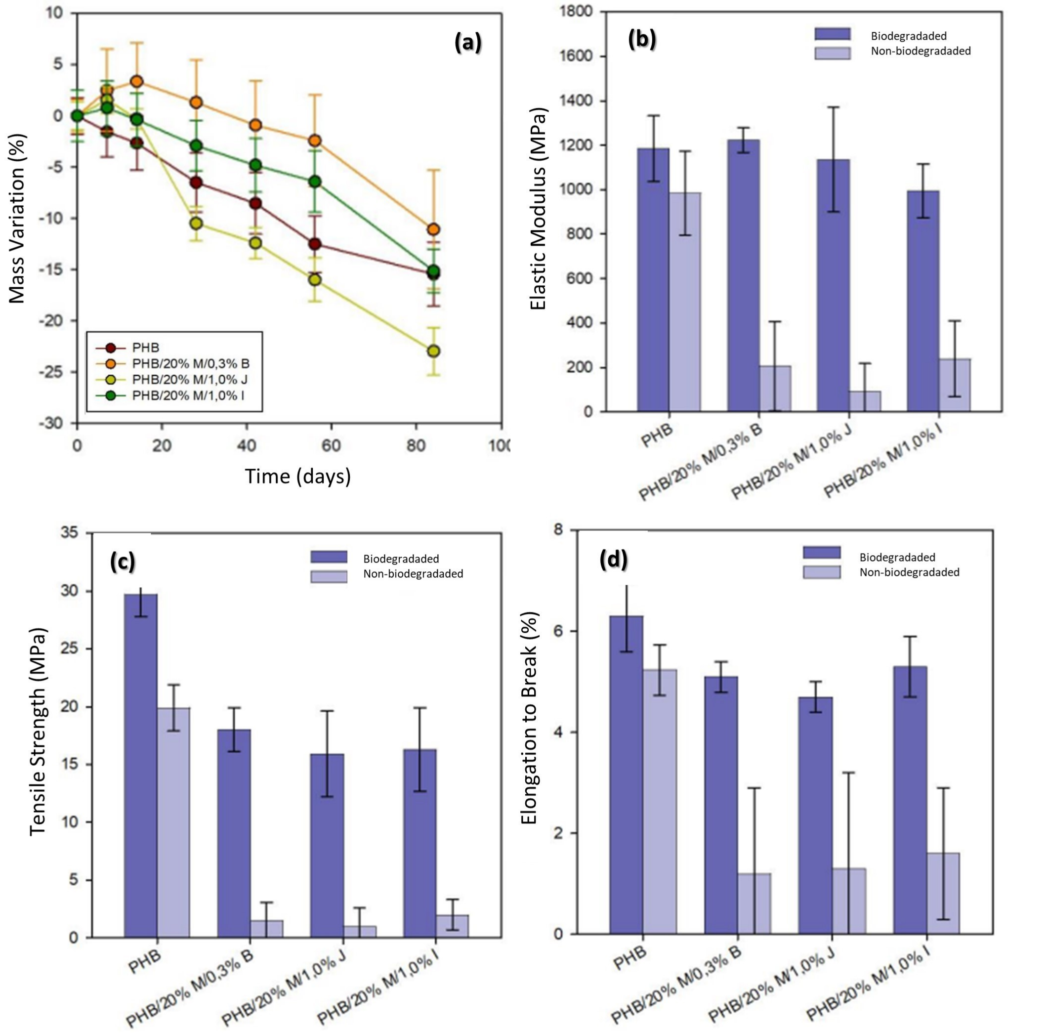

Figure 9. Results of the properties of PHB/babassu composites: (**a**) biodegradation results; (**b**) effect of biodegradation on the elastic modulus of the composites; (**c**) effect of biodegradation on the tensile strength of the composites; (**d**) effect of biodegradation on the elongation at break of the composites. Adapted with permission from ref. [198]. Licensed under CC BY-NC-ND 4.0.

3.3. Buriti

The fiber from the Buriti palm (*Mauritia Flexuosa*) originates from a plant that is widely found in different regions of Brazil, with the main occurrence in the Amazon. Although buriti is also found in the Brazilian central region, as well as in the states of Bahia, Ceará, Maranhão, Minas Gerais, and Piauí, it is found predominantly in regions with a tropical climate, with an annual average temperature of between 26 °C and 30 °C and a rainfall of between 200 mm and 400 mm [199,200].

Buriti palm trees (Figure 10a) display some notable characteristics, reaching significant heights of up to 40 m, with a stem diameter between 50 and 60 cm. The leaves, which are over 15 cm long, remain attached to the stem after death, before eventually falling off. These leaves are widely used to make handicrafts and as roofing material in community dwellings. The fruit of the Buriti palm tree has horny scales with a reddish-brown hue, while the inner pulp displays an orange color. This pulp proves to be versatile, serving as human food, bait for hunting, a source of oil, and with potential medicinal applications. This diversity of uses highlights the ecological and socioeconomic significance of this species in local communities [201].

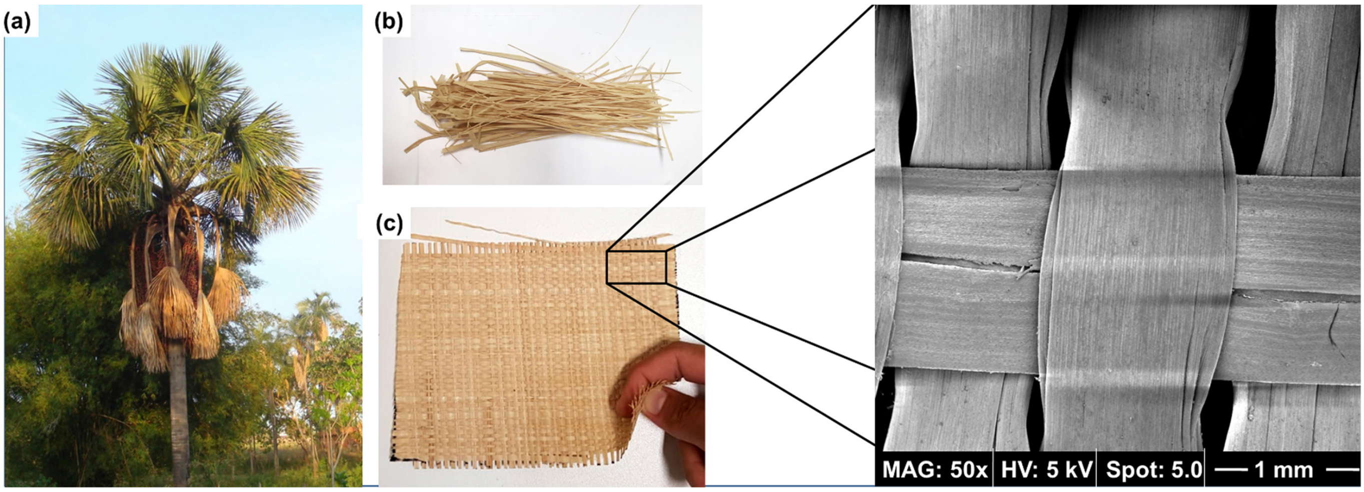

Figure 10. *Buriti (Mauritia flexuosa.)*: (**a**) palm tree; (**b**) bundle of fibers extracted from the leaf; (**c**) fabric produced from the extracted fibers with an inset for viewing the weave from an SEM micrograph. Reprinted with permission from ref. [202]. Copyright 2020, Elsevier. Licensed under CC BY-NC-ND 4.0.

Products derived from buriti have gained high market value, and the practice of destructive harvesting of palm trees is a growing concern. The felling of palm trees to collect fruit in the Peruvian Amazon has been documented as a threat since the late 1980s [203]. Other products, such as young leaves and oil extracted from the buriti palm, are rapidly gaining economic value, presenting potential challenges of overexploitation [204]. Considering that a buriti palm produces, on average, one leaf per month [205], the intensive collection of young leaves, as opposed to the collection of fallen fruit and extraction of mature leaves for subsistence, can result in significant negative impacts on the sustainability of the buriti palm. In addition to its commercial value, buriti plays a vital role in indigenous communities, being one of the most relevant plant species for their subsistence needs, such as food, shelter, building material, and ornaments [206].

The extraction of buriti fiber (Figure 10b,c) is carried out in an artisanal manner, where residents of rural areas climb the trees, remove the green leaves, and cut the fibers, which can be obtained from both the leaves (known as linen) and the petiole [207]. The petiole, or stem of the leaf, can reach up to 3m long and its fibers have a high cellulose content (77.8%) and a low lignin content (24.0%). These fibers, extracted from the epidermis of the petiole, are useful for making mats and curtains [208]. However, a deep understanding of the inherent physical and chemical properties and characteristics of buriti fiber is essential to anticipate the behavior of this material when used as reinforcement in polymer matrix composites. Based on the properties and characteristics exhibited by buriti fibers, several researchers suggest their application as reinforcement in polymer matrix composites [209–212].

The buriti fibers exhibit a comparatively low density ranging from 0.63 to 1.12 g/cm^3, coupled with a moderate tensile strength within the range of 129 to 254 MPa. This characteristic renders them suitable as reinforcement for polymer composites characterized by lower density yet relatively weaker strength [213].

The epoxy composite reinforced with buriti fabric at 10 vol.% showed promising results as a second layer of MAS against high-speed level III NIJ ammunition [214,215]. The work evaluated the ballistic performance of composite fabrics reinforced with synthetic and natural fabrics as a second layer of MAS with the same thickness (10 mm). Figure 11 shows a comparison in terms of indentation depth caused by the impact of a 7.62 mm projectile against a clay witness simulating a human body. However, this buriti fabric composite was unable to maintain its integrity after the impact of the 7.62 mm projectile. In practice, this constitutes a ballistic failure in a multiple-impact test, which requires the second MAS layer to be a whole number after six shots, according to the [215]. As a second MAS layer, the smaller the indentation depth, the better the ballistic performance. A depth greater than 44 mm is considered lethal trauma for a human being.

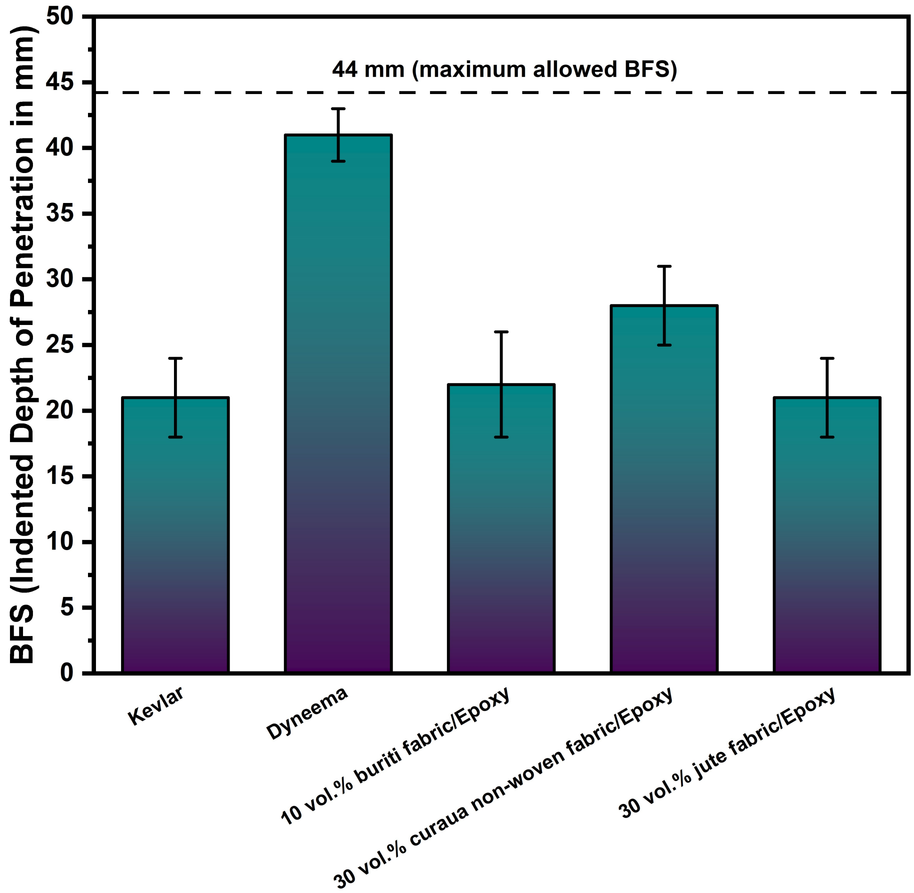

Figure 11. Comparison between the ballistic performance of both synthetic fabrics and natural fiber-reinforced polymer composites as the MAS second layer with the same thickness. Adapted from ref. [208].

According to Demonsthenes et al. [208], the buriti composites reinforced with 10 vol.% epoxy failed to maintain their integrity and are not recommended according to the NIJ Standard [215]. Those reinforced with 20 vol.% buriti showed cracks, indicating that they also do not comply with the NIJ Standard. However, the composites reinforced with 30 vol.% showed partial damage caused by the cloud of fragments in the center of the plate, but did not manifest any open failure, unlike the 10 vol% and 20 vol% composites. This suggests that the 30 vol% proportion can be used as a material for ballistic vests, resisting level III 7.62 mm ammunition.

Cattani and Ramos [216] explored differents treatments for fibers extracted from a buriti palm tree, separated into five different groups: the group of fibers in natura; the fibers boiled by the original community; the fibers boiled in bleach (2–2.5 % sodium hypochlorite, boiled in 500 mL of water and 30 mL of bleach for 15 min); the fibers boiled in fabric softener for 15 min (boiled in 500 mL of water and 30 mL of fabric softener for 15 min); and the fibers boiled in lemon juice (500 mL of water with half a Tahiti lemon for 15 min). The results of the tensile properties of these fibers are shown in Table 8. According to the authors [216], there is no significant difference in the tensile properties associated with the treatment.

Table 8. Results of tensile tests. The values are expressed as average of 20 determinations, including standard deviation and variation coefficient [216].

Set of Samples	Count Number (tex)	Rupture Strength (N)	Toughness (cN/tex)	Elongation (%)	Young Modulus (N/tex)
In natura fibers	223.4 ± 77.7 (34.8%)	64.1 ± 28.0 (43.6%)	28.4 ± 5.5 (19.6%)	8.3 ± 0.5 (6.8%)	6.1 ± 0.8 (13.1%)
Fibers boiled by the origin community	196.9 ± 71.7 (36.4%)	60.4 ± 25.7 (42.6%)	31.1 ± 7.6 (24.7%)	8.3 ± 0.7 (9.2%)	7.2 ± 0.6 (9.5%)
Fibers boiled in bleach	199 ± 81.8 (41.1%)	55.3 ± 28.6 (51.7%)	27.6 ± 7.1 (25.9%)	7.8 ± 0.5 (7.4%)	5.9 ± 1.1 (19.9%)
Fibers boiled in softener	208.7 ± 83.8 (40.1%)	49.9 ± 31.8 (63.7%)	22.0 ± 8.7 (39.7%)	8.6 ± 1.8 (21.5%)	4.9 ± 0.9 (19.7%)
Fibers boiled in lemom juice	194.6 ± 67.2 (34.5%)	58.4 ± 25.9 (44.3%)	29.7 ± 6.4 (21.7%)	8.5 ± 0.5 (6.4%)	5.8 ± 0.7 (13.4%)

Buriti fiber is also used in civil engineering. Castro et al. [217] studied the use of buriti fibers treated with NaOH in mortar in civil construction. The author used a 1:2:0.5 mortar mix, adding 2% fiber treated with 2% NaOH. The mortar underwent a wet curing process for 28 days. The composites reinforced with buruti fibers obtained an 87–96% increase in flexural strength compared to pure mortar. Owing to its versatility and good properties, buriti stands out as a high-potential fiber for use in composite materials, which can be applied to both polymer and cementitious matrices.

3.4. Carnauba

The Carnauba tree, illustated in Figure 12a, is classified as a palm of the Arecaceae family and has xerophytic characteristics. Its scientific name is *Copernícia prunífera* and it originated in Brazil. The term "carnauba" comes from the indigenous language and means "the tree that scratches", an allusion to the 44 thorns distributed along the stem. In addition to its primary name, the plant is also known by variations such as carnaúva, carnaba, carandaúba, and carnaíba. The genus Copernicia comprises approximately 28 species, distributed in regions of India and South America. On the South American continent, species such as Copernícia tectorum (found in Venezuela and Colombia), Copernícia alba (found in Bolivia, Argentina, and Paraguay), and Copernícia prunífera are predominant in Brazil [218].

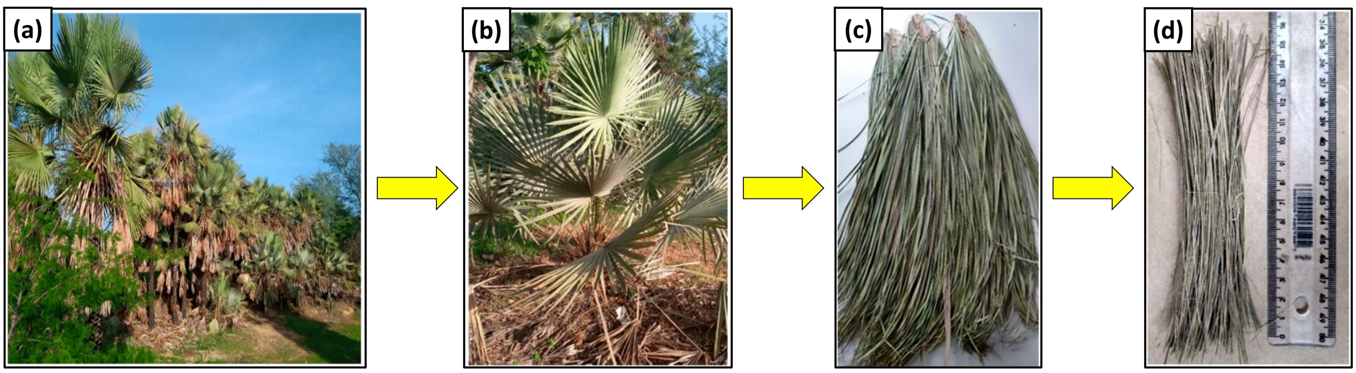

Figure 12. Carnauba (*Copernícia prunífera*): (**a**) carnauba tree; (**b**) leaf stalks of carnauba tree; (**c**) leaf stalks of carnauba tree; (**d**) carnauba fibers extracted from leaf stalks. Adapted with permission from ref. [219]. Copyright 2020, MDPI AG. Licensed under CC BY 4.0.

It is estimated that the carnauba tree can reach a height between 10 and 15 m, with a productive life expectancy of around 200 years. Demonstrating remarkable resistance, this species adapts effectively to adverse climatic phenomena, such as severe droughts and floods. Its ideal habitat includes floodplains and riverbanks, and the plant thrives at altitudes ranging from 45 m above sea level to around 500 m. Natural propagation takes place predominantly in its native environment, especially in sandy, moist soils. The palm has opaque green leaves, arranged in a spiral around the stem, concentrated in the crown of the plant [220].

Every part of the carnauba palm finds utility; its roots are employed for medicinal purposes, the fruits serve as a significant component in animal nutrition, and the trunk constitutes a valuable source of timber for civil construction. Carnauba wax, derived from the palm, is extensively utilized in the manufacturing of lubricants and anti-corrosive agents. Additionally, the leaves of the carnauba palm find application in various domains, including house roofing, handicraft production, and the extraction of fibers [218,220].

Carnauba fiber exhibits highly promising outcomes for its application as reinforcement in epoxy matrix composites or within a biodegradable polyhydroxybutyrate (PHB) matrix. Noteworthy mechanical properties of carnauba fibers include significant elongation (1.7–2.6%), impressive tensile strength (205–264 MPa), and a substantial Young's modulus (8.2–9.2 GPa) [219].

The quantification of chemical constituents within carnauba fibers constitutes a crucial aspect for comprehending the thermal and mechanical properties of these materials. As elucidated by Monteiro et al. [221], several factors exert direct influence on the properties of natural fibers, including cultivation and storage location, plant age, porosity, and internal defects. Ref. [218] conducted a comprehensive analysis encompassing chemical composition, thermal behavior, and morphological characteristics. The investigation revealed a moisture content of 7.2%, a notably lower value compared to other natural fibers (NLFs). Specifically, the examined carnauba fibers comprised 4.8% wax, 36.9% lignin, 40.9% hemicellulose, and 20.2% cellulose. Notably, when compared to other NLFs, carnauba fibers exhibited a lower percentage of cellulose in their composition. Through SEM micrographs, it is possible to identify surface defects present on the longitudinal surfaces of the fibers. Defects such as cracks, roughness, and surface porosity are identified. Furthermore, XRD analysis of carnauba fibers enabled the calculation of the crystallinity index (86.9%) and microfibril angle (7.48%). These parameters serve as indicative measures of favorable mechanical properties, emphasizing the comprehensive insights derived from the integrated analysis of various characterization techniques [218].

