



Research Article

Amazonian tucum (*Astrocaryum chambira* Burret) leaf fiber and handcrafted yarn characterization

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Abstract

Astrocaryum chambira is an important palm tree employed for many people along the Amazonian region in handcrafts and other products, by traditional manipulation techniques. The aim of this study is to perform a physical and chemical characterization of *A. chambira* Burret (Tucum) fibers, comparing the obtained parameters with others from commonly employed textile fibers, and to perform the characterization of the handcrafted yarn manufactured by this traditional Amazonian community in Brazil. Reflections about the relation between this fiber and traditional communities were also made. Main characteristics were determined, namely: 90 ± 12 cm fiber length; 1.510 ± 0.007 g/cm³ density; $10.0 \pm 0.34\%$ regain; 80.3% index of crystallinity; TGA; DTG and DSC profiles with estimated values of holocellulose (68.4%) and lignin (21.7%); and tensile tests resulting in: 37.4 ± 5.6 cN/Tex tenacity; $6.6 \pm 0.4\%$ elongation; 8.3 ± 1.0 N/Tex Young's Modulus. Siliceous bodies (phytoliths) are found along the longitudinal surfaces of *A. chambira* Burret fibers. The results obtained may be a database of *A. chambira* fibers, helping future research that will address its application potential as an alternative textile fiber.

Keywords Textile · Natural fiber · *Astrocaryum chambira* · Tucum · Palm fibers

1 Introduction

The leaves of the palm *Astrocaryum chambira* are a potential source of vegetal fiber. Studies report the use of this palm fibers by traditional communities located throughout Amazon region. Traditional knowledge of extraction, spinning and the handcraft manufacturing, as well as the economic and emotional importance of this fiber for such communities are the most exploited points by the authors [1–7].

In Brazil *A. chambira* palm is known as “Tucum”. It is also named as “corombolo” or “palm-coconut” (Colombia), “chambira” or “coconut” (Ecuador) and “chambira” (Peru) [8].

The *Astrocaryum* genus comprises 40 species with main distribution in South and Central America. Like other genus of the Arecaceae, it presents economic importance in the regions in which it occurs [9]. Many species of *Astrocaryum* have edible fruits and fibers that can be extracted from the leaves (Fig. 1a). The genus ranges from large palms to smaller palm trees, all containing spines in their trunk (Fig. 1b) [8].

Botanically, it is characterized by having a solitary, erect stipe, up to 15 m long and 30 cm in diameter, internodes densely covered by black spines up to 20 cm long [13]. *Astrocaryum chambira* has its fibers extracted from its leaves, more specifically from its leaflets (Fig. 1c),

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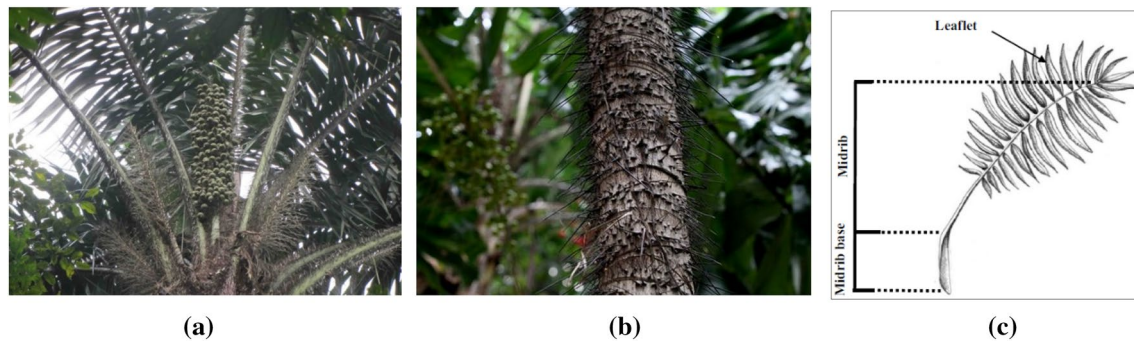


Fig. 1 Tucum palm (*Astrocaryum chambira* Burret): **a** leaves and fruits [10] [11]; **b** trunk with spines [11]; **c** Palm leaf anatomy [12]

which are employed often by forest people for manufacturing nets, bags and other handcrafts [4].