According to Junio et al. [222], the negative factors that influence the quality and properties of carnauba fibers can be minimized by selecting the average fiber diameter. NLFs in general show a tendency to reduce their properties as the average diameter increases, a fact related to the reduction in voids present in fibers with smaller diametrical intervals, giving the smaller fibers more resistance [223].

Junio et al. [222] studied the influence of the average diameter of carnauba fiber. When conducting studies with fibers with an average of 0.765 $\pm$ 0.22 mm, the author observed that the average density of the fibers was 1.13 $\pm$ 0.22 g/cm^3, and there was a 54.5% reduction in density with increasing fiber diameter compared to the beginning and end of the fiber, as well as an 87.3% reduction in Young's modulus and 83.4% in tensile strength.

Melo et al. [220] investigated the effect of chemical modification on the development of biodegradable composites of polyhydroxybutyrate (PHB) reinforced with carnauba fibers. Enhanced interfacial bonding was evident with alkali, peroxide, potassium permanganate, and acetylation treatments. Composites treated with hydrogen peroxide exhibited superior tensile strength compared to those utilizing untreated fibers or other fiber treatments. Scanning electron microscopy (SEM) observations further disclosed improved fiber–matrix adhesion after this treatment, contributing to heightened mechanical properties. Dynamic mechanical thermal analysis indicated an augmentation in storage modulus at elevated temperatures.

Eduard et al. [224] investigated the effects of incorporating carnauba fibers, at concentrations of 3% and 5%, with lengths of 20, 40, and 60 mm, into mortar. The study scrutinized the behavior of the mortar in both fresh and hardened states. In terms of the fresh state, the addition of fibers resulted in decreased consistency, indicating reduced fluidity and workability. This effect was attributed to the porous surface of carnauba fibers, leading to heightened water absorption and subsequently diminishing the flow capacity of the mortars [225]. Concerning the hardened state, compression tests demonstrated a reduction in compressive strength due to the incorporation of fibers, which increased the void content in the mixture, rendering the mortar less compact. Interestingly, the introduction of 60 mm long fibers contributed to enhanced ductility, acting as a retarder in crack initiation [226]. Additionally, the inclusion of 3% fibers (20, 40 mm) and 5% fibers (20 mm, 40 mm, and 60 mm) resulted in a reduction in flexural strength by 12–20%. However, the incorporation of 3% fiber (60 mm) led to a notable 10% improvement in flexural strength. Pellegrin et al. [227] posit that longer fibers impart superior mechanical performance to mortars, particularly in terms of flexural strength.

3.5. Curaua

Curauá (*Ananas Erectifolius*) is a hydrophilic species native to the Amazon region, from which lignocellulosic fibers are extracted, known for their excellent mechanical properties [228]. In the Amazon, curauá fibers are widely recognized in the Amazon River basin region, particularly in the western part of the state of Pará, where the first commercial plantations of this plant were pioneeringly established [229,230].

Distinctive characteristics of curauá include hard, flat, and erect leaves, with an average length of 1–1.5 m, a width of approximately 40 mm, and a thickness of 5 mm. Each curauá plant exhibits a remarkable leaf production, averaging 50–60 per year, weighing about 150 g each [231]. This yield results in an annual production of 3–9 tons of dry fibers per hectare, notably relying on natural irrigation from rainfall throughout the year [230,232].

Beyond its economic significance, curauá fibers play a crucial role in the traditional practices of indigenous peoples. Indigenous communities use these fibers to craft ropes, hammocks, and fishing lines, requiring materials with high strength and deformability [233]. This application underscores the versatility of curauá fibers, combining remarkable mechanical properties with a sustainable origin. Figure 13 illustrates the curauá plant and the fiber resulting from the extraction of the plant's leaves.

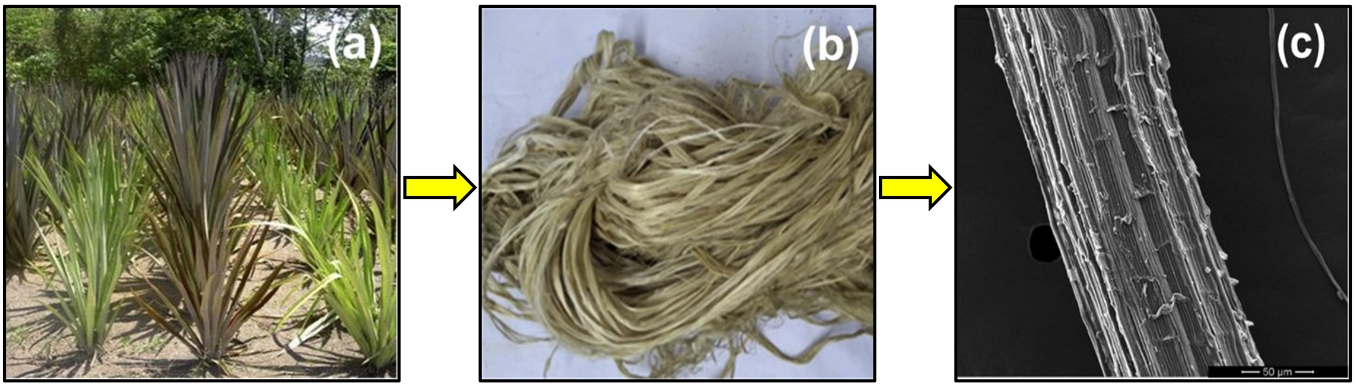

Figure 13. Curauá (*Ananas Erectifolius*): (**a**) curauá plant; (**b**) bundle of manually extracted fibers; (**c**) SEM micrograph of a cross-section of a curauá fiber. Reprinted with permission from ref. [234]. Copyright 2020, Elsevier. Licensed under CC BY-NC-ND 4.0.

Curauá fibers are obtained from the leaves of the plant, which are manually cut. These leaves undergo a process called decortication, in which rudimentary machines equipped with rotating cutting blades remove the mucilage, extracting the fibers. Subsequently, the extracted fibers undergo a mercerization process in tanks, lasting 36 h, followed by washing to remove mucilage residues. Finally, the fibers are dried in an oven at 50 °C for 5 h or in the open air for 2 days before being baled. Each curauá leaf produces between 3 and 8% of dry fibers. The majority of curauá fiber production is still carried out by small farmers in the city of Santarém and the state of Amazonas, characterizing a traditional process without the use of advanced technology and appropriate safety measures [229,231].

Since the early 2000s, the production of curauá fibers has experienced exponential growth, driven by their use in automotive components. Renowned companies such as Volkswagen and Mercedes Benz have played a crucial role in this advancement, adopting curauá fibers as reinforcement in polypropylene matrix composites [235]. This substitution of glass fibers has become particularly notable in the manufacturing of automotive parts, including bumpers, interior panels, trunk lids, and various other components. The success of this transition is evident in the successful integration of curauá fibers in the construction of vehicle parts, notably in Volkswagen's VW Fox and VW Polo models [236,237]. This significant milestone has further propelled research into the application of curauá fibers not only in the automotive sector but also in various areas such as construction [238–240], ballistic armor [241–244], and biodegradable packaging [245–247], among other applications.

An example illustrating the application of curauá fiber is found in the work of Barbalho et al. [248]. In this study, the authors produced and characterized composites of biodegradable polyethylene derived from sugarcane alcohol (B-HDPE), reinforced with curauá in fractions of 0.1, 3, and 5 wt.%, along with 10 wt.% of maleic anhydride (PP-g-MA). This composition results in a fully biodegradable and sustainable composite. From the results obtained through thermal, chemical, and mechanical characterization, the authors revealed that the addition of small amounts of curauá fibers to this specific matrix contributed to a synergistic effect. This synergistic effect led to an increase in the mechanical properties and improvement in the thermal stability of the composite compared to pure B-HDPE. These findings highlight the significant potential of this material for applications in the automotive sector, emphasizing that it is biodegradable and sustainable.

Significant research related to curauá fiber has explored enhancements in its properties and those of the composite through functionalization with carbonaceous materials such as graphene, graphene oxide, and carbon nanotubes. The study conducted by Neto et al. [249] investigated the impact of functionalization using multi-walled carbon nanotubes (MWCNTs) on the thermal and morphological properties of epoxy matrix composites reinforced with curauá fibers. Both the epoxy matrix and the curauá fiber were independently functionalized. The influence of carbon nanotubes in each composite configuration was assessed and compared with the control group, which did not contain MWCNTs. Functionalizing the curauá fiber resulted in a significant increase in mechanical strength compared to the "in natura" fiber, as illustrated in Figure 14a. The addition of MWCNTs promoted a considerable increase in the flexural strength of the composites, as shown in Figure 14b.

When evaluating the composite configurations, it was observed that resin functionalization contributed to an increase in mechanical strength. However, functionalizing the curauá fiber resulted in higher flexural strength values. This observation was supported by scanning electron microscopy (SEM) analyses of the curauá fiber, as presented in Figure 14c,d. In Figure 14c, the fiber without the presence of MWCNTs exhibits a smooth and less rough surface, which may hinder interfacial adhesion with the matrix. In contrast, functionalization allowed the fiber, as depicted in Figure 14d, to obtain a rougher surface due to the MWCNT adherence in the fiber spaces, favoring interlocking between curaua fibers and epoxy matrix.

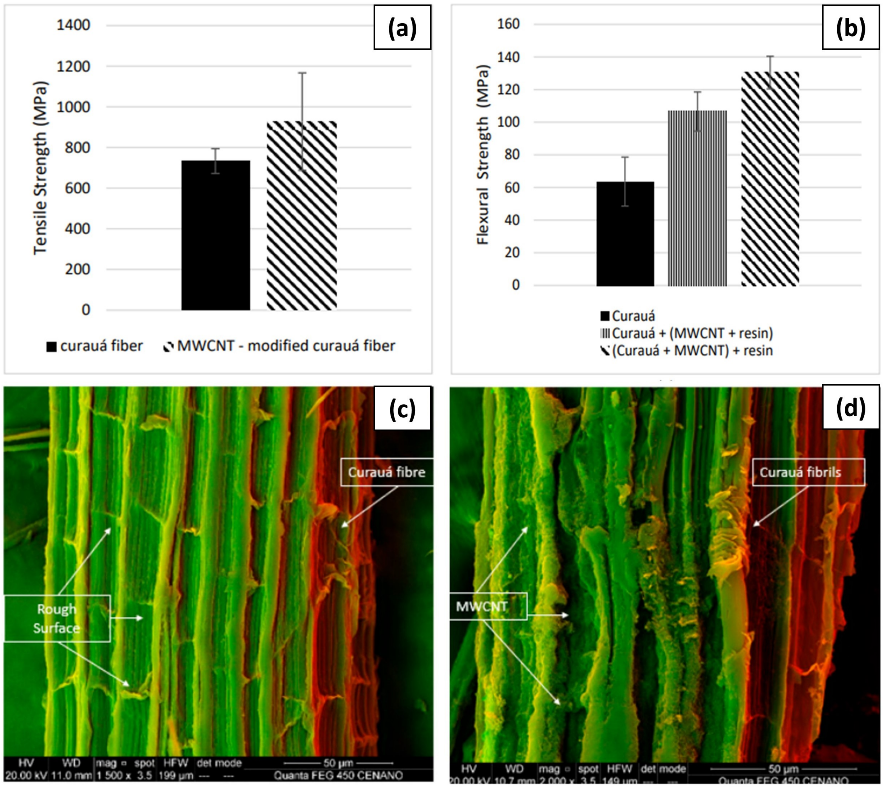

Figure 14. Results of epoxy matrix composites reinforced with curauá fibers and functionalized with MWCNTs: (**a**) tensile test results of the fibers; (**b**) flexural test results of the composites; (**c**) SEM micrograph of the "in natura" fiber; (**d**) SEM micrograph of the fiber functionalized with MWCNTs. Adapted with permission from ref. [249]. Copyright 2023, MDPI AG. Licensed under CC BY 4.0.

3.6. Guaruman

The guaruman plant (*Ischnoshiphon Koern*) is frequently found along the riverbanks in the Amazon region, especially in the Salgado Paeaense area in the state of Pará. Extracted from this region, these plants play a crucial role as raw material for handicrafts [250]. The Amazon is renowned for its vast diversity of native plant species, which play fundamental roles in food, medicine, construction, and fiber production. In the specific context of guaruman, this plant holds significant importance in the culture of riverside caboclos and various indigenous tribes. It is widely used in crafting, particularly in the creation of the famous straw weaving, a highly popular practice in the Para region [250,251].

Guaruman, also known as arumã, belongs to the Marantaceae family and is typically found in flooded várzea areas along riverbanks [252]. Barcarena, in the state of Pará, and more specifically, the Utinga-Açu community, are the main hubs for artisanal production of products made from guaruman fibers. The extraction process involves processing the guaruman stem, resulting in flexible, durable fibers with a distinctive golden hue, as illustrated in Figure 15 [250].

The crafting of handicrafts from these fibers often constitutes the main source of economic sustenance for the surrounding riverside communities. Similar to other non-timber materials used in artisanal production, the goal is always to transform these resources into higher value-added goods [250,252]. Research focused on the development of new products from guaruman not only contributes to the technological innovation of the country but also addresses the specific needs of the regional population that relies on the trade of these fibers.

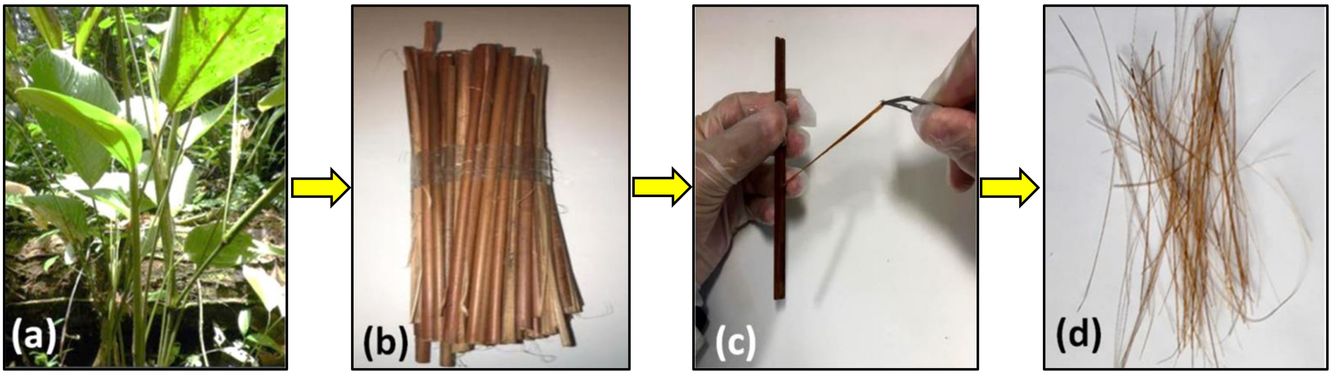

Figure 15. Guaruman (*Ischnoshiphon Koern*): (**a**) guaruman plant; (**b**) as-received, mechanically divided splints from the stalk; (**c**) manual separation of fibers from the splint; (**d**) bunch of the final isolated fibers (**d**). Adapted with permission from ref. [253]. Copyright 2020, Elsevier. Licensed under CC BY-NC-ND 4.0.

Guaruman fiber is underexplored concerning the assessment of its properties, encompassing both the individual characteristics and properties of the fiber, as well as its application as reinforcement in composites. The lack of dissemination, coupled with the potential difficulty in obtaining the plant, may constrain studies on this fiber. However, although rare, some works have been identified in the literature. Reis et al. [253] conducted an analysis of the characteristics and properties of guaruman fibers, comparing them with commonly studied natural fibers. The results, presented in Table 9, highlight the favorable properties of guaruman compared to other natural fibers, such as low density and a reduced microfibril angle (MFA).

Table 9. Comparison of the mechanical properties and microfibril angle of guaruman fiber with other fibers known in the literature [253].

Fiber	Density (g/cm^3)	Tensile Strength (MPa)	Young Modulus (GPa)	MFA (°)
Guaruman	0.57	614	21	7.8
Jute	1.45	597	20	8.0
Ramie	1.50	685	44	6.2
Hemp	1.45	539	35	7.5
Sisal	1.38	478	19	20.0
PALF	1.44	180	59	11.5
Coir	1.52	135	5	51.0

Continuing the study of guaruman fibers, Reis et al. [254] conducted research in which they employed guaruman fibers as reinforcement in epoxy matrix composites for use in multi-layer ballistic armor. To achieve this, they developed a prototype ballistic vest with a front layer made of aluminum oxide ceramic (Al_2O_3), the second layer composed of a composite using 30 vol.% guaruman fiber, and the final layer made of Kevlar. Ballistic tests were conducted using 7.62 × 51 mm caliber ammunition, and the prototype's performance was assessed by measuring the indentation in the clay positioned behind it. The indentation in the clay, known as Backface Signature (BFS), should be less than 44 mm. The results of the ballistic tests, depicted in Figure 16, demonstrated that the prototype met the standard, with BFS below 44 mm. To illustrate, the authors compared the results with composites produced under similar conditions but using PALF fibers, achieving similar outcomes, meeting ballistic test standards, and showcasing the potential of guaruman fiber for military applications.

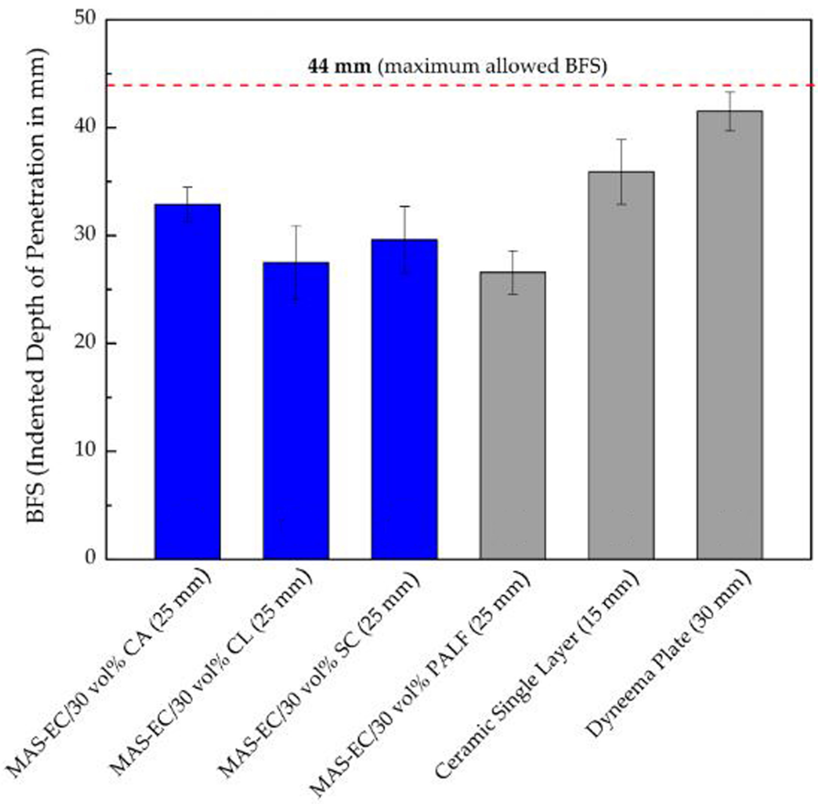

Figure 16. Results of BFS of composites produced with guaruman fibers after ballistic testing using 7.62 × 51 mm ammunition. Reprinted with permission from ref. [254]. Copyright 2021, MDPI AG. Licensed under CC BY 4.0.

A more recent example is the work of Azevedo et al. [86], in which the authors conducted a preliminary study on the use of guaruman fiber as reinforcement in cementitious matrix composites. They used a Portland cement matrix of type CPIII, widely used in Brazilian construction, and added guaruman fibers in fractions of 2.5, 5, and 7.5 wt.% Additionally, they investigated two different conditions: untreated fibers and fibers treated with alkali using NaOH. Through the characterization of the composites, the authors observed that the addition of fibers reduced the density of the cementitious composite as the fiber content increased. However, the alkali-treated fibers showed an even greater reduction in density and, consequently, in liquid absorption.

Guaruman fiber has good mechanical properties and great potential to be explored in composites and sustainable applications, both in the field of materials science and engineering and in other areas of knowledge. However, the lack of knowledge about this fiber compared to other natural fibers, such as jute and sisal, for example, limits its utilization.

3.7. Periquiteira

The Periquiteira (*Cochlospermum orinocense*), also known as tree cotton, Envira-Branca, or Buxixão, is a plant from the Bixaceae family. This plant is characterized by being a medium-sized tree, ranging from 12 to 28 m in height, with a straight cylindrical trunk that can measure 40 to 75 cm and remain unbranched for up to half of the tree's height. Its bark is whitish, with vertical fissures and fiber detachment, with 60 cm of cataphylls [255,256].

The wood has a coarse texture, a straight grain, is tasteless but slightly fragrant when fresh, lightweight, smooth, with low resistance to decay and attack by wood-eating insects, and it grows best in a sunny position. It is a fast-growing tree [256,257].

The occurrence of the Periquiteira is in Brazil, specifically in the Amazon Rainforest, but it also extends to countries in South America such as Peru, Colombia, Venezuela, and the Guianas. It mainly grows in more open areas of advanced secondary growth, in upland areas not subject to periodic flooding, plain areas, and highlands, usually on dry clay at altitudes of up to 450 m in Peru [256]. In Brazil, the Periquiteira is found in the states of Roraima, Rondônia, Amapá, Pará, Amazonas, Acre, Maranhão, and Mato Grosso [257].

Little is known about this plant, as there is still no precise information about its edible and/or medicinal uses. So far, it is known that the fiber is extracted from the inner bark of the fruit and is commonly used in rope manufacturing. The only studies found in the literature on the properties of periquiteira fibers are the works of [258,259]. The study conducted by Silva et al. [258] was the first to analyze the properties of periquiteira fibers, including the composition of lignocellulosic components and mechanical properties through tensile tests. The results of this study are presented in Table 10.

Table 10. Properties of periquiteira fiber [258].

Fiber	Hemicellulose (%)	Lignin (%)	Cellulose (%)	Tensile Strength (MPa)	Young Modulus (GPa)	Elongation (%)
Periquiteira	-	12.03	60.15	83.93–168.19	4.04–7.09	0.19–0.81

Based on the original results obtained by Silva et al. [258], the recently published paper by Pinheiro et al. [259] continued to map the knowledge about periquiteira fiber, bringing other fiber information such as density, crystallinity, microfibril angle, thermal stability, and tensile properties as a function of fiber diameter. As illustrated in Figure 17, the authors manually extracted the fiber from the plant's bark.

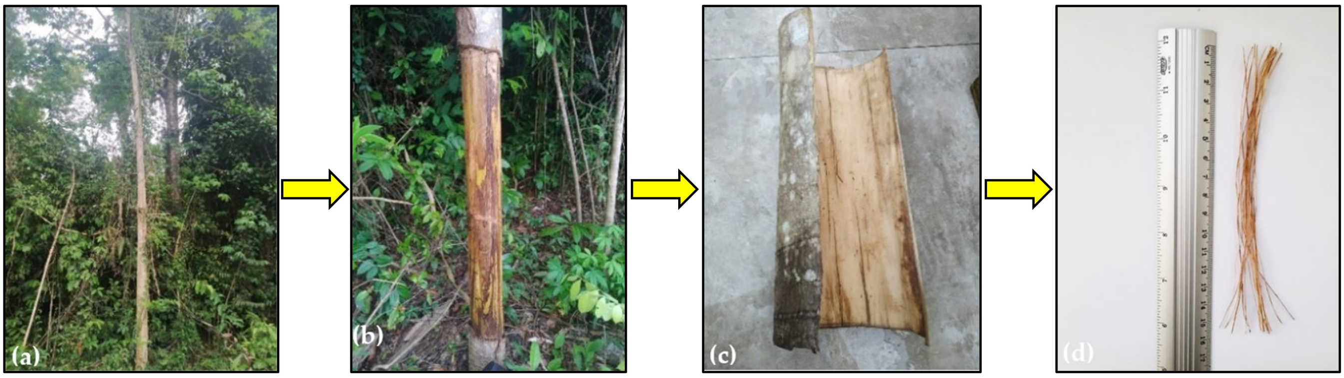

Figure 17. Periquiteira (*Cochlospermum orinocense*): (**a**) periquiteira plant; (**b**) bark extraction site; (**c**) bark of the plant; (**d**) periquiteira fibers. Adapted with permission from ref. [259]. Copyright 2023, MDPI AG. Licensed under CC BY 4.0.

Through the analysis, the authors identified the fiber diameter distribution, as well as characteristics such as high crystallinity (70.49%), low MFA (7.39°), thermal analysis results similar to other lignocellulosic fibers, and tensile strength values ranging from 100 to 255 MPa, where the smaller the fiber diameter range, the higher the mechanical strength.

In conclusion, the periquiteira plant holds great potential for application, both in the biomedical and botanical field due to its yet unknown properties, as well as in engineering and sustainability, thanks to the properties extracted from it and their possible applications. It is highly likely that in the coming years, new studies on this fiber will emerge, pushing the boundaries of knowledge about this plant and its fibers even further.

3.8. Piassava

Piaçava is a palm tree native to Brazil, belonging to the Arecaceae family. Its popular name comes from the indigenous Tupi language, meaning "Fibrous Plant". The different species of Piaçava are found mainly in the states of Acre (*Aphandria natalia*), Figure 18a and Bahia (*Attalea funifera*), and Amazonas (*Leopoldinia piassaba*). This palm is capable of growing in low-fertility soils that are unsuitable for many crops [260].

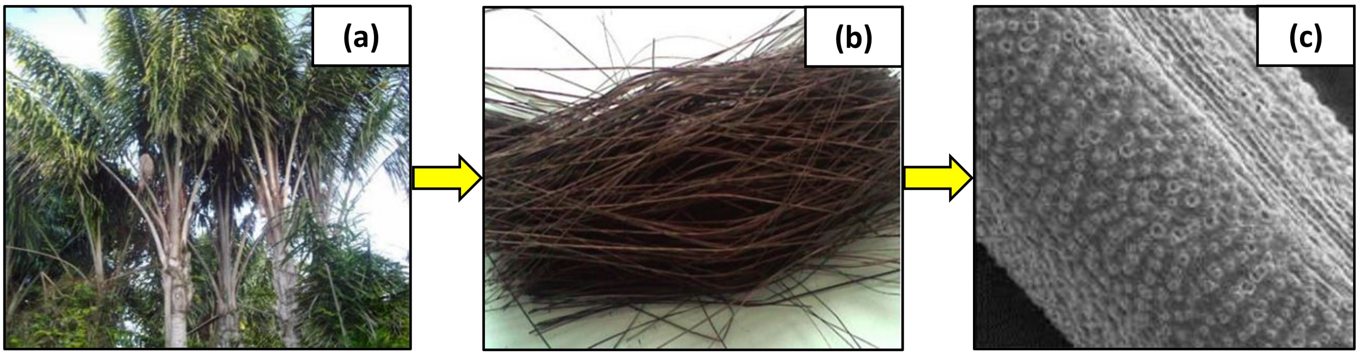

Figure 18. Piassava (*Attalea funifera*): (**a**) piassava palm tree; (**b**) piassava fibers extracted from leaf; (**c**) SEM micrograph of piassava fiber surface. Adapted with permission from ref. [261]. Copyright 2018, Scielo. Licensed under CC BY 4.0.

Among the species of Piassava, Bahia is the largest fiber producer in the country, representing 95% of the national production, followed by the Piassava from Amazonas and Acre. These species of Piassava differ in the characteristics of their fibers [119,262]. The fiber from Bahia is the most commercialized due to its long, rigid, and waterproof fibers that maintain their elasticity even when wet. On the other hand, the fibers from Amazonas are softer, more flexible, and elastic. These fibers are commonly used in the manufacturing of brushes, brooms, ropes, crafts, and also in the composition of rustic coverings [260].

The extraction of Piassava fibers is carried out through extractivism, with different systems in the producing states. In Bahia, there are associations of collectors in the communities, which generates income and, at the same time, preserves the ecosystem in the Atlantic Forest [262,263]. In Amazonas, on the other hand, extractivism occurs through aviation, where the boss provides advanced food and goods in exchange for the services of the collectors. This type of extractivism does not benefit the collectors, often leaving them in a situation similar to slavery [264].

The collection of Piassava plant fibers is conditioned by the water level, which means that during dry periods, collectors are isolated without the opportunity to receive supplies and goods since the rivers are not navigable. Piassavas can be classified in two ways: by height and by the presence or absence of previous cutting [265]. The cutting method varies according to the size of the palm tree. As for height, Piassavas are classified as follows: new Piassava (up to 2 m), garrote (2 to 4 m), garrotão (4 to 6 m), and giant or old (over 6 m). Regarding the type of cutting, they can be non-extractable (poor or fiberless), mamaipoca (already cut, ready for recutting), or virgin (never cut) [266]. Piassava fibers originate from the base of the palm leaves and are collected manually. In this process, they are untangled, arranged, cut, and then tied together for commercialization, generating the fibers as illustrated in Figure 18b,c [267–269].

Piassava fibers have been widely used due to the high production of this palm tree, which can yield around 8 to 10 kg of fibers per tree. These fibers have various applications, ranging from crafts, utensils, and ropes, to engineering, as reinforcement in composites. As a result, numerous research studies are conducted annually using this fiber.

An example of the application of piassava fibers as reinforcement in composites is a study conducted by Carvalho et al. [270], in which a preliminary investigation was carried out to assess the effectiveness of piassava fibers as a reinforcement agent in polyurethane matrix plates for flooring. In the study, the piassava fibers were crushed and added to the composite in powdered form, at volume fractions of 10, 20, and 30 vol.%. The authors conducted abrasion tests on the composites, following the NBR 14050 standard [271], and observed that the composite with 30 vol.% fiber content showed potential for application, although it did not fully meet the requirements of the standard. The authors mentioned the need to investigate other parameters to achieve the specified requirements.

Silva et al. [272] evaluated the performance of polyester matrix composites reinforced with different fibers in impact and bending tests. For comparison, they used raffia, jute, mallow, piassava, and sisal fibers as reinforcements in similar compositions. The results of the Charpy test are illustrated in Figure 19.

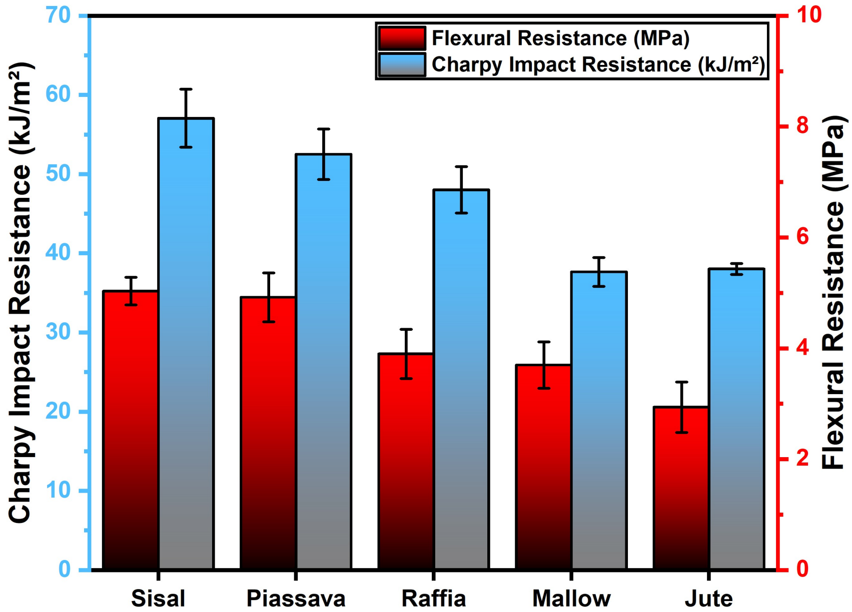

Figure 19. Comparison of impact resistance and flexural strength results as a function of the type of fiber used in polyester matrix composites. Graph produced with data results from ref. [272].

Based on the results obtained, the authors observed that piassava fibers have high resistance compared to other fibers such as mallow, raffia, and jute, although their performance was slightly lower than the composite with sisal fibers. Among all natural fibers, sisal is one of the most resistant, if not the most resistant natural fiber among the species [273,274].

As another example, Nunes et al. [275] produced composites from recycled polypropylene (PPr), using piassava fibers as a reinforcing agent. To improve the interfacial adhesion of these composites, the authors added MAPP to the material at a fraction of 10 wt.%. The content of piassava fibers in the composite varied between 0, 10, 20, and 30 wt.%. From the results of the characterization of the mechanical properties of the composites, the authors observed that the addition of piassava fibers in the fractions of 20 and 30 wt.% considerably increased the flexural strength of the composites, in which the group without the presence of fiber presented a value of 32.7 MPa, while the composites with 20 and 30 wt.% of piassava presented values of 41.7 and 45.0 MPa, respectively. This behavior was repeated in the tensile and Shore D hardness tests, in which the composites with 20 and 30% piassava fibers showed superior performance; however, in the impact test, the sample without fiber showed superior performance to all the composites. The piassava fiber allowed the distribution of stresses, increasing the mechanical strength of the PPr, but the presence of MAPP allowed an increase in interfacial adhesion, resulting in superior properties.

The application of piassava fiber has many benefits. Its mechanical strength and durability make it ideal for making utensils and even for reinforcing construction materials and engineering composites. In addition, its use contributes to the preservation of the environment, as piassava is a native plant and its sustainable extraction promotes the socioeconomic development of local communities. Given its unique properties and environmental benefits, piassava fiber certainly has a promising role to play in a wide range of industries.

3.9. Tucum

The tucum, scientifically named *Astrocaryum vulgare* (Figure 20a), is a palm tree typical of the Amazon region. This plant has several scientific names, such as *Astrocaryum chambira Burret* and *Astrocaryum aculeatum G.* The fruits of the tucum are called tucumã and are widely used in local cuisine. In addition, the palm has a thorny trunk and can be used as a living fence to protect crops in short-cycle forestry of pioneer species. The purpose of this fence is to protect the seedlings from herbivory by animals [276].

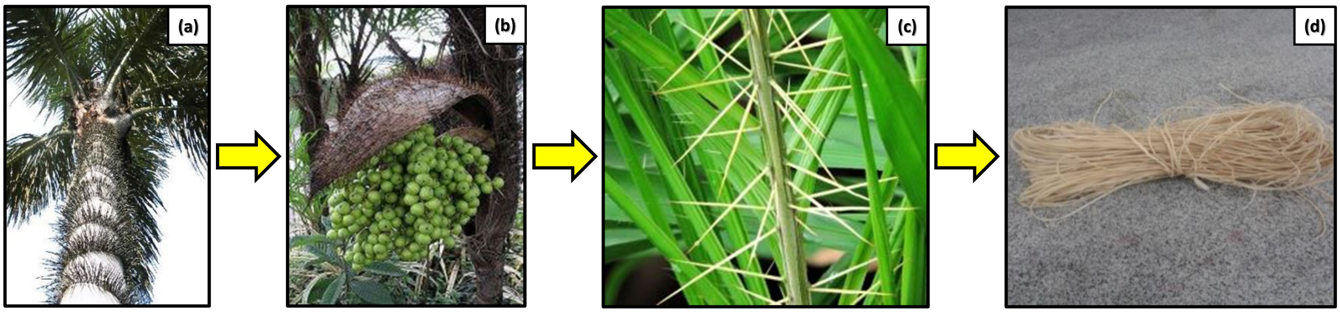

Figure 20. Tucum: (**a**) tucum palm tree; (**b**) tucum fruits; (**c**) tucum leaves exhibiting a thorny characteristic to ward off predators; (**d**) tucum fibers extracted from the leaf. Adapted from ref. [277].

Their fruits (Figure 20b) are up to 6 cm long and vary between 4 and 5 cm in diameter, with a rounded shape, a greenish color, and a sour taste. When ripe, the fruit is black in color and tastes sweet [278].

Tucum fibers are taken from the palm's leaves (Figure 20c), which are very resistant and have the following characteristics: sheath and petiole covered in flat, yellowish spines; sheath 1.1 m long; petiole 2.6 m long; rachis 4.8 m long; 160 spines per side, linear or linear-lanceolate, irregularly arranged and arranged in different planes; with small spines on the margins, midribs subterminal; midribs 1.51–1.63 m long and 4–4.5 cm wide [278,279].

Tucum fiber, illustrated in Figure 20d, is obtained after the palm leaves have been removed and dried. This fiber contains a considerable amount of cellulose, over 80%, and has been an important source of income for communities in the region, being widely used in handicrafts. For several indigenous communities in the northwestern Amazon region, tucum fiber is of significant value. The fibers obtained from the unexpanded leaves are used to make a wide variety of products, such as hammocks, bags, and fishing nets [203,280–283]. Harvesting and processing these fibers is part of Aboriginal traditions and represents important moments of social interaction [284].

In recent years, products made from tucum fibers have become very popular with tourists and in craft shops. The tucum palm has become an important cash crop for indigenous families. However, frequent extraction, often carried out in a destructive manner, has depleted the natural populations of tucum in some areas of the Amazon [282,285].

The application of tucum fiber in engineering composites has been attracting a great deal of interest from researchers in recent years, especially in Brazil. This interest has intensified due to the potential of this fiber to improve the properties of composites and open up new application possibilities in industry. Various studies have been carried out to better understand the characteristics and behavior of this fiber in composites, with the aim of optimizing its use and exploiting its full potential. Cunha et al. [192] compared the effect of tucum fibers (*Astrocaryum chambira Burret*) and mallow fibers in polyurethane (PU) matrix composites. The authors produced composites only reinforced with tucum fibers (TPU) and only with mallow fibers (MPU), in fractions of 30, 50, and 70 wt.%, and the properties of the fibers and composites were analyzed. XRD analysis showed that the crystallinity of the tucum fiber was higher than that of the mallow fiber, with values of 79.34 and 68.56%, respectively. The results of the thermogravimetric analysis (TGA) indicated that the tucum fiber has slightly higher thermal stability. In the mechanical analysis, using the flexural test, the composites reinforced with tucum fibers showed higher values than the composites reinforced with mallow fibers, in all compositions. Based on the water absorption results, the TPU composites showed much higher absorption values due to greater interfacial adhesion.

Oliveira et al. [286] investigated the mechanical and ballistic properties of epoxy matrix composites reinforced with tucum fibers from the genus *Astrocaryum vulgare*. The authors produced composites by the cold compression method, using 20 and 40 vol.% fractions of tucum fibers. The results obtained by the authors are shown in Figure 21.

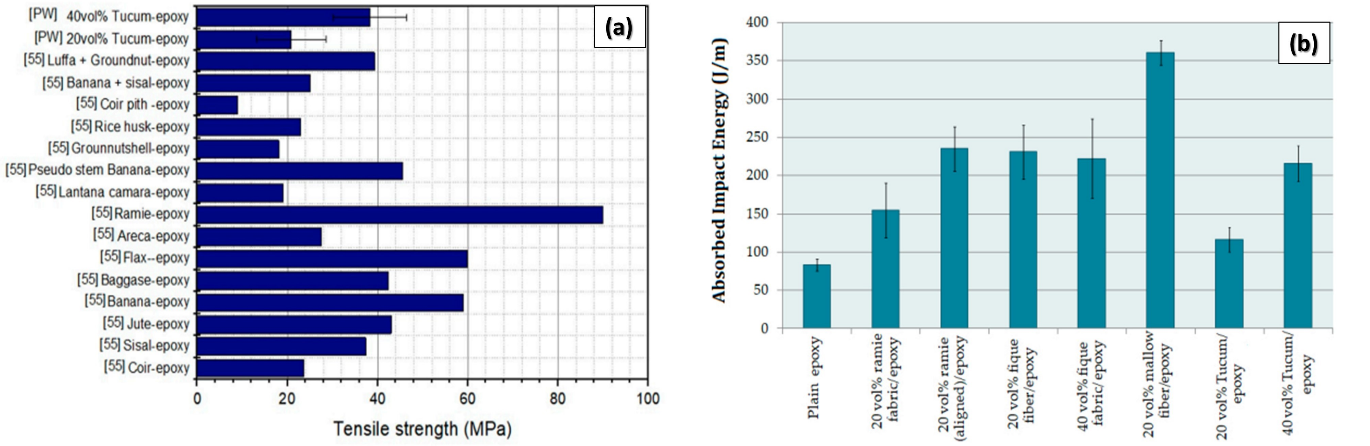

Figure 21. Results of the epoxy/tucum composites: (**a**) comparison of the tensile strength results of the epoxy/tucum composite with the literature; (**b**) comparison of the Izod impact resistance results. Adapted from ref. [286]. Copyright 2020, MDPI AG. Licensed under CC BY 4.0.