In Brazil, more specifically in the community “Ceú do Juruá”, located in the state of Amazonas, the palm *A. chambira* is known as “Tucum” and therefore its fibers as “Tucum fibers”. The people of that region have a traditional knowledge passed from generation to generation of fiber extraction and handmade spinning, resulting in a yarn known locally as “Tucum Yarn”, with which they develop many handcraft products [14].

The aim of this study is to perform a physical and chemical characterization of *Astrocaryum chambira* Burret (Tucum) fibers, comparing the obtained parameters with others from commonly employed textile fibers, and to perform the characterization of the handcrafted yarn manufactured by this traditional Amazonian community in Brazil. Reflections about the relation between this fiber and traditional communities were also made.

2 Experimental

2.1 Materials

To carry out the experimental stage of the study, fibers from Tucum palm (*Astrocaryum chambira* Burret) grown leaflets (Fig. 1c) were provided by the Community “Vila Ecológica Ceú do Juruá”, in the municipality of Ipixuna, Southwest of the state of Amazonas, Brazil, near the border with Acre state, GPS 07° 03' 04" S and 71° 41' 43" W. This location is comprised in Brazilian Amazon Forest biome, but it should be noted that obtaining these materials does not require authorization from IBAMA (Brazilian Institute of Environment) or any other federal or state environmental agency, since the material is usually collected and marketed and its purchase and possession has no legal restriction in any of the Brazilian states.

2.2 Length and linear density

The length of the fibers was measured in 100 fibers, using a stainless-steel manual ruler. Linear density was estimated according standard ISO 1973-1995 [15] weighing the fibers in analytical balance (Sartorius, ED124S model, Germany).

2.3 SEM and surface morphology

The Environmental Scanning Electron Microscope (ESEM) Quanta 650 FEG (FEI) as well as the energy dispersive EDX system Quantax (Bruker) were employed. The magnifications of 250; 1000; 2000 and 6000 times for SEM images were used.

2.4 Density

Density values were determined employing a gas pycnometer Ultrapycometer 1000 (Quantachrome Instruments).

Before starting the analysis, itself, the sample, placed in the respective chamber, is subjected to a degassing process consisting of repeated purges with helium to remove impurities and moisture that may be present. After the entire system is brought to atmospheric pressure, the expansion chamber is isolated, the expansion valve is closed and the chamber containing the sample is pressurized to a pressure P1.

Thereafter, the expansion valve is opened and, as a consequence, a pressure lowering for P2 occurs. Assuming ideal helium behavior, the volume of the solid and density can be calculated [16], through the relationship between the mass of the solid (entered as input data) and the volume derived from Eq. 1.

$$V_p = V_c - \frac{V_r}{\frac{P_1}{P_2} - 1} \quad (1)$$

V_p = Volume of the sample (cm^3); V_c = Volume of the sample port (cm^3); V_r = Volume of reference (cm^3).

2.5 Regain (moisture percentage recovery)

Regain determinations were performed according to the method adapted from ISO/TR 6741-4: 1987 [17]. Percent Moisture Regain (or "Regain") is defined as the weight of water calculated as a percentage of dry weight. After acclimatization at 20 °C and 65% relative humidity [18–20], the samples were weighed on analytical balance (Sartorius, ED124S model, Germany). The drying was performed in an oven with forced air circulation (Binder FD Model 115, Germany) at 70 °C for 24 h or more until constant weight and the sample was again weighed. Five repetitions were carried out. The regain calculation was performed according to Eq. 2 [17]:

$$\text{Regain} = \frac{\text{original weight} - \text{dry weight}}{\text{dry weight}} \cdot 100 \quad (2)$$

2.6 Crystallinity index

The XRD spectrum was obtained at room temperature (25 °C) in a diffractometer Siemens D5000, DIFFRAC PLUS XRD (Germany), Cu X-Ray tube, $K\beta$ filter, 40 kV and 30 mA. Dispersion ranged from 4° to 80°, 2°/min continuous scan, 0.020° sampling width and $2\theta/\theta$ scan axis.

The crystallinity index (%) was calculated according to empirical method proposed by Segal et al. [21] (Eq. 3), relating in a diffraction spectrum of X-ray diffraction intensity peak (representing the crystalline material) with the peak that represents the amorphous material (minimum valley).

$$I_c = \left(\frac{I(002) - I(\text{am})}{I(002)} \right) \times 100 \quad (3)$$

I_c = crystallinity index (%); $I(002)$ = diffraction intensity representing the crystalline material (maximum peak) near $2\theta = 22^\circ$, $I(\text{am})$ = diffraction intensity peak representing the amorphous material (minimum valley) near $2\theta = 18^\circ$.

2.7 DSC, TGA and percentage of constituents

DSC (Digital Scanning Calorimetry) and TGA (Thermogravimetry Analysis) tests were carried out in Thermogravimetric Analyzer Mettler Toledo (model TGA/DSC 2, Netherlands), temperature from 30 to 1000 °C, 10 °C/min, 50 mL/min nitrogen atmosphere and 70 μL alumina crucible. For lignocellulosic materials, the events (peaks characterized by inflection points) in the DTG (Derivative Thermogravimetry) curves can be associated to processes that occur to

the different constituents of the analyzed material. Thus, in many cases, the approximate composition of the analyzed lignocellulosic material can be estimated by comparing the DTG and TGA curves [22].

2.8 Tensile PROPERTIES

Tensile properties of the fibers (rupture load, elongation, tenacity and Young's modulus), from fibers and yarns, were determined according to ASTM D 3 822-2001 [23] employing tester machine Instron (model 5569, Norwood, USA). Formerly, in order to determine tenacity (strength value shared by count number) fiber fineness (linear density or count number) was calculated in terms of TEX, defined as the weight in grams per 1000 m of the fiber, by weighing a known length of the fiber. A gauge length of 25 mm, automatic pre-tension and crosshead speed of 50 mm/min and a cell of 1000 N were employed. The results are an average from at least twenty samples. The total length of the sample was approximately 100 mm, sufficient to allow the distance between the jaws of 25 mm.

The tenacity for fibers was determined by the presented in Eq. 4 [19, 20]:

$$\gamma = \frac{F}{T_m} \quad (4)$$

γ = tenacity (cN/Text); F = breaking load (cN); T_m = count number (Text).

The Young's modulus (or textile initial modulus or module) of a fiber is determined by the slope of the tenacity-elongation curve in its initial linear part as presented in Eq. 5 [20]:

$$\text{Young's modulus} = \frac{\gamma_1}{\varepsilon_1} \quad (5)$$

γ_1 = Tenacity in the initial part of the tenacity-elongation curve (cN/Text); ε_1 = elongation in the initial part of the tenacity-elongation curve (%).

2.9 Yarn characterization

The following methods and standards were used to characterize the yarn:

- Count number tested according to ASTM D1907 [24]— 10 yarn samples of 10 cm length were weighted the fibers in analytical balance (Sartorius, ED124S model, Germany);
- Twist and retwist according to ASTM D1422 [25] and ASTM D1423 [26] respectively; both testing 10 samples in twist tester Marte (2200 model, Brazil) with 0.5 cN/Text pre-tension;

- Mechanical properties according to ASTM D2256 [27] using the tester machine Katros (K501 model, Brazil), gauge length of 250 mm, automatic pre-tension, cross-head speed of 321.50 mm/min and a cell of 500 Kgf (4903 N).

3 Results and discussion

3.1 Length and linear density

The length and linear density (Tex) of the fiber are respectively 89.5 ± 12.2 cm (CV = 13.7%) and 2.42 Tex. In order to compare the linear density magnitude of this fiber, the count number of a regular sewing thread 100% cotton is 34 Tex.