The results of the mechanical characterization of the epoxy/tucum composites were not good compared to some composites. As illustrated in Figure 21a, the tucum-reinforced composites showed superior performance to composites reported by other authors, reinforced with coir, ground nut shell, and lantana camara fibers. However, performance was much lower than composites reinforced with ramie, banana, and flax fibers, showing intermediate properties. In the Izod impact results, shown in Figure 21b, the composite reinforced with 20 vol.% tucum showed similar performance to plain epoxy, with little improvement in impact resistance, making the mechanical performance inferior to that of the other fibers used in the comparison, present in the Figure. On the other hand, the composite with 40 vol.% performed similarly to composites reinforced with fique fibers, both in the form of fibers, fabric, and ramie fibers, although the result was much lower than a composite reinforced with 20 vol.% mallow. The results of the ballistic tests carried out with 0.22 ammunition are inferior to plain epoxy. In general, the addition of natural fibers to epoxy in fractions ranging from 10 to 40 vol.% promotes an increase in ballistic resistance, as observed in studies with similar tests and compositions, but with epoxy/hemp [287] and epoxy/kenaf [288] composites. Even though the ballistic performance is lower, the authors report the importance of using natural fibers in composites for ballistic applications, where cost is a fundamental factor. The cost of natural fibers is significantly lower than synthetic fibers, and certain natural fibers have the potential for ballistic applications, aggregating sustainability and low production costs.

Another interesting example is the study carried out by Kieling et al. [23], in which the researchers produced composites using tucum powder, extracted from the seed of the genus *Astrocaryum aculeatum*. Recycled polypropylene was used as the polymer matrix. The composites were processed with different fractions of tucum (0, 10, 20, 30, 40, and 50 wt.%) and their properties were analyzed. During the tensile, flexural, and impact tests, the addition of tucum as a reinforcing agent resulted in a reduction in the mechanical performance of the composites. However, in the compression test, the tucum-reinforced composites showed a considerable improvement as the load increased. In relation to the water absorption test, the composites with 40 and 50 wt.% tucum showed a greater capacity to absorb liquid. This also resulted in greater resistance to the flammability test, where these two groups showed a lower flame propagation speed. Therefore, even with lower mechanical properties, tucum proved to be effective as a flame retardant additive in polypropylene.

Tucum fiber has significant potential to be explored as a reinforcement in composites. Although this fiber does not have excellent mechanical properties like sisal, curauá, or piassava, it can be used in studies in which different surface treatments can be applied to the fiber to improve interfacial adhesion with the composites and, consequently, their final properties. With the growing popularity of fiber in the engineering field, it is expected that new studies will emerge to further explore its potential.

3.10. Ubim

Ubim is a palm from the Arecaceae family, also known by its scientific name *Geonoma baculífera* [289]. The word ubim comes from the indigenous language, specifically the Tupi u'bi. The palm is also known by other names, such as *Geonoma estevaniana Burret*, *Gynestum baculiferum Poit.*, *Geonoma acutiflora Mart* [290].

The Arecaceae family includes the genus *geonoma*, which is made up of small palms that generally grow in the understory. This genus is one of the largest in the Americas and is home to 15 species that are widely distributed across the continent, especially in tropical regions [291]. The species of *Geonoma* are commonly found in areas with high levels of rainfall, and are one of the most prevalent plant species in these environments. Palms of the genus *Geonoma* have a preference for riparian forest vegetation that occurs along watercourses, as well as open vegetation [292].

Ubim, illustrated in Figure 22, is a small cespitose palm with multiple, smooth stems and elongated, unbranched fibers. Its height varies between 1 and 4 m, with a diameter of 1 to 3 cm. The stem can be erect or partially creeping, and the plant has seven to twelve leaves, sparsely branched inflorescences, and globose or ovoid fruits. This species is typically found in the understory of forests with high rainfall, riparian forests, floodplains and igapós. The ubim is adapted to humid environments, is considered shade-tolerant, and generally grows in places with low incidence of direct light [289].

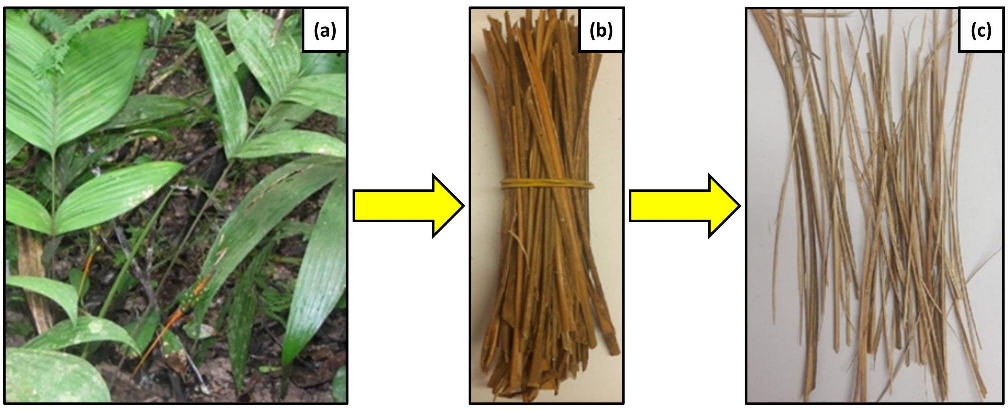

Figure 22. Ubim (*Geonoma baculífera*): (**a**) ubim plant; (**b**) ubim stem; (**c**) ubim fibers extracted from the stem. Adapted from ref. [293].

The occurrence of the ubim covers Central and South America, with records in the Guianas, Peru, Bolivia, and Venezuela. In Brazil, this plant can be found in the states of Amazonas, Acre, Amapá, Pará, Maranhão, and Piauí [294,295]. This species is widely used in the Amazon by extractivist communities who depend on the sustainable exploitation of various native species to meet their needs for construction materials for rural buildings.

The leaves of the ubim, when intertwined along a stick, form ubim "cloths", which are used as a covering in the constructions of these communities. This is a traditional practice, especially among those who live close to the border between Brazil and Bolivia. In Bolivia, ubim is commercially exploited, which indicates that the species may also have commercial potential on the Brazilian side [296].

In addition to its use in construction, ubim also has ecological importance for some indigenous and riverside communities. Ubim fibers (Figure 22b,c) are used to make baskets, mats, and other handicrafts. In addition, this plant has potential for ornamental purposes in gardens and interiors.

Ubim is widely used in the Amazon and Acre regions; however, the plant's potential application depends on the development of the market, which currently lacks a regular and abundant supply of the product. It also faces the apparent lack of awareness of its existence on the part of consumers in the city of Rio Branco, in the state of Acre, which represents the largest potential market for this product in the region [296]. In addition to the potential of ubim daughters, ubim fiber has yet to be widely applied as a reinforcing material in industrialized products and engineering applications. Unlike better-known fibers such as sisal, bamboo, curaua, coconut, jute, and others, there are practically no scientific reports studying the properties of ubim fiber and its application.

Studies into the properties of ubim fiber and its applications are still limited. Recently, a pioneering study by Marchi et al. [297] evaluated the characteristics and properties of this fiber. The researchers identified important characteristics for evaluating the fiber, such as crystallinity, microfibril angle, diameter, density, and cellulose content. The results of this study are shown in Table 11.

Table 11. Physical properties of ubim fiber [297].

Fiber	Diameter (μm)	Density (g/cm^3)	Cellulose (%)	Crystallinity (%)	Microfibril Angle (°)
Ubim	510–620	0.44–0.97	66	63–83	7.46

The authors' results show that the fiber has good characteristics such as high crystallinity, low microfibril angle, and low density. These characteristics suggest that the fiber has potential for application in engineering composites, combining low weight and possibly good mechanical properties.

Carrying on from their previous work, Marchi et al. [298] investigated the thermal, chemical, and ballistic properties of epoxy matrix composites reinforced with ubim fibers. Composites were produced with fiber fractions of 10, 20, and 30 vol.%, in which the properties were compared with pure epoxy. Fourier transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), and ballistic tests were carried out. The FTIR analysis showed peaks characteristic of other natural lignocellulosic fibers. The thermal analyses showed that the fibers slightly improved the thermal stability of the composites, even though the onset degradation temperatures (T_{onset}) and maximum degradation temperatures (T_{max}) occurred slightly earlier in the case of the composites. The data obtained from the ballistic test are shown in Table 12.

Table 12. Ballistic parameters obtained in ballistic test with 7.62 mm ammunition [298].

Samples	v_i (m/s)	v_r (m/s)	E_{abs} (J)	v_L (m/s)
Epoxy	812.58 ± 3.84	786.28 ± 5.93	203.82 ± 18.92	204.82 ± 9.36
10 vol.%	833.75 ± 12.81	810.28 ± 15.39	187.03 ± 25.99	195.98 ± 13.57
20 vol.%	808.42 ± 9.84	786.56 ± 10.81	169.07 ± 33.73	185.98 ± 18.00
30 vol.%	815.28 ± 8.70	794.85 ± 10.54	159.42 ± 26.32	180.79 ± 14.93

Based on the results of the ballistic test, the authors pointed out that the energy absorbed (E_{abs}) was reduced as a result of the increase in ubim fibers, but the velocity limit

(v_L) was also reduced. In general, the composites with fibers absorbed less energy, but reduced the velocity of the projectile, compared to pure epoxy, which points to a potential application of composites reinforced with ubim fibers for ballistic applications.

In summary, ubim fibers have potential application in engineering composites. Based on the promising results observed by Marchi et al. [298], it would be possible to expand the applications of ubim fibers by investigating other fiber properties, in addition to their application in composites with different matrices.

4. Final Remarks and Conclusions

The abundance of biodiversity in the Amazon region is reflected in the wide variety of natural fibers found in this area. Additionally, the local communities possess ancestral knowledge of the sustainable use of these resources, further underscoring the importance of preserving and valuing these fibers. The preservation of not only the Amazon rainforest but also the economic and social development of the communities that rely on these resources are intrinsically linked to this preservation.

It is important to highlight that there are several plants in the Amazon region whose fibers were not addressed in this study but also have promising applications in engineering composites. Some examples of these fibers include ouricuri [299], embira [300], taboa [301], titica vine [302,303], tururi [304–306], inajá [307], ubuçu [308,309], jarina [310], and patauá [311,312], among others. These fibers have significant potential for use in various industrial applications, replacing synthetic reinforcements with natural materials and promoting sustainability.

The development of new research is crucial to expand our knowledge about the properties of these natural fibers and further encourage their use in the industry. Advanced research is being conducted daily, covering topics such as hybrid composites, laminates, new processing methods, and many others. These studies aim to push the boundaries of knowledge about composite materials and maximize the potential of these natural fibers in engineering.

This review article highlights the potential of natural fibers found in the Amazon Rainforest for use in engineering composites and sustainable actions. The region's natural fibers have a high cellulose content and exhibit mechanical properties that make them a promising alternative to synthetic fibers in various applications.

The use of natural fibers contributes to sustainable actions by reducing the environmental impact of production processes and promoting the use of renewable resources. However, it is important to note that there are challenges and limitations to be overcome. More research and development are needed to optimize the properties of natural fibers and improve processing methods.

The use of natural fibers drives industrial development, whether in the production of clothing and textiles or as reinforcement in composites to enhance the properties of plastic or cementitious materials. Sectors such as automotive and construction benefit by combining the cost-effectiveness of these materials with the excellent properties that reinforcements can impart to the matrix. In the well-established Brazilian market, cotton fiber stands out as one of the most utilized, particularly in clothing manufacturing. However, Amazonian natural fibers have the potential to further boost the country's economy in the production of composite fabrics for engineering applications.

The lack of knowledge about these fibers has contributed to their underutilization in the national industry. Nevertheless, there is an observable growth in research involving these materials, exploring their properties and applications. Therefore, these fibers, previously unknown to the general public, have the potential to be incorporated into the industry on a large scale, generating income in the regions where the plants are extracted and boosting the economy of the Amazon region.

In summary, the use of natural fibers from the Amazon has the potential to drive economic growth and promote sustainable development. Furthermore, this utilization contributes to the preservation of the unique biodiversity of this important region.

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Abbreviations

The following abbreviations are used in this manuscript:

°	Angle symbol
°C	Celsius
µm	micrometer
Al_2O_3	Aluminium Oxide
BC	Before Christ
BFS	Backface Signature
CC	Creative Commons
DNFI	Discover Natural Fibers Initiative
DSC	Differential Scanning Calorimetry
E_{abs}	Energy absorbed
g	Gram
g/cm^3	Gram per cubic centimeter
GJ	Gigajoule
GPa	Gigapascal
HDPE	High Density Polyethylene
HIPS	High-Impact Polystyrene
J	Joule
kg	Kilogram
m/s	Meters per second
MAS	Multilayered Armor System
MFA	Microfibril Angle
mm	milimeter
MPA	Megapascal
MWCNT	Multi-Walled Carbon Nanotube
N	Newton
N_2	Nitrogen
NaOH	Sodium Hydroxide
NIJ	National Institute of Justice
nm	nanometer
NFRPC	Natural Fiber-Reinforced Polymer Composite
PHB	Polyhydroxybutyrate
PP	Polypropylene
PPr	Recycled Polypropylene
PP-g-MA	Maleic Anhydride
SDGs	Sustainable Development Goals
SEM	Scanning Electron Microscopy
tex	Unit of textile measurement
TGA	Thermogravimetric Analysis
ton	Tonne
US$	Dollar

UV	Ultraviolet
v_i	Initial velocity
v_L	Limit velocity
v_r	Residual velocity
vol.%	Volume percent
wt.%	Weight percent

References

1. Fisher, C.H. History of natural fibers. *J. Macromol. Sci. Chem.* **1981**, *15*, 1345–1375. [CrossRef]
2. Viot, C.R.; Wendel, J.F. Evolution of the cotton genus, Gossypium, and its domestication in the Americas. *Crit. Rev. Plant Sci.* **2023**, *42*, 1–33. [CrossRef]
3. Kieling, A.C.; de Macedo Neto, J.C.; Del Pino, G.G.; da Silva Barboza, R.; Diáz, F.R.V.; Rivera, J.L.V.; Fernández, M.V.; Ketterer, C.G.; Ortega, A.G.; Abarzúa, R.I. Development of an Epoxy Matrix Hybrid Composite with Astrocaryum Aculeatum (Tucumã) Endocarp and Kaolin from the Amazonas State in Brazil. *Polymers* **2023**, *15*, 2532. [CrossRef] [PubMed]
4. Pezzolo, D.B. *Tecidos: História, Rramas, Tipos e Usos*; Editora Senac São Paulo: São Paulo, Brazil, 2021.
5. Baldia, C.M.; Armitage, R.A. Archaeological Textiles as Secondary Plant and Animal Products. *Handb. Archaeol. Sci.* **2023**, *2*, 797–811.
6. Xhauflair, H.; Jago-On, S.; Vitales, T.J.; Manipon, D.; Amano, N.; Callado, J.R.; Tandang, D.; Kerfant, C.; Choa, O.; Pawlik, A. The invisible plant technology of Prehistoric Southeast Asia: Indirect evidence for basket and rope making at Tabon Cave, Philippines, 39–33,000 years ago. *PLoS ONE* **2023**, *18*, e0281415. [CrossRef] [PubMed]
7. Bairagi, N.; Selvadhas, A.; Archarya, S. Innovative Collaboration and Co-designing with Santhal and Mohli Tribes of Dumka, India. 2023. Available online: https://dl.designresearchsociety.org/iasdr/iasdr2023/fullpapers/175/ (accessed on 15 November 2023).
8. Galán-Guevara, C. Understanding change in traditional sustainable livelihoods: A complex socio-ecological system in an indigenous community in Mexico. *Community Dev. J.* **2023**, bsad010. [CrossRef]
9. Balsalobre-Lorente, D.; Abbas, J.; He, C.; Pilař, L.; Shah, S.A.R. Tourism, urbanization and natural resources rents matter for environmental sustainability: The leading role of AI and ICT on sustainable development goals in the digital era. *Resour. Policy* **2023**, *82*, 103445. [CrossRef]
10. Adebayo, T.S.; Ullah, S.; Kartal, M.T.; Ali, K.; Pata, U.K.; Ağa, M. Endorsing sustainable development in BRICS: The role of technological innovation, renewable energy consumption, and natural resources in limiting carbon emission. *Sci. Total Environ.* **2023**, *859*, 160181. [CrossRef]
11. Cardoso, R.L.B.; da Silva Rodrigues, J.; Ramos, R.P.B.; de Castro Correa, A.; Leão Filha, E.M.; Monteiro, S.N.; da Silva, A.C.R.; Fujiyama, R.T.; Candido, V.S. Use of Yarn and Carded Jute as Epoxy Matrix Reinforcement for the Production of Composite Materials for Application in the Wind Sector: A Preliminary Analysis for the Manufacture of Blades for Low-Intensity Winds. *Polymers* **2023**, *15*, 3682. [CrossRef]
12. Ravindran, G.; Mahesh, V.; Bheel, N.; Chittimalla, S.; Srihitha, K.; Sushmasree, A. Usage of Natural Fibre Composites for Sustainable Material Development: Global Research Productivity Analysis. *Buildings* **2023**, *13*, 1260. [CrossRef]
13. Elfaleh, I.; Abbassi, F.; Habibi, M.; Ahmad, F.; Guedri, M.; Nasri, M.; Garnier, C. A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials. *Results Eng.* **2023**, *19*, 101271. [CrossRef]
14. Hasan, K.F.; Horváth, P.G.; Alpár, T. Potential natural fiber polymeric nanobiocomposites: A review. *Polymers* **2020**, *12*, 1072. [CrossRef] [PubMed]
15. Zhang, Z.; Cai, S.; Li, Y.; Wang, Z.; Long, Y.; Yu, T.; Shen, Y. High performances of plant fiber reinforced composites—A new insight from hierarchical microstructures. *Compos. Sci. Technol.* **2020**, *194*, 108151. [CrossRef]
16. Silva, J.R.S.d.; Fonseca, J.C.P.; Santos, T.d.S.; Oliveira, J.B.d.; Maquiné, T.M.; Freitas, B.M.d.; Silva, R.N.A.; Nascimento, N.R.d.; Costa, J.M.d.; Bello, R.H.; et al. Polymer composite produced with Brazil nut residues and high impact polystyrene. *Polímeros* **2023**, *32*. [CrossRef]
17. Initiative, D.N.F. World Natural Fibre Update November 2023. Discover Natural Fibers Initiative. Technical Report. 2023. Available online: https://dnfi.org (accessed on 15 November 2023).
18. da Silveira, P.H.P.M.; Santos, M.C.C.d.; Chaves, Y.S.; Ribeiro, M.P.; Marchi, B.Z.; Monteiro, S.N.; Gomes, A.V.; Tapanes, N.d.L.C.O.; Pereira, P.S.d.C.; Bastos, D.C. Characterization of Thermo-Mechanical and Chemical Properties of Polypropylene/Hemp Fiber Biocomposites: Impact of Maleic Anhydride Compatibilizer and Fiber Content. *Polymers* **2023**, *15*, 3271. [CrossRef] [PubMed]
19. Das, S.C.; La Rosa, A.D.; Goutianos, S.; Grammatikos, S. Effect of accelerated weathering on the performance of natural fibre reinforced recyclable polymer composites and comparison with conventional composites. *Compos. Part C Open Access* **2023**, *12*, 100378. [CrossRef]
20. Murali, B.; Karthik, K.; Marotrao, S.S.; Laxmaiah, G.; Yadav, A.S.; Prasanth, I.; Abbas, M. Mechanical and dynamic mechanical properties of hybrid kevlar/natural fiber composites. *Mater. Res. Express* **2023**, *10*, 105305. [CrossRef]
21. Vinod, A.; Sanjay, M.; Siengchin, S. Recently explored natural cellulosic plant fibers 2018–2022: A potential raw material resource for lightweight composites. *Ind. Crops Prod.* **2023**, *192*, 116099. [CrossRef]