3.2 SEM and surface morphology

The longitudinal and transversal SEM microscopies are shown in Fig. 2.

According to the analysis of images shown in Fig. 2, the approximately determination of transversal dimension of this fiber was 35–40 μm . In addition, formations were

observed being regularly distributed along the transversal surface of all fibers. Each one of these formations presents an elliptical format with approximate dimensions of 20 by 10 μm (probably constituted by organic material considering the gray color) and in its center there is a dot with an approximate diameter of 3.5–5 μm (probably constituted by inorganic material considering the white color).

In order to verify the chemical composition of these formations and respective dots, the EDS analysis was performed on both surfaces. The EDS profile for the dots is shown in Fig. 3.

EDS analysis confirm the preliminary SEM findings. The dots are structures of silica (phytoliths), meanwhile the rest of fiber surface formations are composed by molecules with carbon and oxygen, typic in lignocellulosic materials.

Plants absorb silicon from the soil as silicic acid, and it is deposited as amorphous hydrated silica or opal ($\text{SiO}_2 \cdot n\text{H}_2\text{O}$) in the cell walls, inside the cells (intracellular spaces or cell lumen), and in the extracellular spaces of different plant organs such as leaves, pods, stems, inflorescences (i.e., herringbones), and epidermal appendages (trichomes) [28]. Silica was also found in the leaves of the palm *Oenocarpus Mart.* (Arecaceae), for example. [29] According to the same study, silica occurs in the form

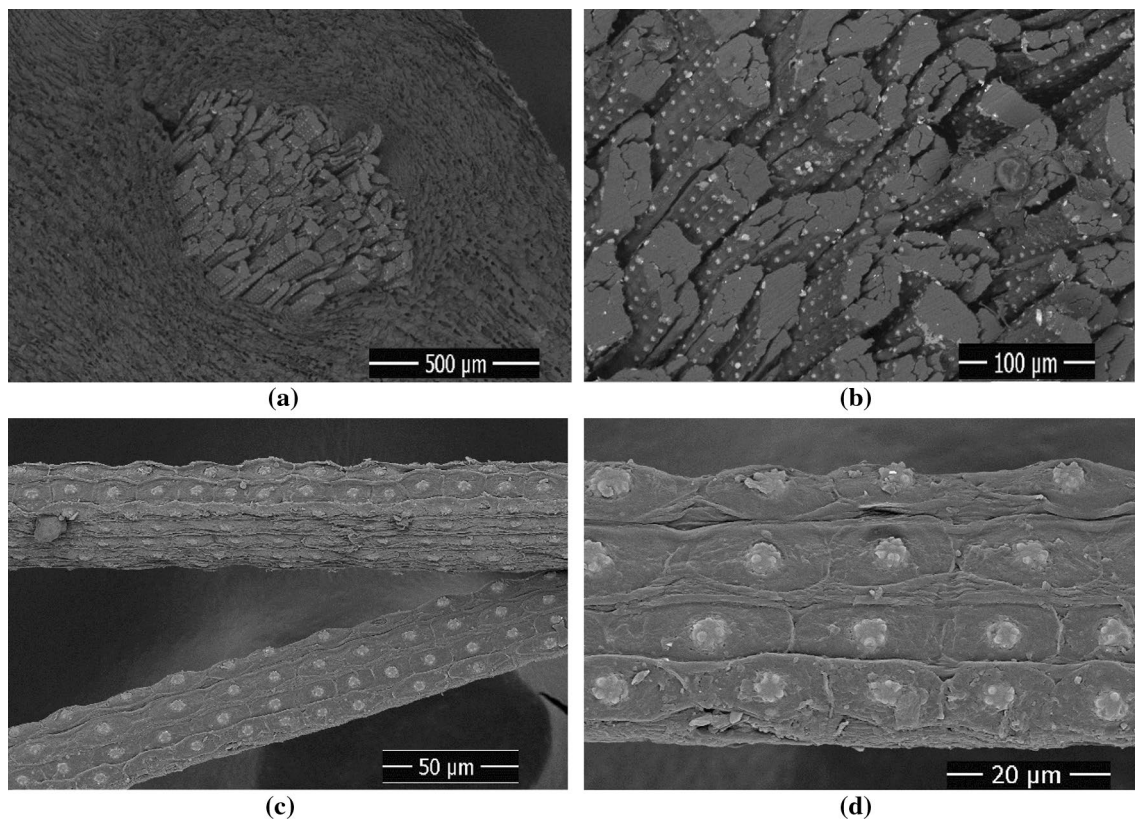


Fig. 2 Sectional and longitudinal SEM microscopies of *Astrocaryum chambira* Burret fibers, magnification and scale, respectively of: **a** $\times 250$ and 500 μm ; **b** $\times 1000$ and 100 μm ; **c** $\times 2000$ and 50 μm ; **d** $\times 6000$ and 20 μm (ESEM, Quanta 650 FEG, FEI)

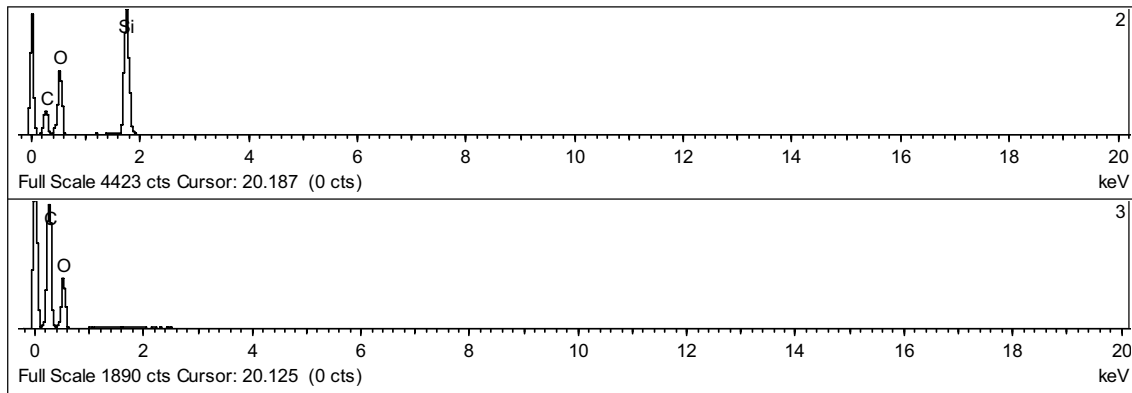


Fig. 3 EDS analysis of chemical composition of dots on *Astrocaryum chambira* Burret fibers (above), indicating the presence of silica, and the fiber surface formations (below), presenting only carbon and oxygen (typical in lignocellulosic materials) (EDX system Quantax, Bruker)

of mineral opal fouling. Within the epidermal cells of the leaves, the siliceous bodies are elliptical and covered by granulations [29] such as the results found in the study. However, to our knowledge, it is the first time that this is related to *Astrocaryum chambira* Burret.

3.3 Density

The determined density for *Astrocaryum chambira* Burret is $1.5100 \pm 0.0072 \text{ g/cm}^3$ (CV = 0.48%). The density of natural vegetal fibers of recognized textile employability is about 1.5 g/cm^3 [30], such as cotton (1.54 g/cm^3), flax (1.59 g/cm^3), jute (1.48 g/cm^3) and hemp (1.48 g/cm^3) [31], so the density of *A. chambira* fibers is within the estimate.

3.4 Regain (moisture percentage recovery)

The regain for *Astrocaryum chambira* Burret is $10.0 \pm 0.34\%$ (CV = 3.44%) and it is compatible with other ones from species of recognized textile employability, such as sisal (13.5%), cotton (8.5%), flax (12%), jute (13.8%) and hemp (10%) [31]. All of them are considered hydrophilic fibers.