22. Neto, J.S.; de Queiroz, H.F.; Aguiar, R.A.; Banea, M.D. A review on the thermal characterisation of natural and hybrid fiber composites. *Polymers* **2021**, *13*, 4425. [CrossRef]
23. Kieling, A.C.; Santana, G.P.; Santos, M.C.D.; Neto, J.C.D.M.; Pino, G.G.D.; Santos, M.D.D.; Duvoisin Jr, S.; Panzera, T.H. Wood-plastic composite based on recycled polypropylene and Amazonian tucumã (*Astrocaryum aculeatum*) endocarp waste. *Fibers Polym.* **2021**, *22*, 2834–2845. [CrossRef]
24. Park, H. A study on structural design and analysis of small wind turbine blade with natural fibre (flax) composite. *Adv. Compos. Mater.* **2016**, *25*, 125–142. [CrossRef]
25. Klose, L.; Meyer-Heydecke, N.; Wongwattanarat, S.; Chow, J.; Pérez García, P.; Carré, C.; Streit, W.; Antranikian, G.; Romero, A.M.; Liese, A. Towards Sustainable Recycling of Epoxy-Based Polymers: Approaches and Challenges of Epoxy Biodegradation. *Polymers* **2023**, *15*, 2653. [CrossRef] [PubMed]
26. Panzera, T.H.; Jeannin, T.; Gabrion, X.; Placet, V.; Remillat, C.; Farrow, I.; Scarpa, F. Static, fatigue and impact behaviour of an autoclaved flax fibre reinforced composite for aerospace engineering. *Compos. Part B Eng.* **2020**, *197*, 108049. [CrossRef]
27. Rangappa, S.M.; Siengchin, S.; Parameswaranpillai, J.; Jawaid, M.; Ozbakkaloglu, T. Lignocellulosic fiber reinforced composites: Progress, performance, properties, applications, and future perspectives. *Polym. Compos.* **2022**, *43*, 645–691. [CrossRef]
28. United Nations. Sustainable Development Goals. 2015. Available online: https://www.un.org/sustainabledevelopment/inequality (accessed on 20 November 2023).
29. Maximo, Y.I.; Hassegawa, M.; Verkerk, P.J.; Missio, A.L. Forest bioeconomy in Brazil: Potential innovative products from the forest sector. *Land* **2022**, *11*, 1297. [CrossRef]
30. Kardung, M.; Cingiz, K.; Costenoble, O.; Delahaye, R.; Heijman, W.; Lovrić, M.; van Leeuwen, M.; M'barek, R.; van Meijl, H.; Piotrowski, S.; et al. Development of the circular bioeconomy: Drivers and indicators. *Sustainability* **2021**, *13*, 413. [CrossRef]
31. Barañano, L.; Garbisu, N.; Alkorta, I.; Araujo, A.; Garbisu, C. Contextualization of the bioeconomy concept through its links with related concepts and the challenges facing humanity. *Sustainability* **2021**, *13*, 7746. [CrossRef]
32. Kamarudin, S.H.; Mohd Basri, M.S.; Rayung, M.; Abu, F.; Ahmad, S.; Norizan, M.N.; Osman, S.; Sarifuddin, N.; Desa, M.S.Z.M.; Abdullah, U.H.; et al. A review on natural fiber reinforced polymer composites (NFRPC) for sustainable industrial applications. *Polymers* **2022**, *14*, 3698. [CrossRef]
33. Barbosa, B.M.; Vaz, S., Jr.; Colodette, J.L.; de Siqueira, H.F.; da Silva, C.M.S.; Cândido, W.L. Effects of Kraft Lignin and Corn Residue on the Production of Eucalyptus Pellets. *BioEnergy Res.* **2023**, *16*, 484–493. [CrossRef]
34. Barros, M.A.L.; Silva, C.R.C.D.; Lima, L.M.D.; Farias, F.J.C.; Ramos, G.A.; Santos, R.C.D. A review on evolution of cotton in Brazil: GM, white, and colored cultivars. *J. Nat. Fibers* **2022**, *19*, 209–221. [CrossRef]
35. Soares, V.L.; Faber, M.d.O.; Monteiro, A.F.; Cammarota, M.C.; Ferreira-Leitão, V.S. Potential use of sisal juice as raw material for sequential biological production of hydrogen and methane. *Braz. J. Chem. Eng.* **2023**, 1–12. [CrossRef]
36. Raya, F.T.; Carvalho, L.M.; José, J.; da Cruz, L.P.; Almeida, R.L.; Delevatti, H.A.d.A.; Silveira, N.; da Silva, S.F.; Pissolato, M.D.; Oliveira, A.B.; et al. Rescuing the Brazilian Agave breeding program: Morphophysiological and molecular characterization of a new germplasm. *Front. Chem. Eng.* **2023**, *5*, 1218668. [CrossRef]
37. de Souza, L.A.G. Biodiversity of Fabaceae in the Brazilian Amazon and Its Timber Potential for the Future. In *Tropical Forests-Ecology, Diversity and Conservation Status*; IntechOpen: London, UK, 2023.
38. Rodrigues, L.d.A.P.; Nunes, D.D.G.; Hodel, K.V.S.; Viana, J.D.; Silva, E.P.; Soares, M.B.P. Exotic fruits patents trends: An overview based on technological prospection with a focus on Amazonian. *Heliyon* **2023**, *9*, e22060. [CrossRef] [PubMed]
39. Neves, P.D.; Cabral, M.R.; Santos, V.; Mafra, M.R.P.; Junior, H.S. Technical assessment of leaf fibers from curaua: An amazonian bioresource. *J. Nat. Fibers* **2022**, *19*, 5900–5909. [CrossRef]
40. Akil, H.; Omar, M.; Mazuki, A.M.; Safiee, S.; Ishak, Z.M.; Bakar, A.A. Kenaf fiber reinforced composites: A review. *Mater. Des.* **2011**, *32*, 4107–4121. [CrossRef]
41. Sanjay, M.R.; Arpitha, G.; Yogesha, B. Study on mechanical properties of natural-glass fibre reinforced polymer hybrid composites: A review. *Mater. Today Proc.* **2015**, *2*, 2959–2967. [CrossRef]
42. Tonk, R. Natural fibers for sustainable additive manufacturing: A state of the art review. *Mater. Today Proc.* **2021**, *37*, 3087–3090. [CrossRef]
43. Crewther, W. The stress—Strain characteristics of animal fibers after reduction and alkylation. *Text. Res. J.* **1965**, *35*, 867–877. [CrossRef]
44. Liu, X.; Wang, L.; Wang, X. Evaluating the softness of animal fibers. *Text. Res. J.* **2004**, *74*, 535–538. [CrossRef]
45. Ammar, Z.; Ibrahim, H.; Adly, M.; Sarris, I.; Mehanny, S. Influence of natural fiber content on the frictional material of brake pads—A review. *J. Compos. Sci.* **2023**, *7*, 72. [CrossRef]
46. Al-Kharabsheh, B.N.; Arbili, M.M.; Majdi, A.; Alogla, S.M.; Hakamy, A.; Ahmad, J.; Deifalla, A.F. Basalt fiber reinforced concrete: A compressive review on durability aspects. *Materials* **2023**, *16*, 429. [CrossRef] [PubMed]
47. Tao, W.; Wang, B.; Wang, N.; Guo, Y.; Li, J.; Zhou, Z. Research progress on basalt fiber-based functionalized composites. *Rev. Adv. Mater. Sci.* **2023**, *62*, 20220300. [CrossRef]
48. Dvorkin, L.; Konkol, J.; Marchuk, V.; Huts, A. Efficient, Fine-Grained Fly Ash Concrete Based on Metal and Basalt Fibers. *Materials* **2023**, *16*, 3969. [CrossRef]
49. Peng, Z.; Zhang, H.; Feng, Q.; Zheng, Y. Improvement of basalt fiber dispersion and its effect on mechanical characteristics of oil well cement. *J. Build. Eng.* **2023**, *76*, 107244. [CrossRef]

50. Wang, N.; Liu, H.; Huang, F. Effects of Hybrid Rockwool–Wood Fiber on the Performance of Asbestos-Free Brake Friction Composites. *Lubricants* **2023**, *11*, 27. [CrossRef]
51. Yavuz, H. Effect of limestone usage on tribological properties in copper and asbestos-free brake friction materials. *Ind. Lubr. Tribol.* **2023**, *75*, 238–245. [CrossRef]
52. Suphamitmongkol, W.; Khanoonkon, N.; Rungruangkitkrai, N.; Boonyarit, J.; Changniam, C.; Sampoompuang, C.; Chollakup, R. Potential of Pineapple Leaf Fibers as Sound and Thermal Insulation Materials in Thailand. *Prog. Appl. Sci. Technol.* **2023**, *13*, 26–32.
53. Patel, R.V.; Yadav, A.; Winczek, J. Physical, Mechanical, and Thermal Properties of Natural Fiber-Reinforced Epoxy Composites for Construction and Automotive Applications. *Appl. Sci.* **2023**, *13*, 5126. [CrossRef]
54. Khatri, H.; Naveen, J.; Jawaid, M.; Jayakrishna, K.; Norrrahim, M.; Rashedi, A. Potential of natural fiber based polymeric composites for cleaner automotive component Production-A comprehensive review. *J. Mater. Res. Technol.* **2023**, *25*, 1086–1104.
55. El Hawary, O.; Boccarusso, L.; Ansell, M.P.; Durante, M.; Pinto, F. An overview of natural fiber composites for marine applications. *J. Mar. Sci. Eng.* **2023**, *11*, 1076. [CrossRef]
56. Haramina, T.; Hadžić, N.; Keran, Z. Epoxy Resin Biocomposites Reinforced with Flax and Hemp Fibers for Marine Applications. *J. Mar. Sci. Eng.* **2023**, *11*, 382. [CrossRef]
57. Sangmesh, B.; Patil, N.; Jaiswal, K.K.; Gowrishankar, T.; Selvakumar, K.K.; Jyothi, M.; Jyothilakshmi, R.; Kumar, S. Development of sustainable alternative materials for the construction of green buildings using agricultural residues: A review. *Constr. Build. Mater.* **2023**, *368*, 130457.
58. Özkılıç, Y.O.; Beskopylny, A.N.; Stel'makh, S.A.; Shcherban, E.M.; Mailyan, L.R.; Meskhi, B.; Chernil'nik, A.; Ananova, O.; Aksoylu, C.; Madenci, E. Lightweight expanded-clay fiber concrete with improved characteristics reinforced with short natural fibers. *Case Stud. Constr. Mater.* **2023**, *19*, e02367. [CrossRef]
59. Mansor, M.; Nurfaizey, A.; Tamaldin, N.; Nordin, M. Natural fiber polymer composites: Utilization in aerospace engineering. In *Biomass, Biopolymer-Based Materials, and Bioenergy*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 203–224.
60. Asim, M.; Saba, N.; Jawaid, M.; Nasir, M. Potential of natural fiber/biomass filler-reinforced polymer composites in aerospace applications. In *Sustainable Composites for Aerospace Applications*; Elsevier: Amsterdam, The Netherlands, 2018; pp. 253–268.
61. Dhas, J.E.R.; Arun, M. A review on development of hybrid composites for aerospace applications. *Mater. Today Proc.* **2022**, *64*, 267–273. [CrossRef]
62. Ramamoorthy, S.K.; Skrifvars, M.; Persson, A. A review of natural fibers used in biocomposites: Plant, animal and regenerated cellulose fibers. *Polym. Rev.* **2015**, *55*, 107–162. [CrossRef]
63. Bismarck, A.; Mishra, S.; Lampke, T. Plant fibers as reinforcement for green composites. In *Natural Fibers, Biopolymers, and Biocomposites*; CRC Press: Boca Raton, FL, USA, 2005; pp. 52–128.
64. Anandjiwala, R.D.; Blouw, S. Composites from bast fibres-prospects and potential in the changing market environment. *J. Nat. Fibers* **2007**, *4*, 91–109. [CrossRef]
65. Ticoalu, A.; Aravinthan, T.; Cardona, F. A review of current development in natural fiber composites for structural and infrastructure applications. In Proceedings of the Southern Region Engineering Conference (SREC 2010), Toowoomba, Australia, 11–12 November 2010.
66. Bhattacharyya, D.; Subasinghe, A.; Kim, N.K. Natural fibers: Their composites and flammability characterizations. *Multifunct. Polym. Compos.* **2015**, *1*, 102–143.
67. John, M.J.; Thomas, S. Biofibres and biocomposites. *Carbohydr. Polym.* **2008**, *71*, 343–364. [CrossRef]
68. Wei, J.; Meyer, C. Degradation mechanisms of natural fiber in the matrix of cement composites. *Cem. Concr. Res.* **2015**, *73*, 1–16. [CrossRef]
69. Jayaraman, K. Manufacturing sisal–polypropylene composites with minimum fibre degradation. *Compos. Sci. Technol.* **2003**, *63*, 367–374. [CrossRef]
70. Tsoumis, G. *Science and Technology of Wood: Structure, Properties, Utilization*; Van Nostrand Reinhold New York: New York, NY, USA, 1991; Volume 115.
71. Satyanarayana, K.; Ravikumar, K.; Sukumaran, K.; Mukherjee, P.; Pillai, S.; Kulkarni, A. Structure and properties of some vegetable fibres: Part 3 Talipot and palmyrah fibres. *J. Mater. Sci.* **1986**, *21*, 57–63. [CrossRef]
72. Komuraiah, A.; Kumar, N.S.; Prasad, B.D. Chemical composition of natural fibers and its influence on their mechanical properties. *Mech. Compos. Mater.* **2014**, *50*, 359–376. [CrossRef]
73. Karimah, A.; Ridho, M.R.; Munawar, S.S.; Adi, D.S.; Damayanti, R.; Subiyanto, B.; Fatriasari, W.; Fudholi, A. A review on natural fibers for development of eco-friendly bio-composite: Characteristics, and utilizations. *J. Mater. Res. Technol.* **2021**, *13*, 2442–2458. [CrossRef]
74. Brink, M.; Escobin, R. *Plant Resources of South-East Asia*; Backhuys Publ.: Leiden, The Netherlands, 2003.
75. Stokke, D.D.; Wu, Q.; Han, G. *Introduction to Wood and Natural Fiber Composites*; John Wiley & Sons: Hoboken, NJ, USA, 2013; 314p, ISBN 978-0-470-71091-3.
76. Oksman, K.; Bengtsson, M. Wood fibre thermoplastic composites: Processing, properties and future developments. 2007.
77. Mwaikambo, L.Y.; Ansell, M.P. The effect of chemical treatment on the properties of hemp, sisal, jute and kapok for composite reinforcement. *Die Angew. Makromol. Chem.* **1999**, *272*, 108–116. [CrossRef]

78. Koohestani, B.; Darban, A.; Mokhtari, P.; Yilmaz, E.; Darezereshki, E. Comparison of different natural fiber treatments: A literature review. *Int. J. Environ. Sci. Technol.* **2019**, *16*, 629–642. [CrossRef]
79. Moudood, A.; Rahman, A.; Öchsner, A.; Islam, M.; Francucci, G. Flax fiber and its composites: An overview of water and moisture absorption impact on their performance. *J. Reinf. Plast. Compos.* **2019**, *38*, 323–339. [CrossRef]
80. Baltazar-y Jimenez, A.; Bismarck, A. Wetting behaviour, moisture up-take and electrokinetic properties of lignocellulosic fibres. *Cellulose* **2007**, *14*, 115–127. [CrossRef]
81. Kostic, M.; Pejic, B.; Skundric, P. Quality of chemically modified hemp fibers. *Bioresour. Technol.* **2008**, *99*, 94–99. [CrossRef]
82. Shahzad, A. Hemp fiber and its composites—A review. *J. Compos. Mater.* **2012**, *46*, 973–986. [CrossRef]
83. Li, Z.; Li, Z.; Ding, R.; Yu, C. Composition of ramie hemicelluloses and effect of polysaccharides on fiber properties. *Text. Res. J.* **2016**, *86*, 451–460. [CrossRef]
84. Zhou, J.; Li, Z.; Yu, C. Property of ramie fiber degummed with Fenton reagent. *Fibers Polym.* **2017**, *18*, 1891–1897. [CrossRef]
85. Wang, C.; Bai, S.; Yue, X.; Long, B.; Choo-Smith, L.P. Relationship between chemical composition, crystallinity, orientation and tensile strength of kenaf fiber. *Fibers Polym.* **2016**, *17*, 1757–1764. [CrossRef]
86. Azevedo, A.R.; Lima, T.E.; Reis, R.H.; Oliveira, M.S.; Candido, V.S.; Monteiro, S.N. Guaruman fiber: A promising reinforcement for cement-based mortars. *Case Stud. Constr. Mater.* **2022**, *16*, e01029. [CrossRef]
87. Wang, W.M.; Cai, Z.S.; Yu, J.Y.; Xia, Z.P. Changes in composition, structure, and properties of jute fibers after chemical treatments. *Fibers Polym.* **2009**, *10*, 776–780. [CrossRef]
88. Mishra, S.; Mohanty, A.K.; Drzal, L.T.; Misra, M.; Hinrichsen, G. A review on pineapple leaf fibers, sisal fibers and their biocomposites. *Macromol. Mater. Eng.* **2004**, *289*, 955–974. [CrossRef]
89. Zhu, Z.; Hao, M.; Zhang, N. Influence of contents of chemical compositions on the mechanical property of sisal fibers and sisal fibers reinforced PLA composites. *J. Nat. Fibers* **2018**, *17*, 101–112. [CrossRef]
90. Tenazoa, C.; Savastano, H.; Charca, S.; Quintana, M.; Flores, E. The effect of alkali treatment on chemical and physical properties of ichu and cabuya fibers. *J. Nat. Fibers* **2021**, *18*, 923–936. [CrossRef]
91. Chokshi, S.; Parmar, V.; Gohil, P.; Chaudhary, V. Chemical composition and mechanical properties of natural fibers. *J. Nat. Fibers* **2022**, *19*, 3942–3953. [CrossRef]
92. Saragih, S.W.; Lubis, R.; Wirjosentono, B.; Eddyanto, E. Characteristic of abaca (*Musa textilis*) fiber from Aceh Timur as bioplastic. In *AIP Conference Proceedings*; AIP Publishing: Melville, NY, USA, 2018; Volume 2049, p. 020058. [CrossRef]
93. Hassan, M.M.; Wagner, M.H.; Zaman, H.; Khan, M.A. Physico-mechanical performance of hybrid betel nut (*Areca catechu*) short fiber/seaweed polypropylene composite. *J. Nat. Fibers* **2010**, *7*, 165–177. [CrossRef]
94. Yusriah, L.; Sapuan, S.; Zainudin, E.; Mariatti, M. Exploring the potential of betel nut husk fiber as reinforcement in polymer composites: Effect of fiber maturity. *Procedia Chem.* **2012**, *4*, 87–94. [CrossRef]
95. Ibrahim, M.M.; Dufresne, A.; El-Zawawy, W.K.; Agblevor, F.A. Banana fibers and microfibrils as lignocellulosic reinforcements in polymer composites. *Carbohydr. Polym.* **2010**, *81*, 811–819. [CrossRef]
96. Jagadeesh, D.; Venkatachalam, R.; Nallakumarasamy, G. Characterisation of banana fiber-a review. *J. Environ. Nanotechnol.* **2015**, *4*, 23–26.
97. Chollakup, R.; Smitthipong, W.; Kongtud, W.; Tantatherdtam, R. Polyethylene green composites reinforced with cellulose fibers (coir and palm fibers): Effect of fiber surface treatment and fiber content. *J. Adhes. Sci. Technol.* **2013**, *27*, 1290–1300. [CrossRef]
98. Adeniyi, A.G.; Onifade, D.V.; Ighalo, J.O.; Adeoye, A.S. A review of coir fiber reinforced polymer composites. *Compos. Part B Eng.* **2019**, *176*, 107305. [CrossRef]
99. Yueping, W.; Ge, W.; Haitao, C.; Genlin, T.; Zheng, L.; Feng, X.Q.; Xiangqi, Z.; Xiaojun, H.; Xushan, G. Structures of bamboo fiber for textiles. *Text. Res. J.* **2010**, *80*, 334–343. [CrossRef]
100. Nahar, S.; Hasan, M. Effect of chemical composition, anatomy and cell wall structure on tensile properties of bamboo fiber. *Eng. J.* **2013**, *17*, 61–68. [CrossRef]
101. Satyanarayana, K.; Guimarães, J.; Wypych, F. Studies on lignocellulosic fibers of Brazil. Part I: Source, production, morphology, properties and applications. *Compos. Part A Appl. Sci. Manuf.* **2007**, *38*, 1694–1709. [CrossRef]
102. Guimaraes, J.L.; Frollini, E.; Da Silva, C.; Wypych, F.; Satyanarayana, K. Characterization of banana, sugarcane bagasse and sponge gourd fibers of Brazil. *Ind. Crops Prod.* **2009**, *30*, 407–415. [CrossRef]
103. Tanobe, V.O.; Sydenstricker, T.H.; Munaro, M.; Amico, S.C. A comprehensive characterization of chemically treated Brazilian sponge-gourds (*Luffa cylindrica*). *Polym. Test.* **2005**, *24*, 474–482. [CrossRef]
104. Johar, N.; Ahmad, I.; Dufresne, A. Extraction, preparation and characterization of cellulose fibres and nanocrystals from rice husk. *Ind. Crops Prod.* **2012**, *37*, 93–99. [CrossRef]
105. Panthapulakkal, S.; Zereshkian, A.; Sain, M. Preparation and characterization of wheat straw fibers for reinforcing application in injection molded thermoplastic composites. *Bioresour. Technol.* **2006**, *97*, 265–272. [CrossRef] [PubMed]
106. Reddy, K.O.; Maheswari, C.U.; Shukla, M.; Rajulu, A.V. Chemical composition and structural characterization of Napier grass fibers. *Mater. Lett.* **2012**, *67*, 35–38. [CrossRef]
107. Tomczak, F.; Satyanarayana, K.G.; Sydenstricker, T.H.D. Studies on lignocellulosic fibers of Brazil: Part III–Morphology and properties of Brazilian curauá fibers. *Compos. Part A Appl. Sci. Manuf.* **2007**, *38*, 2227–2236. [CrossRef]
108. Malkapuram, R.; Kumar, V.; Negi, Y.S. Recent development in natural fiber reinforced polypropylene composites. *J. Reinf. Plast. Compos.* **2009**, *28*, 1169–1189. [CrossRef]