3.5 Crystallinity index

In the X-ray diffraction graphs of the *A. chambira* fibers, the minimum valley intensity, that is, the amorphous fraction (I_{am}) is $19^\circ \leq 2\theta \leq 20^\circ$ (19.26°). The maximum peak intensity, which corresponds to the crystalline fraction (I_{002}), is between $23^\circ \leq 2\theta \leq 24^\circ$ (23.46°).

With the data obtained by the diffractogram (Fig. 4), the crystallinity index of 80.25% was calculated. This index is higher than that one of cotton (60%), but compatible with those of other leaf fibers, such as sisal (85%) [32].

3.6 DSC, TGA and percentage of constituents

The analyzes are performed by evaluating the weight loss, the time and temperature flow in the TGA graphs as well as in its Derivative Thermogravimetry (DTG). In the DSC charts the initial and final temperatures of the peaks are analyzed and whether they are endothermic or exothermic (Figs. 5, 6, 7) [33].

Analyzing all the profiles (DSC, TGA and DTG), three events are observed. The first event occurs between room temperature and 100°C and can be attributed to moisture loss. The second event, approximately from 200 to 370°C , can be attributed to the degradation of total or holocellulose (hemicellulose and α -cellulose). The last event happens from 370°C to 580°C , corresponding to the degradation of the lignin.

Thus, from this analysis, relating the events with the corresponding loss of mass, it was possible to obtain the approximate quantities of these constituents in the *Astrocaryum chambira* Burret fiber, namely: 5.90% moisture; 68.43% holocellulose; and 21.65% lignin.

In comparison with the values for other species, including two from other palm tree species (buriti—*Mauritia flexuosa* Mart and tururi—*Manicaria saccifera* Gaertn), and other two which fibers are withdrawn from leaves (sisal—*Agave sisalana* and curaua—*Ananas erictifolius*) the values present variations among them (Table 1).

3.7 Tensile properties

The values for tensile results on fibers of tucum (*Astrocaryum chambira* Burret) are: $6.57 \pm 0.38\%$ elongation (CV = 5.81%); $37.44 \pm 6.57 \text{ cN/Tex}$ tenacity (CV = 14.85%) (near 565 MPa); and $8.25 \pm 1.03 \text{ N/Tex}$ Young's Modulus (near 12.5 GPa). A comparison between these values and

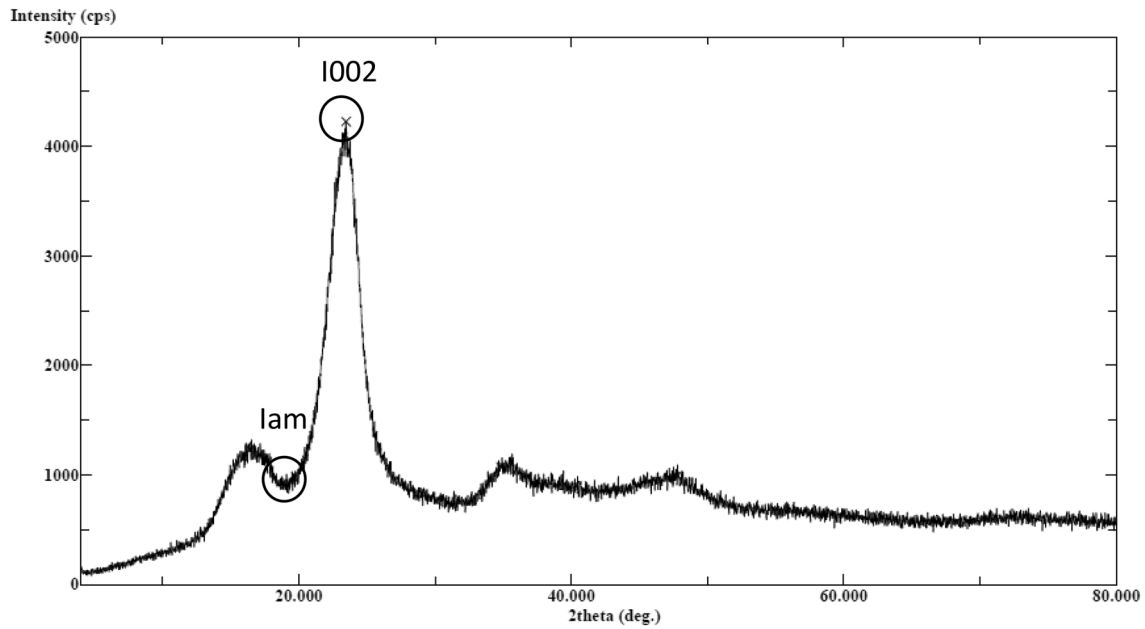


Fig. 4 X-ray diffractogram for *Astrocarium chambira* Burret fiber (D5000, DIFFRAC PLUS XRD, Siemens)

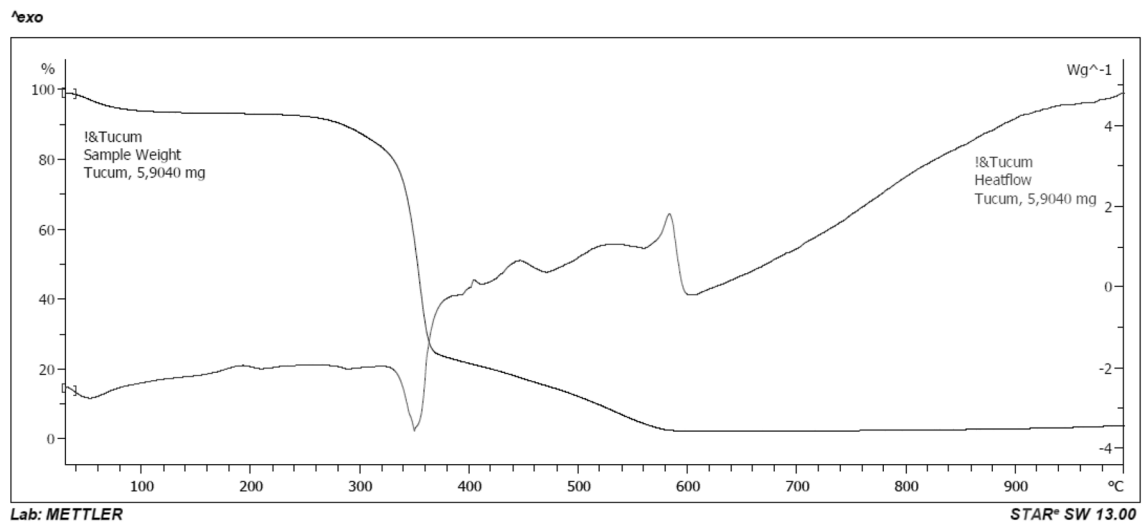


Fig. 5 TGA and DSC graph for *Astrocarium chambira* Burret fiber (thermogravimetric analyzer mettler toledo, model TGA/DSC 2)

other ones from fibers of recognized textile employability are shown in Table 2.

According to the values shown in Table 2, tucum (*Astrocarium chambira* Burret) fibers are much more resistant (comparing tenacity values) than the most used vegetal fibers like cotton and flax, but inferior to hemp and equivalent to sisal. However, excepted cotton value, tucum presents the lowest stiffness when Young’s modulus values are compared.

The elongation is much superior to all, including sisal, a leaf fiber that has been presenting characteristics similar to *A. chambira*, such as tenacity, crystallinity index, percentage of constituents and regain.

3.8 Yarn characterization

In the Amazonian Brazilian community “Ceú do Jurua”, the process of manufacturing the yarn known as “Linha