109. Yasin, P.; Ramana, M.V.; Vamshi, C.K.; Pradeep, K. A study of continuous Henequen/Epoxy composites. *Mater. Today Proc.* **2019**, *18*, 3798–3811. [CrossRef]
110. Ioelovich, M.; Leykin, A. Structural investigations of various cotton fibers and cotton celluloses. *BioResources* **2008**, *3*, 170–177. [CrossRef]
111. Dorez, G.; Ferry, L.; Sonnier, R.; Taguet, A.; Lopez-Cuesta, J.M. Effect of cellulose, hemicellulose and lignin contents on pyrolysis and combustion of natural fibers. *J. Anal. Appl. Pyrolysis* **2014**, *107*, 323–331. [CrossRef]
112. Bacci, L.; Di Lonardo, S.; Albanese, L.; Mastromei, G.; Perito, B. Effect of different extraction methods on fiber quality of nettle (*Urtica dioica* L.). *Text. Res. J.* **2011**, *81*, 827–837. [CrossRef]
113. Viju, S.; Thilagavathi, G. Characterization of surface modified nettle fibers for composite reinforcement. *J. Nat. Fibers* **2022**, *19*, 1819–1827. [CrossRef]
114. Laftah, W.A.; Wan Abdul Rahman, W.A. Pulping process and the potential of using non-wood pineapple leaves fiber for pulp and paper production: A review. *J. Nat. Fibers* **2016**, *13*, 85–102. [CrossRef]
115. Neto, A.R.S.; Araujo, M.A.; Barboza, R.M.; Fonseca, A.S.; Tonoli, G.H.; Souza, F.V.; Mattoso, L.H.; Marconcini, J.M. Comparative study of 12 pineapple leaf fiber varieties for use as mechanical reinforcement in polymer composites. *Ind. Crops Prod.* **2015**, *64*, 68–78. [CrossRef]
116. Duarte, G.V.; Ramarao, B.V.; Amidon, T.E.; Ferreira, P.T. Effect of hot water extraction on hardwood kraft pulp fibers (*Acer saccharum*, sugar maple). *Ind. Eng. Chem. Res.* **2011**, *50*, 9949–9959. [CrossRef]
117. Neus Anglès, M.; Salvadó, J.; Dufresne, A. Steam-exploded residual softwood-filled polypropylene composites. *J. Appl. Polym. Sci.* **1999**, *74*, 1962–1977. [CrossRef]
118. Bledzki, A.; Franciszczak, P.; Osman, Z.; Elbadawi, M. Polypropylene biocomposites reinforced with softwood, abaca, jute, and kenaf fibers. *Ind. Crops Prod.* **2015**, *70*, 91–99. [CrossRef]
119. Elzubair, A.; Bonelli, C.M.C.; Suarez, J.C.M.; Mano, E.B. Morphological, structural, thermal and mechanical characterization of piassava fibers. *J. Nat. Fibers* **2007**, *4*, 13–31. [CrossRef]
120. Arce, C.; Garzon, E.; Sanchez-Soto, P.J. Phyllite clays as raw materials replacing cement in mortars: Properties of new impermeabilizing mortars. *Constr. Build. Mater.* **2019**, *224*, 348–358. [CrossRef]
121. Lertwattanaruk, P.; Suntijitto, A. Properties of natural fiber cement materials containing coconut coir and oil palm fibers for residential building applications. *Constr. Build. Mater.* **2015**, *94*, 664–669. [CrossRef]
122. Lilargem Rocha, D.; Tambara Júnior, L.U.D.; Marvila, M.T.; Pereira, E.C.; Souza, D.; de Azevedo, A.R.G. A review of the use of natural fibers in cement composites: Concepts, applications and Brazilian history. *Polymers* **2022**, *14*, 2043. [CrossRef]
123. Carr, D.J.; Cruthers, N.M.; Laing, R.M.; Niven, B.E. Fibers from Three Cultivars of New Zealand Flax (*Phormium tenax*). *Text. Res. J.* **2005**, *75*, 93–98. [CrossRef]
124. Sreenivasan, V.; Somasundaram, S.; Ravindran, D.; Manikandan, V.; Narayanasamy, R. Microstructural, physico-chemical and mechanical characterisation of Sansevieria cylindrica fibres—An exploratory investigation. *Mater. Des.* **2011**, *32*, 453–461. [CrossRef]
125. Syed, N.F.; Zakaria, M.H.; Bujang, J.S. Fiber Characteristics and Papermaking of Seagrass Using Hand-beaten and Blended Pulp. *BioResources* **2016**, *11*, 5358–5380. [CrossRef]
126. Mathew, L.; Joseph, K.; Joseph, R. Isora fibre: Morphology, chemical composition, surface modification, physical, mechanical and thermal properties—A potential natural reinforcement. *J. Nat. Fibers* **2007**, *3*, 13–27. [CrossRef]
127. Chirayil, C.J.; Joy, J.; Mathew, L.; Mozetic, M.; Koetz, J.; Thomas, S. Isolation and characterization of cellulose nanofibrils from Helicteres isora plant. *Ind. Crops Prod.* **2014**, *59*, 27–34. [CrossRef]
128. Sreekala, M.; Kumaran, M.; Thomas, S. Oil palm fibers: Morphology, chemical composition, surface modification, and mechanical properties. *J. Appl. Polym. Sci.* **1997**, *66*, 821–835. [CrossRef]
129. Ammar, H.; Abid, M.; Abid, S. Cellulose fibers obtained by organosolv process from date palm rachis (*Phoenix dactylifera* L.). In Proceedings of the Materiaux 2010, Mahdia, Tunisia, 4–7 January 2010; IOP Publishing: Bristol, UK, 2012; 28, p. 012002. [CrossRef]
130. Sivamurugan, P.; Selvam, R.; Pandian, M.; Ashraf, M.S.; Chakrapani, I.S.; Thanikasalam, A.; Roshith, P.; Ramesh, K.; Ramesh, B. Extraction of novel biosilica from finger millet husk and its coconut rachilla-reinforced epoxy biocomposite: Mechanical, thermal, and hydrophobic behaviour. *Biomass Convers. Biorefinery* **2022**, 1–9. [CrossRef]
131. da Silva Nicolau, G.; Weber, R.P.; Monteiro, S.N.; Loureiro, G.A.; Lavinsky, A.A.; da Fonseca, L.V.; da Silva, E.G.; dos Santos, P.L.B.; Abranches, R.P.; Machado, V.C. Influence of Mercerization Process on the Surface of Coconut Fiber for Composite Reinforcement. In Proceedings of the Materials Science Forum, Chennai, India, 16–17 September 2020; Trans Tech Publications: Wollerau, Switzerland, 2020; Volume 1012, pp. 37–42.
132. Brígida, A.; Calado, V.; Gonçalves, L.; Coelho, M. Effect of chemical treatments on properties of green coconut fiber. *Carbohydr. Polym.* **2010**, *79*, 832–838. [CrossRef]
133. Kulandaivel, N.; Muralikannan, R.; KalyanaSundaram, S. Extraction and characterization of novel natural cellulosic fibers from pigeon pea plant. *J. Nat. Fibers* **2018**, *17*, 769–779. [CrossRef]
134. Fiore, V.; Scalici, T.; Valenza, A. Characterization of a new natural fiber from *Arundo donax* L. as potential reinforcement of polymer composites. *Carbohydr. Polym.* **2014**, *106*, 77–83. [CrossRef]
135. Bledzki, A.K.; Mamun, A.A.; Volk, J. Physical, chemical and surface properties of wheat husk, rye husk and soft wood and their polypropylene composites. *Compos. Part A Appl. Sci. Manuf.* **2010**, *41*, 480–488. [CrossRef]

136. Belkhir, S.; Koubaa, A.; Khadhri, A.; Ksontini, M.; Nadji, H.; Smiti, S.; Stevanovic, T. Seasonal effect on the chemical composition of the leaves of *Stipa tenacissima* L. and implications for pulp properties. *Ind. Crops Prod.* **2013**, *44*, 56–61. [CrossRef]
137. Guna, V.; Ilangovan, M.; Adithya, K.; CV, A.K.; Srinivas, C.; Yogesh, S.; Nagananda, G.; Venkatesh, K.; Reddy, N. Biofibers and biocomposites from sabai grass: A unique renewable resource. *Carbohydr. Polym.* **2019**, *218*, 243–249. [CrossRef] [PubMed]
138. Nath Barman, D.; Haque, M.A.; Kang, T.H.; Kim, G.H.; Kim, T.Y.; Kim, M.K.; Yun, H.D. Effect of mild alkali pretreatment on structural changes of reed (Phragmites communis Trinius) straw. *Environ. Technol.* **2014**, *35*, 232–241. [CrossRef] [PubMed]
139. Loganathan, T.M.; Sultan, M.T.H.; Ahsan, Q.; Jawaid, M.; Naveen, J.; Shah, A.U.M.; Hua, L.S. Characterization of alkali treated new cellulosic fibre from Cyrtostachys renda. *J. Mater. Res. Technol.* **2020**, *9*, 3537–3546. [CrossRef]
140. Chow, P.; Nakayama, F.S.; Blahnik, B.; Youngquist, J.A.; Coffelt, T.A. Chemical constituents and physical properties of guayule wood and bark. *Ind. Crops Prod.* **2008**, *28*, 303–308. [CrossRef]
141. Song, Y.; Han, G.; Li, M.; Jiang, W.; Li, X.; Zhang, Y.; Yu, R. Performance analysis of kudzu fiber prepared by using combined steam explosion and chemical degumming. *J. Nat. Fibers* **2017**, *14*, 759–768. [CrossRef]
142. Kazama, E.H.; Ferreira, F.M.; Silva, A.R.B.d.; Fiorese, D.A. Influência do sistema de colheita nas características da fibra do algodão. *Rev. Ceres* **2016**, *63*, 631–638. [CrossRef]
143. Mohammed, L.; Ansari, M.N.; Pua, G.; Jawaid, M.; Islam, M.S. A review on natural fiber reinforced polymer composite and its applications. *Int. J. Polym. Sci.* **2015**, *2015*, 243947. [CrossRef]
144. Petroudy, S.D. Physical and mechanical properties of natural fibers. In *Advanced High Strength Natural Fibre Composites in Construction*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 59–83.
145. Madsen, B.; Gamstedt, E.K. Wood versus plant fibers: Similarities and differences in composite applications. *Adv. Mater. Sci. Eng.* **2013**, *2013*, 564346. [CrossRef]
146. Joseph, K.; Thomas, S.; Pavithran, C. Effect of chemical treatment on the tensile properties of short sisal fibre-reinforced polyethylene composites. *Polymer* **1996**, *37*, 5139–5149. [CrossRef]
147. Khalid, M.Y.; Imran, R.; Arif, Z.U.; Akram, N.; Arshad, H.; Al Rashid, A.; Garcia Marquez, F.P. Developments in chemical treatments, manufacturing techniques and potential applications of natural-fibers-based biodegradable composites. *Coatings* **2021**, *11*, 293. [CrossRef]
148. Sonawane, G.H.; Patil, S.P.; Sonawane, S.H. Nanocomposites and its applications. In *Applications of Nanomaterials*; Elsevier: Amsterdam, The Netherlands, 2018; pp. 1–22.
149. Meneghetti, P.; Qutubuddin, S. Synthesis, thermal properties and applications of polymer-clay nanocomposites. *Thermochim. Acta* **2006**, *442*, 74–77. [CrossRef]
150. Vilaseca, F.; Corrales, F.; Llop, M.F.; Pelach, M.A.; Mutjé, P. Chemical treatment for improving wettability of biofibres into thermoplastic matrices. *Compos. Interfaces* **2005**, *12*, 725–738. [CrossRef]
151. Faruk, O.; Bledzki, A.K.; Fink, H.P.; Sain, M. Biocomposites reinforced with natural fibers: 2000–2010. *Prog. Polym. Sci.* **2012**, *37*, 1552–1596. [CrossRef]
152. Gholampour, A.; Ozbakkaloglu, T. A review of natural fiber composites: Properties, modification and processing techniques, characterization, applications. *J. Mater. Sci.* **2020**, *55*, 829–892. [CrossRef]
153. Rahman, A.S.; Mathur, V.; Asmatulu, R. Effect of nanoclay and graphene inclusions on the low-velocity impact resistance of Kevlar-epoxy laminated composites. *Compos. Struct.* **2018**, *187*, 481–488. [CrossRef]
154. Sanjay, M.; Madhu, P.; Jawaid, M.; Senthamaraikannan, P.; Senthil, S.; Pradeep, S. Characterization and properties of natural fiber polymer composites: A comprehensive review. *J. Clean. Prod.* **2018**, *172*, 566–581. [CrossRef]
155. Amiandamhen, S.; Meincken, M.; Tyhoda, L. Natural fibre modification and its influence on fibre-matrix interfacial properties in biocomposite materials. *Fibers Polym.* **2020**, *21*, 677–689. [CrossRef]
156. Nurazzi, N.; Asyraf, M.; Rayung, M.; Norrrahim, M.; Shazleen, S.; Rani, M.; Shafi, A.; Aisyah, H.; Radzi, M.; Sabaruddin, F.; et al. Thermogravimetric analysis properties of cellulosic natural fiber polymer composites: A review on influence of chemical treatments. *Polymers* **2021**, *13*, 2710. [CrossRef]
157. Mohammed, M.; Rahman, R.; Mohammed, A.M.; Adam, T.; Betar, B.O.; Osman, A.F.; Dahham, O.S. Surface treatment to improve water repellence and compatibility of natural fiber with polymer matrix: Recent advancement. *Polym. Test.* **2022**, *115*, 107707. [CrossRef]
158. Corrales, F.; Vilaseca, F.; Llop, M.; Girones, J.; Mendez, J.; Mutje, P. Chemical modification of jute fibers for the production of green-composites. *J. Hazard. Mater.* **2007**, *144*, 730–735. [CrossRef]
159. Gallego, R.; Piras, C.C.; Rutgeerts, L.A.; Fernandez-Prieto, S.; De Borggraeve, W.M.; Franco, J.M.; Smets, J. Green approach for the activation and functionalization of jute fibers through ball milling. *Cellulose* **2020**, *27*, 643–656. [CrossRef]
160. Sood, M.; Dwivedi, G. Effect of fiber treatment on flexural properties of natural fiber reinforced composites: A review. *Egypt. J. Pet.* **2018**, *27*, 775–783. [CrossRef]
161. Ku, H.; Wang, H.; Pattarachaiyakoop, N.; Trada, M. A review on the tensile properties of natural fiber reinforced polymer composites. *Compos. Part B Eng.* **2011**, *42*, 856–873. [CrossRef]
162. Benítez, A.N.; Monzón, M.D.; Angulo, I.; Ortega, Z.; Hernández, P.M.; Marrero, M.D. Treatment of banana fiber for use in the reinforcement of polymeric matrices. *Measurement* **2013**, *46*, 1065–1073. [CrossRef]
163. Huda, M.; Drzal, L.; Ray, D.; Mohanty, A.; Mishra, M. Natural-fiber composites in the automotive sector. In *Properties and Performance of Natural-Fibre Composites*; Elsevier: Amsterdam, The Netherlands, 2008; pp. 221–268.

164. da Costa Tavares, M.G. A Amazônia brasileira: Formação histórico-territorial e perspectivas para o século XXI. *GEOUSP Espaço E Tempo (Online)* **2011**, *15*, 107–121.
165. Rorato, A.C.; Dal'Asta, A.P.; Lana, R.M.; Dos Santos, R.B.; Escada, M.I.S.; Vogt, C.M.; Neves, T.C.; Barbosa, M.; Andreazzi, C.S.; Dos Reis, I.C.; et al. Trajetorias: A dataset of environmental, epidemiological, and economic indicators for the Brazilian Amazon. *Sci. Data* **2023**, *10*, 65. [CrossRef]
166. Buchdid Camargo Neves, L.T.; Dos Santos Campos, D.C.; Souza Mendes, J.K.; Urnhani, C.O.; Mattos De Araujo, K.G. Quality of Fruits Manually Processed of Acai (*Euterpe oleracea* MART.) and BACABA (*Oenocarpus bacaba* MART.). *Rev. Bras. De Frutic.* **2015**, *37*, 729–738. [CrossRef]
167. Yokomizo, G.K.I.; Mochiutti, S.; de Queiroz, J.A.L.; dos Santos, G.R.; Furtado, R.G.; Brandão, A.P.; Colares, I.B. Parameter estimates for genetic characters of assai palm trees fruits in Amapá State. *Ciência Florest.* **2016**, *26*, 985–993. [CrossRef]
168. Nascimento, R.J.S.d.; Couri, S.; Antoniassi, R.; Freitas, S.P. Composição em ácidos graxos do óleo da polpa de açaí extraído com enzimas e com hexano. *Rev. Bras. De Frutic.* **2008**, *30*, 498–502. [CrossRef]
169. Rogez, H. *Açai: Preparo, Composição e Melhoramento da Conservação*; EDUFPA: Belém, Brazil, 2000; 313p.
170. Rodrigues, R.B.; Lichtenthäler, R.; Zimmermann, B.F.; Papagiannopoulos, M.; Fabricius, H.; Marx, F.; Maia, J.G.; Almeida, O. Total oxidant scavenging capacity of Euterpe oleracea Mart.(açaí) seeds and identification of their polyphenolic compounds. *J. Agric. Food Chem.* **2006**, *54*, 4162–4167. [CrossRef]
171. Matias dos Santos, G.; Arraes Maia, G.; Machado de Sousa, P.H.; Correia da Costa, J.M.; Wilane de Figueiredo, R.; Matias do Prado, G. Correlação entre atividade antioxidante e compostos bioativos de polpas comerciais de açaí (*Euterpe oleracea* Mart). *Arch. Latinoam. De Nutr.* **2008**, *58*, 187–192.
172. Global Biodiversity Information Facility GBIF. Ocorrência Euterpe Oleracea Mart. 2023. Available online: https://www.gbif.org/pt/species/5293398 (accessed on 10 November 2023).
173. Costa, D.d.S.; El Banna, W.R.; Lima, L.S.; Almeida, D.F.; Santos, E.d.J.S.d.; Lopes, C.E.P.; Fujiyama, R.T. Compósito De Fibras De Açaí E Resina Poliéster. In Proceedings of the 68th abm International Annual Congress, Belo Horizonte, Brazil, 30 July–2 August 2013; pp. 1393–1401.
174. Bufalino, L.; de Sena Neto, A.R.; Tonoli, G.H.D.; de Souza Fonseca, A.; Costa, T.G.; Marconcini, J.M.; Colodette, J.L.; Labory, C.R.G.; Mendes, L.M. How the chemical nature of Brazilian hardwoods affects nanofibrillation of cellulose fibers and film optical quality. *Cellulose* **2015**, *22*, 3657–3672. [CrossRef]
175. Subramoniam, R.; Huisingh, D.; Chinnam, R.B.; Subramoniam, S. Remanufacturing Decision-Making Framework (RDMF): Research validation using the analytical hierarchical process. *J. Clean. Prod.* **2013**, *40*, 212–220. [CrossRef]
176. Al-Oqla, F.M.; Sapuan, M.S.; Ishak, M.R.; Aziz, N.A. Combined multi-criteria evaluation stage technique as an agro waste evaluation indicator for polymeric composites: Date palm fibers as a case study. *BioResources* **2014**, *9*, 4608–4621. [CrossRef]
177. Al-Oqla, F.M.; Sapuan, S. Natural fiber reinforced polymer composites in industrial applications: Feasibility of date palm fibers for sustainable automotive industry. *J. Clean. Prod.* **2014**, *66*, 347–354. [CrossRef]
178. Castro, C.D.P.d.C.; Dias, C.G.B.T.; Faria, J.d.A.F. Production and evaluation of recycled polymers from açaí fibers. *Mater. Res.* **2010**, *13*, 159–163. [CrossRef]
179. Bastos, L.P.; Lima, L.d.C.; Santos, G.B.; Melo, G.d.S.V.d.; Mesquita, A.L.A. Simulação com painéis de fibra de açaí para melhoria da inteligibilidade da fala em sala de aula. *Ambiente Construído* **2021**, *21*, 45–63. [CrossRef]
180. Martins, M.A.; Mattoso, L.H.C.; Pessoa, J.D.C. Comportamento térmico e caracterização morfológica das fibras de mesocarpo e caroço do açaí (*Euterpe oleracea* Mart.). *Rev. Bras. De Frutic.* **2009**, *31*, 1150–1157. [CrossRef]
181. de Carvalho, C.M.R.G.; Castro, G.C.; dos Santos, G.M.; Campelo, J.E.G.; Sarmento, J.L.R.; Carvalho, M.D.F. Aproveitamento integral do coco babaçu como estratégia de educação e desenvolvimento social sustentável. *Extensão Em Foco* **2020**, *21*, 156–164.
182. Lorenzine, H.; Sousa, H.; Coelho, L.; Medeiros, J.; Nikolaus, B. *Palmeiras No Brasil*; Plantarum: Nova Odessa, Brazil, 1996; p. 70.
183. Lorenzi, H.; Noblick, L.; Kahn, F.; Ferreira, E. *Flora Brasileira-Arecaceae (Palmeiras)*; Instituto Plantarum: Nova Odessa, Brazil, 2010.
184. González-Pérez, S.E.; Coelho-Ferreira, M.; Robert, P.d.; Garcés, C.L.L. Conhecimento e usos do babaçu (Attalea speciosa Mart. e Attalea eichleri (Drude) AJ Hend.) entre os Mebêngôkre-Kayapó da Terra Indígena Las Casas, estado do Pará, Brasil. *Acta Bot. Bras.* **2012**, *26*, 295–308. [CrossRef]
185. Silva, G.; Barroso, M.E.; Silva, D.L.; Conceição, G. A importância do coco babaçu para a comunidade escolar e extrativista no município de São João do Arraial/PI. *Agrar. Acad.* **2016**, *3*. [CrossRef]
186. Santana, S.A.; Vieira, A.P.; da Silva Filho, E.C.; Melo, J.C.; Airoldi, C. Immobilization of ethylenesulfide on babassu coconut epicarp and mesocarp for divalent cation sorption. *J. Hazard. Mater.* **2010**, *174*, 714–719. [CrossRef] [PubMed]
187. Global Biodiversity Information Facility GBIF. Ocorrência Attalea Speciosa Mart. ex Spreng. 2023. Available online: https://www.gbif.org/pt/species/8174773 (accessed on 10 November 2023).
188. Carrazza, L.R.; Ávila, J.C.C.; Silva, M.L.D. *Manual Tecnológico de Aproveitamento Integral do Fruto e da Folha do Babaçu (Attalea spp.)*, 2nd ed.; ISPN: Brasília, Brazil, 2012; ISBN 978-85-63288-06-6.
189. Soler, M.P.; Vitali, A.d.A.; Muto, E.F. Tecnologia de quebra do coco babaçu (*Orbignya speciosa*). *Food Sci. Technol.* **2007**, *27*, 717–722. [CrossRef]
190. de Morais, J.P.G.; Campana, M.; Del Valle, T.A.; Moreira, T.G.; da Silva, E.D.R.; do Prado, R.F.; de Oliveira, R.E. Inclusion of babassu bran produced in milk production in Amazonia. *Trop. Anim. Health Prod.* **2021**, *53*, 527. [CrossRef]

191. Costa, R.M.; Leite, M.R.L.; Matos, S.d.S.; Sousa, R.C.M.d.; Silva-Matos, R.R.S.d.; Bezerra, A.A.d.C. Quality of pre-sprouted sugarcane seedlings grown on substrates with decomposed babassu palm stem. *Pesqui. Agropecu. Trop.* **2021**, *51*. [CrossRef]
192. dos Anjos, S.S.N.; do Nascimento Neto, J.O. Avaliação do impacto de política de subvenção econômica na cadeia produtiva de biodiesel de Babaçu. *Rev. Em Agronegócio E Meio Ambiente* **2021**, *14*, 1–16. [CrossRef]
193. Chaves, Y.S.; da Silveira, P.H.P.; Neuba, L.d.M.; Junio, R.F.P.; Ribeiro, M.P.; Monteiro, S.N.; Nascimento, L.F.C. Evaluation of the density, mechanical, thermal and chemical properties of babassu fibers (*Attalea speciosa*.) for potential composite reinforcement. *J. Mater. Res. Technol.* **2023**, *23*, 2089–2100. [CrossRef]
194. De Lemos, A.L.; Mauss, C.J.; Santana, R.M.C. Characterization of natural fibers: Wood, sugarcane and babassu for use in biocomposites. *Cellul. Chem. Technol.* **2017**, *51*, 711–718.
195. Chaves, Y.S.; da Silveira, P.H.P.M.; Monteiro, S.N.; Nascimento, L.F.C. Babassu Coconut Fibers: Investigation of Chemical and Surface Properties (*Attalea speciosa*). *Polymers* **2023**, *15*, 3863. [CrossRef]
196. Furtado, J.B.d.M.; Furtado Filho, P.A.; Oliveira, T.P.; Caetano, M.R.d.S.; Araujo, I.M.d.S.; Figueiredo, F.C.; Santos Júnior, J.R.d. Enhancement of the photodegradative potential of polymer composites containing babassu fiber. *Mater. Res.* **2020**, *23*. [CrossRef]
197. de Oliveira Libório Dourado, J.B.; Alves, M.E.R.; de Oliveira Júnior, W.A.; de Oliveira, B.L.M.; de Jesus Bezerra da Silva, H.; López-Galindo, A.; Viseras, C.; Furtini, M.B.; dos Santos, V.B. Babassu Fibers as Green Mortar Additives. *J. Nat. Fibers* **2023**, *20*, 2256471. [CrossRef]
198. Marinho, V.A.D.; Almeida, T.; Carvalho, L.; Canedo, E.L. Aditivação e biodegradação de compósitos PHB/babaçu. *Rev. Eletrônica De Mater. E Process.* **2018**, *13*, 37–41.
199. Endress, B.A.; Horn, C.M.; Gilmore, M.P. Mauritia flexuosa palm swamps: Composition, structure and implications for conservation and management. *For. Ecol. Manag.* **2013**, *302*, 346–353. [CrossRef]
200. Peters, C.M.; Balick, M.J.; Kahn, F.; Anderson, A.B. Oligarchic forests of economic plants in Amazonia: Utilization and conservation of an important tropical resource. *Conserv. Biol.* **1989**, *3*, 341–349. [CrossRef] [PubMed]
201. Lawrence, A.; Phillips, O.L.; Ismodes, A.R.; Lopez, M.; Rose, S.; Wood, D.; Farfan, A.J. Local values for harvested forest plants in Madre de Dios, Peru: Towards a more contextualised interpretation of quantitative ethnobotanical data. *Biodivers. Conserv.* **2005**, *14*, 45–79. [CrossRef]
202. da Cruz Demosthenes, L.C.; Nascimento, L.F.C.; Monteiro, S.N.; Costa, U.O.; da Costa Garcia Filho, F.; da Luz, F.S.; Oliveira, M.S.; Ramos, F.J.H.T.V.; Pereira, A.C.; Braga, F.O. Thermal and structural characterization of buriti fibers and their relevance in fabric reinforced composites. *J. Mater. Res. Technol.* **2020**, *9*, 115–123. [CrossRef]
203. Mesa, L.; Galeano, G. Palms uses in the Colombian Amazon. *Caldasia* **2013**, *35*, 351–369.
204. Abreu, Y.; Ávila, R.; Gonçalves, T. The buriti agro extractivism: An alternative for the development of the Brazilian Amazon Region. *Int. J. Soc. Sci. Entrep.* **2014**, *1*, 189–197.
205. Virapongse, A. Social mechanisms and mobility: Buriti palm (*Mauritia flexuosa*) extractivism in Brazil. *Hum. Ecol.* **2017**, *45*, 119–129. [CrossRef]
206. Sosnowska, J.; Walanus, A.; Balslev, H. Asháninka palm management and domestication in the Peruvian Amazon. *Hum. Ecol.* **2015**, *43*, 451–466. [CrossRef] [PubMed]
207. Draper, F.C.; Roucoux, K.H.; Lawson, I.T.; Mitchard, E.T.; Coronado, E.N.H.; Lähteenoja, O.; Montenegro, L.T.; Sandoval, E.V.; Zaráte, R.; Baker, T.R. The distribution and amount of carbon in the largest peatland complex in Amazonia. *Environ. Res. Lett.* **2014**, *9*, 124017. [CrossRef]
208. Demosthenes, L.C.d.C.; Luz, F.S.d.; Nascimento, L.F.C.; Monteiro, S.N. Buriti Fabric Reinforced Epoxy Composites as a Novel Ballistic Component of a Multilayered Armor System. *Sustainability* **2022**, *14*, 10591. [CrossRef]
209. da Silva Santos, R.; de Souza, A.A.; De Paoli, M.A.; de Souza, C.M.L. Cardanol–formaldehyde thermoset composites reinforced with buriti fibers: Preparation and characterization. *Compos. Part A Appl. Sci. Manuf.* **2010**, *41*, 1123–1129. [CrossRef]
210. Júnior, H.L.O.; Moraes, A.; Poletto, M.; Zattera, A.J.; Amico, S.C. Chemical composition, tensile properties and structural characterization of buriti fiber. *Cellul. Chem. Technol.* **2016**, *50*, 15–22.
211. Pelegrini, K.; Donazzolo, I.; Brambilla, V.; Coulon Grisa, A.M.; Piazza, D.; Zattera, A.J.; Brandalise, R.N. Degradation of PLA and PLA in composites with triacetin and buriti fiber after 600 days in a simulated marine environment. *J. Appl. Polym. Sci.* **2016**, *133*. [CrossRef]
212. Monteiro, S.N.; Calado, V.; Rodriguez, R.J.; Margem, F.M. Thermogravimetric stability of polymer composites reinforced with less common lignocellulosic fibers—An Overview. *J. Mater. Res. Technol.* **2012**, *1*, 117–126. [CrossRef]
213. Neves Monteiro, S.; de Oliveira Braga, F.; Pereira Lima, E.; Henrique Leme Louro, L.; Wieslaw Drelich, J. Promising curaua fiber-reinforced polyester composite for high-impact ballistic multilayered armor. *Polym. Eng. Sci.* **2017**, *57*, 947–954. [CrossRef]
214. Monteiro, S.N.; Lima, É.P.; Louro, L.H.L.; Da Silva, L.C.; Drelich, J.W. Unlocking function of aramid fibers in multilayered ballistic armor. *Metall. Mater. Trans. A* **2015**, *46*, 37–40. [CrossRef]
215. *NIJ 0101.06*; Ballistic Resistance of Body Armor. National Institute of Justice: Washington, DC, USA, 2008.
216. Cattani, I.M.; Baruque-Ramos, J. Buriti palm fiber (*Mauritia flexuosa* MART.): Characterization and studies for its application in design products. *Key Eng. Mater.* **2016**, *668*, 63–74. [CrossRef]
217. Castro, M.F.d.O.; Xavier, G.S.M.; Dias, C.B.; Santos, K.d.S.d.; Leão, R. Resistência à flexão de compósitos reforçados com fibra de buriti tratada com NaOH. In Proceedings of the Congresso Técnico Científico da Engenharia e da Agronomia—CONTECC, Virtual, 15–17 September 2021; pp. 1–6.

218. Junio, R.F.P.; de Mendonça Neuba, L.; Souza, A.T.; Pereira, A.C.; Nascimento, L.F.C.; Monteiro, S.N. Thermochemical and structural characterization of promising carnauba novel leaf fiber (*Copernicia prunifera*). *J. Mater. Res. Technol.* **2022**, *18*, 4714–4723. [CrossRef]
219. Junio, R.F.P.; Nascimento, L.F.C.; Neuba, L.d.M.; Souza, A.T.; Moura, J.V.B.; Garcia Filho, F.d.C.; Monteiro, S.N. Copernicia prunifera leaf fiber: A promising new reinforcement for epoxy composites. *Polymers* **2020**, *12*, 2090. [CrossRef] [PubMed]
220. Melo, J.D.D.; Carvalho, L.F.M.; Medeiros, A.M.; Souto, C.R.; Paskocimas, C.A. A biodegradable composite material based on polyhydroxybutyrate (PHB) and carnauba fibers. *Compos. Part B Eng.* **2012**, *43*, 2827–2835. [CrossRef]
221. Monteiro, S.N.; Lopes, F.P.D.; Barbosa, A.P.; Bevitori, A.B.; Silva, I.L.A.D.; Costa, L.L.D. Natural lignocellulosic fibers as engineering materials—An overview. *Metall. Mater. Trans. A* **2011**, *42*, 2963–2974. [CrossRef]
222. Junio, R.F.P.; de Mendonça Neuba, L.; Pereira, A.C.; Souza, A.T.; Isidoro, L.M.M.; Nascimento, L.F.C.; Monteiro, S.N. Carnauba leaf fibers: Correlation among diametrical variation, physical and mechanical properties. *J. Mater. Res. Technol.* **2023**, *22*, 1888–1899. [CrossRef]
223. Tiwari, Y.M.; Sarangi, S.K. Characterization of raw and alkali treated cellulosic Grewia Flavescens natural fiber. *Int. J. Biol. Macromol.* **2022**, *209*, 1933–1942. [CrossRef]
224. Eduardo, A.F.; Nóbrega, M.V.d.; Ferreira, R.L.d.S. Evaluation of the behavior of mortars produced with fibers from the straw of carnauba: Effects of the content of addition and length used. *Matéria* **2021**, *26*. [CrossRef]
225. Onuaguluchi, O.; Banthia, N. Plant-based natural fibre reinforced cement composites: A review. *Cem. Concr. Compos.* **2016**, *68*, 96–108. [CrossRef]
226. Silva, E.J.d.; Silva, P.D.d.; Marques, M.L.; Fornari Junior, C.; Garcia, F.C.; Luzardo, F.H. Resistência à compressão de argamassas em função da adição de fibra de coco. *Rev. Bras. De Eng. Agríc. E Ambient.* **2014**, *18*, 1268–1273. [CrossRef]
227. De Pellegrin, M.; Acordi, J.; Montedo, O. Influence of the length and the content of cellulose fibers obtained from sugarcane bagasse on the mechanical properties of fiber-reinforced mortar composites. *J. Nat. Fibers* **2019**, *18*, 111–121. [CrossRef]
228. Castro, D.O.d.; Ruvolo-Filho, A.; Frollini, E. Materials prepared from biopolyethylene and curaua fibers: Composites from biomass. *Polym. Test.* **2012**, *31*, 880–888. [CrossRef]
229. Souza, S.; Ferreira, M.; Sain, M.; Ferreira, M.; Pupo, H.; Cherian, B.; Leão, A. The use of curaua fibers as reinforcements in composites. In *Biofiber Reinforcements in Composite Materials*; Elsevier: Amsterdam, The Netherlands, 2015; pp. 700–720.
230. Santos, P.A.; Spinacé, M.A.; Fermoselli, K.K.; De Paoli, M.A. Efeito da forma de processamento e do tratamento da fibra de curauá nas propriedades de compósitos com poliamida-6. *Polímeros* **2009**, *19*, 31–39. [CrossRef]
231. Leão, A.; Sartor, S.M.; Caraschi, J.C. Natural fibers based composites—Technical and social issues. *Mol. Cryst. Liq. Cryst.* **2006**, *448*, 161–763. [CrossRef]
232. de Freitas, A.E.; Padilha, F.d.J.; Barros, S.d.S.; Khan, T.M.; Pereira, B.; Barbosa, W.T.; Barbosa, J.D.; Calderaro, F.L.; da Silva, S.; Quirino, M.G.; et al. Curauá fiber from plants produced by tissue culture: Thermal, mechanical, and morphological characterizations. *Cellulose* **2023**, *30*, 2841–2858. [CrossRef]
233. Garcés, C.L.L.; Pérez, S.E.G.; Silva, J.A.d.; Araújo, M.O.d.; Coelho-Ferreira, M. Objetos indígenas para o mercado: Produção, intercâmbio, comércio e suas transformações. Experiências Ka'apor e Mebêngôkre-Kayapó. *Bol. Do Mus. Para. Emilio Goeldi. Cienc. Humanas* **2015**, *10*, 659–680. [CrossRef]
234. Costa, U.O.; Nascimento, L.F.C.; Garcia, J.M.; Bezerra, W.B.A.; da Luz, F.S.; Pinheiro, W.A.; Monteiro, S.N. Mechanical properties of composites with graphene oxide functionalization of either epoxy matrix or curaua fiber reinforcement. *J. Mater. Res. Technol.* **2020**, *9*, 13390–13401. [CrossRef]
235. Zah, R.; Hischier, R.; Leão, A.L.; Braun, I. Curauá fibers in the automobile industry—A sustainability assessment. *J. Clean. Prod.* **2007**, *15*, 1032–1040. [CrossRef]
236. Gomes, A.; Matsuo, T.; Goda, K.; Ohgi, J. Development and effect of alkali treatment on tensile properties of curaua fiber green composites. *Compos. Part A Appl. Sci. Manuf.* **2007**, *38*, 1811–1820. [CrossRef]
237. Gomes, A.; Goda, K.; Ohgi, J. Effects of alkali treatment to reinforcement on tensile properties of curaua fiber green composites. *JSME Int. J. Ser. A Solid Mech. Mater. Eng.* **2004**, *47*, 541–546. [CrossRef]
238. Ferreira, S.R.; de Andrade Silva, F.; Lima, P.R.L.; Toledo Filho, R.D. Effect of hornification on the structure, tensile behavior and fiber matrix bond of sisal, jute and curauá fiber cement based composite systems. *Constr. Build. Mater.* **2017**, *139*, 551–561. [CrossRef]
239. Teixeira, F.P.; de Andrade Silva, F. On the use of natural curauá reinforced cement based composites for structural applications. *Cem. Concr. Compos.* **2020**, *114*, 103775. [CrossRef]
240. Teixeira, R.S.; Santos, S.F.d.; Christoforo, A.L.; Savastano, H., Jr.; Lahr, F.A.R. Extrudability of cement-based composites reinforced with curauá (*Ananas erectifolius*) or polypropylene fibers. *Constr. Build. Mater.* **2019**, *205*, 97–110. [CrossRef]
241. Meliande, N.M.; Oliveira, M.S.; Silveira, P.H.P.M.d.; Dias, R.R.; Marçal, R.L.S.B.; Monteiro, S.N.; Nascimento, L.F.C. Curaua—Aramid Hybrid Laminated Composites for Impact Applications: Flexural, Charpy Impact and Elastic Properties. *Polymers* **2022**, *14*, 3749. [CrossRef]
242. Meliande, N.M.; Silveira, P.H.P.M.d.; Monteiro, S.N.; Nascimento, L.F.C. Tensile Properties of Curaua—Aramid Hybrid Laminated Composites for Ballistic Helmet. *Polymers* **2022**, *14*, 2588. [CrossRef] [PubMed]

243. Meliande, N.M.; Oliveira, M.S.; Pereira, A.C.; Balbino, F.D.P.; da Silva Figueiredo, A.B.H.; Monteiro, S.N.; Nascimento, L.F.C. Ballistic properties of curaua-aramid laminated hybrid composites for military helmet. *J. Mater. Res. Technol.* **2023**, *25*, 3943–3956. [CrossRef]
244. da Silva, A.O.; de Castro Monsores, K.G.; Oliveira, S.d.S.; Weber, R.P.; Monteiro, S.N. Ballistic behavior of a hybrid composite reinforced with curaua and aramid fabric subjected to ultraviolet radiation. *J. Mater. Res. Technol.* **2018**, *7*, 584–591. [CrossRef]
245. de Campos, A.; Claro, P.C.; Luchesi, B.R.; Miranda, M.; Souza, F.V.; Ferreira, M.D.; Marconcini, J.M. Curaua cellulose sheets dip coated with micro and nano carnauba wax emulsions. *Cellulose* **2019**, *26*, 7983–7993. [CrossRef]
246. Frollini, E.; Bartolucci, N.; Sisti, L.; Celli, A. Biocomposites based on poly (butylene succinate) and curaua: Mechanical and morphological properties. *Polym. Test.* **2015**, *45*, 168–173. [CrossRef]
247. Borsoi, C.; Scienza, L.C.; Zattera, A.J. Characterization of composites based on recycled expanded polystyrene reinforced with curaua fibers. *J. Appl. Polym. Sci.* **2013**, *128*, 653–659. [CrossRef]
248. Barbalho, G.H.d.A.; Nascimento, J.J.d.S.; Silva, L.B.d.; Gomez, R.S.; Farias, D.O.d.; Diniz, D.D.S.; Santos, R.S.; Figueiredo, M.J.d.; Lima, A.G.B.d. Bio-Polyethylene Composites Based on Sugar Cane and Curauá Fiber: An Experimental Study. *Polymers* **2023**, *15*, 1369. [CrossRef] [PubMed]
249. Neto, J.S.; Cavalcanti, D.K.; da Cunha Ferro, L.E.; de Queiroz, H.F.; Aguiar, R.A.; Banea, M.D. Effect of Multi-Walled Carbon Nanotubes on the Mechanical and Thermal Properties of Curauá Natural-Fiber-Reinforced Composites. *C* **2023**, *9*, 102. [CrossRef]
250. Santos, N.S.S.; Carneiro, S.C.P.M.H.d.S. Utilização do trançado de palha como estratégia para o desenvolvimento sustentável do setor moveleiro. *Simpósio De Eng. De Produção* **2005**, *13*, 2005.
251. Costa , M.O.; Souza, F.S.; Andrade, S.M.C. Ensaios de tração e de absorção de água em compósitos de resina poliester e fibra da tala de Guarumã. In Proceedings of the 21º CBECIMAT - Congresso Brasileiro de Engenharia e Ciência dos Materiais, Cuiabá, Brazil, 9–13 November 2014; Volume 21, pp. 3736–3741.
252. Pinheiro, M.A.; Gomes, L.G.; Silva, A.C.R.d.; Candido, V.S.; Reis, R.H.M.; Monteiro, S.N. Guaruman: A natural Amazonian fiber with potential for Polymer composite reinforcement. *Mater. Res.* **2019**, *22*, e20190092. [CrossRef]
253. Reis, R.H.M.; Nunes, L.F.; Oliveira, M.S.; de Veiga Junior, V.F.; Filho, F.D.C.G.; Pinheiro, M.A.; Candido, V.S.; Monteiro, S.N. Guaruman fiber: Another possible reinforcement in composites. *J. Mater. Res. Technol.* **2020**, *9*, 622–628. [CrossRef]
254. Reis, R.H.M.; Nunes, L.F.; da Luz, F.S.; Candido, V.S.; da Silva, A.C.R.; Monteiro, S.N. Ballistic Performance of Guaruman Fiber Composites in Multilayered Armor System and as Single Target. *Polymers* **2021**, *13*, 1203. [CrossRef] [PubMed]
255. Batista, J.S.; de Moraes, M.F.; da Silva, R.S.D.; da Cruz, W.J.A.; Carniello, M.A. Cochlospermum orinocense (bixaceae) ocorrentes na bacia do guaporé, mato grosso, Brasil. In Proceedings of the 64º Congresso Nacional de Botânica, Belo Horizonte, Brazil, 10–15 November 2013; p. 1.
256. Figueiredo, P.S.d.; Ribeiro, É.K.M.D.; Lacerda, D.M.A.; Girnos, E.C. Estratégia reprodutiva de *Cochlospermum orinocense* (Kunth) Steud.: Fenologia, biologia floral e sistema de cruzamento em uma espécie pioneira de florestas na Amazônia. *Braz. J. Bot.* **2009**, *32*, 781–792. [CrossRef]
257. Reflora. *Cochlospermum Orinocense* (Kunth) Steud. 2023. Available online: https://floradobrasil.jbrj.gov.br/reflora/listaBrasil/ConsultaPublicaUC/BemVindoConsultaPublicaConsultar.do?invalidatePageControlCounter=&idsFilhosAlgas=&idsFilhosFungos=&lingua=&grupo=&familia=null&genero=&especie=&autor=&nomeVernaculo=&nomeCompleto=Cochlospermum+orinocense&formaVida=null&substrato=null&ocorreBrasil=QUALQUER&ocorrencia=OCORRE&endemismo=TODOS&origem=TODOS&regiao=QUALQUER&estado=QUALQUER&ilhaOceanica=32767&domFitogeograficos=QUALQUER&bacia=QUALQUER&vegetacao=TODOS&mostrarAte=SUBESP_VAR&opcoesBusca=TODOS_OS_NOMES&loginUsuario=Visitante&senhaUsuario=&contexto=consulta-publica (accessed on 10 November 2023).
258. da Silva, R.N.A.; de Macedo Neto, J.C.; Kimura, S.P.R. Natural fiber for reinforcement in matrix polymeric. *Indep. J. Manag. Prod.* **2022**, *13*, 154–167. [CrossRef]
259. Pinheiro, M.A.; Ribeiro, M.M.; Rosa, D.L.S.; Nascimento, D.d.C.B.; da Silva, A.C.R.; Dos Reis, M.A.L.; Monteiro, S.N.; Candido, V.S. Periquiteira (*Cochlospermum orinocense*): A Promising Amazon Fiber for Application in Composite Materials. *Polymers* **2023**, *15*, 2120. [CrossRef]
260. Monteiro, S.N. Properties and structure of Attalea funifera piassava fibers for composite reinforcement—A critical discussion. *J. Nat. Fibers* **2009**, *6*, 191–203. [CrossRef]
261. Ferreira, D.C.d.O.N.; Ferreira, A.d.S.; Monteiro, S.N. Weibull analysis of tensile tested piassava fibers with different diameters. *Matéria* **2018**, *23*. [CrossRef]
262. Pimentel, N.M.; Del Menezzi, C. Rendimento do processamento dos produtos oriundos da fibra vegetal da piaçava (*Attalea funifera*). *Nativa* **2020**, *8*, 137–144. [CrossRef]
263. Bonelli, C.; Elzubair, A.; Suarez, J.C.M.; Mano, E.B. Comportamento térmico, mecânico e morfológico de compósitos de polietileno de alta densidade reciclado com fibra de piaçava. *Polímeros* **2005**, *15*, 256–260. [CrossRef]
264. Turini, E. Proposta de preços mínimos safra 2013/2014. Produtos da sociobiodiversidade. *Propos. De Preços Mínimos* **2014**, *3*, 5–19.
265. Fornari, C.I.; Fornari, J.; Celso, C. Avaliação da força de cisalhamento de fibras longas de piaçava em poliéster insaturado. *Estud. Tecnol. Em Eng.* **2013**, *9*. [CrossRef]
266. Guimarães, C.A.L.; Silva, L.A.M. *Piaçava da Bahia (Attalea funifera Martius): Do Extrativismo à Cultura Agrícola*; Editus: Ilhéus, Brazil, 2012.

267. Agrize, P.L.; da Silva, B.D.L.; Carvalho Veiga, B.; Rocha, C.A.A.; Garcia Filho, F.d.C.; Braga, F.d.O. Structure and mechanical behavior of lignosulfonate-treated piassava (*Attalea funifera*) fibers. *Matéria* **2023**, *28*, e20230041. [CrossRef]
268. dos Santos, F.M.; de Souza, T.F.; Barquete, D.M.; Amado, F.D. Comparative analysis of the sisal and piassava fibers as reinforcements in lightweight cementitious composites with EVA waste. *Constr. Build. Mater.* **2016**, *128*, 315–323. [CrossRef]
269. Miranda, C.S.; Fiuza, R.P.; Carvalho, R.F.; José, N.M. Efeito dos tratamentos superficiais nas propriedades do bagaço da fibra de piaçava Attalea funifera martius. *Quím. Nova* **2015**, *38*, 161–165.
270. Carvalho, J.P.R.G.d.; Simonassi, N.T.; Lopes, F.P.D.; Monteiro, S.N.; Vieira, C.M.F. Novel sustainable castor oil-based polyurethane biocomposites reinforced with piassava fiber powder waste for high-performance coating floor. *Sustainability* **2022**, *14*, 5082. [CrossRef]
271. *NBR 14050*; Sistemas de Revestimentos de alto Desempenho, à base de Resinas Epoxídicas e Agregados Minerais-Projeto, Execução e Avaliação do Desempenho-Procedimento. Associação Brasileira de Normas Técnicas: São Paulo, Brazil, 1998.
272. Silva, D.S.; Ribeiro, M.M.; da Silva Rodrigues, J.; de Castro Corrêa, A.; Costa, D.C.L.; de Oliveira Costa, H.A.; da Silva, F.J.A.R.; dos Santos, A.J.G.; da Silva, M.H.P.; Fujiyama, R.T. Properties of flexural and impact of matrix composites polyester reinforced with short lignocellulosic fibers. *Res. Soc. Dev.* **2022**, *11*, e32511326612. [CrossRef]
273. Thomas, B.C.; Jose, Y.S. A study on characteristics of sisal fiber and its performance in fiber reinforced concrete. *Mater. Today Proc.* **2022**, *51*, 1238–1242. [CrossRef]
274. Fernandes, R.A.P.; Silveira, P.H.P.M.d.; Bastos, B.C.; Pereira, P.S.d.C.; Melo, V.A.d.; Monteiro, S.N.; Tapanes, N.d.L.C.O.; Bastos, D.C. Bio-based composites for light automotive parts: Statistical analysis of mechanical properties; effect of matrix and alkali treatment in sisal fibers. *Polymers* **2022**, *14*, 3566. [CrossRef] [PubMed]
275. Nunesa, S.G.; da Silvab, L.V.; Amicob, S.C.; Dantas, J.; Vianac, F.D.R.A. Study of Composites Produced with Recovered Polypropylene and Piassava Fiber. *Mater. Res.* **2017**, *20*, 144–150. [CrossRef]
276. Marinelli, A.L.; Monteiro, M.R.; Ambrósio, J.D.; Branciforti, M.C.; Kobayashi, M.; Nobre, A.D. Desenvolvimento de compósitos poliméricos com fibras vegetais naturais da biodiversidade: Uma contribuição para a sustentabilidade amazônica. *Polímeros* **2008**, *18*, 92–99. [CrossRef]
277. Vasques, J.C. Nanocompósito de Poli(óxido de etileno) Reforçado Com Nanocristais de Celulose Extraídos da Fibra de Tucum. Master's Thesis, Universidade de São Paulo, São Paulo, Brazil, 2018.
278. Ferreira, E.L. *Manual das Palmeiras do Acre, Brasil*; Instituto Nacional de Pesquisas/Universidade Federal do Acre: Rio Branco, Brazil, 2005.
279. Abreu, R.; Nunes, N.L. Tecendo a tradição e valorizando o conhecimento tradicional na Amazônia: O caso da "linha do tucum". *Horiz. Antropol.* **2012**, *18*, 15–43. [CrossRef]
280. Jensen, O.H.; Balslev, H. Etnobotánica de la palma de fibra *Astrocaryum chambira* (Arecaceae) en la Amazonía ecuatoriana. *Econ. Bot.* **1995**, *49*, 309–319. [CrossRef]
281. Vormisto, J. Making and marketing chambira hammocks and bags in the village of Brillo Nuevo, northeastern Peru. *Econ. Bot.* **2002**, *56*, 27–40. [CrossRef]
282. Coomes, O.T. Rain forest 'conservation-through-use'? Chambira palm fibre extraction and handicraft production in a land-constrained community, Peruvian Amazon. *Biodivers. Conserv.* **2004**, *13*, 351–360. [CrossRef]
283. Bernal, R.; Torres, C.; García, N.; Isaza, C.; Navarro, J.; Vallejo, M.I.; Galeano, G.; Balslev, H. Palm management in south america. *Bot. Rev.* **2011**, *77*, 607–646. [CrossRef]
284. Acevedo, L.M.G. El tejido en chambira, una actividad que une más que sogas. *Bol. De Antropol. Univ. De Antioq.* **2005**, *19*, 164–185. [CrossRef]
285. Castaño-Arboleda, N.; Cárdenas, D.; Rodriguez, E.O. *Ecología, Aprovechamiento y Manejo Sostenible de Nueve Especies de Plantas del Departamento del Amazonas, Generadoras de Productos Maderables y No Maderables*; Instituto Amazónico de Investigaciones Científicas "SINCHI": Bogotá, Colombia, 2006; ISBN 978-958-8317-21-2.
286. Oliveira, M.S.; Luz, F.S.d.; Teixeira Souza, A.; Demosthenes, L.C.d.C.; Pereira, A.C.; Filho, F.d.C.G.; Braga, F.d.O.; Figueiredo, A.B.H.d.S.; Monteiro, S.N. Tucum fiber from Amazon Astrocaryum vulgare palm tree: Novel reinforcement for polymer composites. *Polymers* **2020**, *12*, 2259. [CrossRef] [PubMed]
287. Ribeiro, M.P.; de Mendonça Neuba, L.; da Silveira, P.H.P.M.; da Luz, F.S.; da Silva Figueiredo, A.B.H.; Monteiro, S.N.; Moreira, M.O. Mechanical, thermal and ballistic performance of epoxy composites reinforced with Cannabis sativa hemp fabric. *J. Mater. Res. Technol.* **2021**, *12*, 221–233. [CrossRef]
288. da Silva, T.T.; Silveira, P.H.P.M.d.; Figueiredo, A.B.H.d.S.; Monteiro, S.N.; Ribeiro, M.P.; Neuba, L.d.M.; Simonassi, N.T.; Garcia Filho, F.d.C.; Nascimento, L.F.C. Dynamic mechanical analysis and ballistic performance of kenaf fiber-reinforced epoxy composites. *Polymers* **2022**, *14*, 3629. [CrossRef] [PubMed]
289. Henderson, A.; Galeano, G.; Bernal, R. *Field Guide to the Palms of the Americas*; Princeton University Press: Princeton, NJ, USA, 2019; Volume 5390.
290. Anderson, A.B. Os nomes e usos de palmeiras entre uma tribo de índios Yanomama. *Acta Amaz.* **1977**, *7*, 5–13. [CrossRef]
291. Jardim, M.A.G.; Santos, G.d.; Medeiros, T.D.S.; Francez, D.d.C. Diversidade e estrutura de palmeiras em floresta de várzea do estuário amazônico. *Amazôn. Ciênc. Desenvolv.* **2007**, *2*, 67–84.
292. Punt, W.; Wessels Boer, J. A palynological study in geonomoid palms. *Acta Bot. Neerl.* **1966**, *15*, 266–275. [CrossRef]

293. Marchi, B.Z. Caracterização e Avaliação Balística de Compósitos Epóxi Reforçados Com Fibras de Ubim. Ph.D. Thesis, Instituto Militar de Engenharia, Rio de Janeiro, Brazil, 2023.
294. de Granville, J.J. La distribución de las palmas en Guyana Francesa. *Acta Amaz.* **1989**, *19*, 115–138. [CrossRef]
295. Rocha, A.E.S.d.; Silva, M.F.F.d. Aspectos fitossociológicos, florísticos e etnobotânicos das palmeiras (Arecaceae) de floresta secundária no município de Bragança, PA, Brasil. *Acta Bot. Bras.* **2005**, *19*, 657–667. [CrossRef]
296. Siviero, A.; Lin, C.M.; Silveira, M.; Daly, D.C.; Wallace, R.H. *Etnobotânica e Botânica Econômica do Acre*; Edufac: Rio Branco, Brazil, 2016; 410p, ISBN 978-85-8236-027-9.
297. Marchi, B.Z.; Oliveira, M.S.; Bezerra, W.B.A.; de Sousa, T.G.; Candido, V.S.; da Silva, A.C.R.; Monteiro, S.N. Ubim fiber (*Geonoma baculífera*): A less known Brazilian amazon natural fiber for engineering applications. *Sustainability* **2021**, *14*, 421. [CrossRef]
298. Marchi, B.Z.; Silveira, P.H.P.M.d.; Bezerra, W.B.A.; Nascimento, L.F.C.; Lopes, F.P.D.; Candido, V.S.; Silva, A.C.R.d.; Monteiro, S.N. Ballistic Performance, Thermal and Chemical Characterization of Ubim Fiber (*Geonoma baculifera*) Reinforced Epoxy Matrix Composites. *Polymers* **2023**, *15*, 3220. [CrossRef] [PubMed]
299. Silva, T.S.; Henrique, D.C.; Meili, L.; SOLETTI, J.I.; Carvalho, S. Utilização da fibra do Ouricuri (*Syagrus coronata*) na remoção do corante azul de metileno: Variáveis de processo e isoterma de adsorção. In Proceedings of the XXXVII Congresso Brasileiro de Sistemas Particulados, São Carlos, Brazil, 18–21 October 2015; pp. 1–10.
300. Silvestrim, R.G.; Santana, R.M.C.; Moura, A.d.S. Avaliação comparativa da degradação por intemperismo natural e por compostagem de compósitos de PLA reforçado com fibra vegetal da árvore Embira. In Proceedings of the Congresso Brasileiro de Polímeros, Bento Gonçalves, Brazil, 27–31 January 2019; pp. 1–5.
301. Holanda, F.S.R.; Castro, J.D.S.d.; Santos, L.D.V.; Andrade, C.E.C.d.; Griza, S.; Rodrigues Junior, J.J.; Pedrotti, A. Degradação de geotêxteis de Typha latifolia Linn utilizados em técnicas de bioengenharia de solos. *Ciênc. Florest.* **2020**, *30*, 1147–1160. [CrossRef]
302. da Cunha, J.d.S.C.; Nascimento, L.F.C.; da Luz, F.S.; Monteiro, S.N.; Lemos, M.F.; da Silva, C.G.; Simonassi, N.T. Physical and Mechanical Characterization of Titica Vine (*Heteropsis flexuosa*) Incorporated Epoxy Matrix Composites. *Polymers* **2021**, *13*, 4079. [CrossRef] [PubMed]
303. Cunha, J.d.S.C.d.; Nascimento, L.F.C.; Luz, F.S.d.; Garcia Filho, F.d.C.; Oliveira, M.S.; Monteiro, S.N. Titica Vine Fiber (*Heteropsis flexuosa*): A Hidden Amazon Fiber with Potential Applications as Reinforcement in Polymer Matrix Composites. *J. Compos. Sci.* **2022**, *6*, 251. [CrossRef]
304. Melo, D.Q.; Vidal, C.B.; da Silva, A.L.; Teixeira, R.N.; Raulino, G.S.C.; Medeiros, T.C.; Fechine, P.B.; Mazzeto, S.E.; De Keukeleire, D.; Nascimento, R.F. Removal of Cd^{2+}, Cu^{2+}, Ni^{2+}, and Pb^{2+} ions from aqueous solutions using tururi fibers as an adsorbent. *J. Appl. Polym. Sci.* **2014**, *131*. [CrossRef]
305. Vidal, C.B.; Melo, D.Q.; Raulino, G.S.; da Luz, A.D.; da Luz, C.; Nascimento, R.F. Multielement adsorption of metal ions using Tururi fibers (*Manicaria Saccifera*): Experiments, mathematical modeling and numerical simulation. *Desalination Water Treat.* **2016**, *57*, 9001–9008. [CrossRef]
306. Monteiro, A.S.; Baruque-Ramos, J. Amazonian Tururi palm fiber material (*Manicaria saccifera* Gaertn). In Proceedings of the 2nd International Conference on Natural Fibers, São Miguel, Portugal, 27–29 April 2015; Springer: Berlin/Heidelberg, Germany, 2016; pp. 127–137, ISBN 978-94-017-7515-1.
307. Viana, Á.L.; Mady, F.T.M.; do Carmo, M.A.; da Silva Guimarães, D.F. Pecíolo de inajá (Maximiliana maripa [aubl.] Drud) como fonte de matéria prima para produção de papel na Amazônia. *Rev. Eletrônica Em Gestão Educ. E Tecnol. Ambient.* **2014**, 1512–1520.
308. Oliveira, A.; d'Almeida, J. Characterization of ubuçu (*Manicaria saccifera*) natural fiber mat. *Polym. Renew. Resour.* **2014**, *5*, 13–28. [CrossRef]
309. Baruque-Ramos, J.; Monteiro, A.; Midani, M.; Seyam, A.F.M.; Leonardi, B.; Pennas, L.; Cattani, I. Textile Palm Fibers from Amazon Biome. *Mater. Res. Proc.* **2019**, *11*, 262–274.
310. Chu, Y.; Meyers A, M.A.; Wang, B.; Yang, W.; Jung, J.Y.; Coimbra, C.F. A sustainable substitute for ivory: The Jarina seed from the Amazon. *Sci. Rep.* **2015**, *5*, 14387. [CrossRef] [PubMed]
311. Cruz, O.M.; de Souza, R.L.F.; de Freitas, R.R.; de Souza, L.M.; Mafra, E.R.M.L.; da Silva e Silva, B.M.; Bufalino, L. The properties of the mesocarp fibers of patauá, a multiple-use palm from the Amazonia forest. *SN Appl. Sci.* **2019**, *1*, 1317. [CrossRef]
312. Cruz, O.M.; Dias, M.C.; Oliveira, D.N.P.S.D.; Silva, M.G.D.; Souza, T.M.D.; Mendes, L.M.; Matos, L.C.; Bufalino, L. Characterization of raw and thermochemically-treated mesocarp fibers of Oenocarpus bataua, an Amazon palm. *CERNE* **2023**, *29*, e103219. [CrossRef]