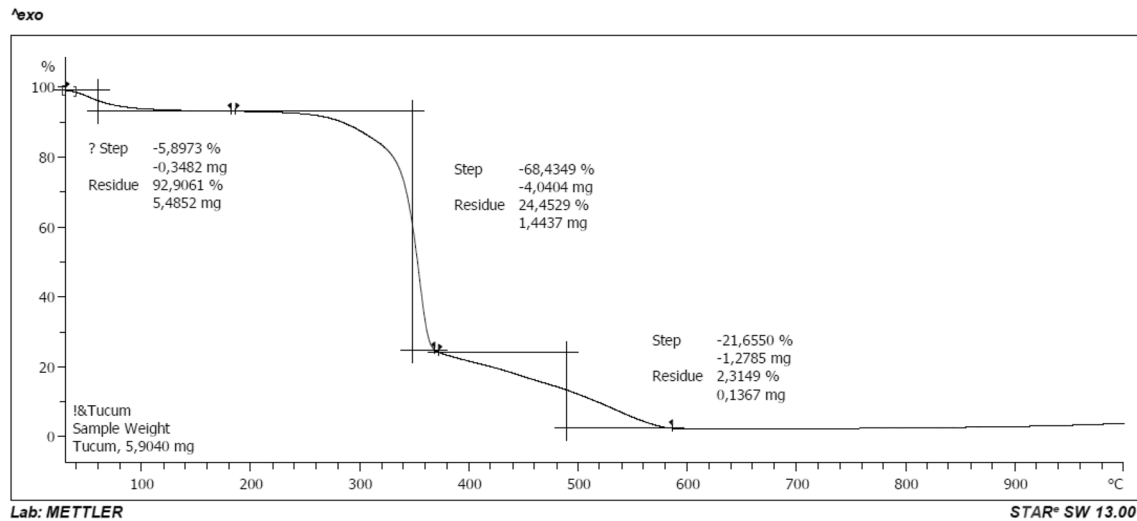


Fig. 6 TGA graph and analysis for *Astrocaryum chambira* Burret fiber (thermogravimetric analyzer mettler toledo, model TGA/DSC 2)

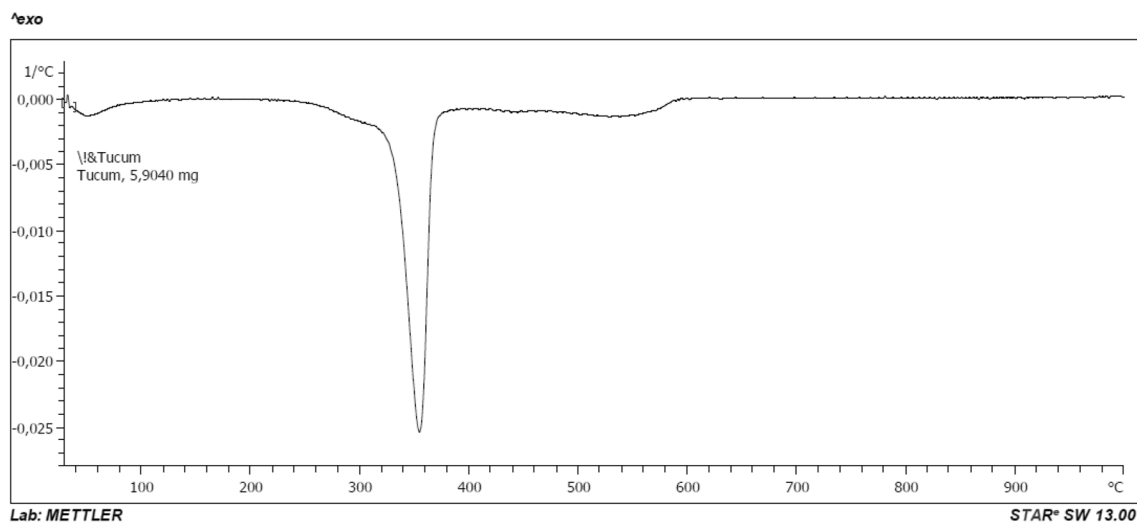


Fig. 7 DTG graph for *Astrocaryum chambira* Burret fiber (thermogravimetric analyzer mettler toledo, model TGA/DSC 2)

Table 1 Estimation of the concentrations of holocellulose and lignin in the tucum (*Astrocaryum chambira* Burret) fiber through the analysis of the TGA and DTG curves

Fiber	Holocellulose (wt%)		Lignin (wt%)
	Cellulose (wt%)	Hemicellulose (wt%)	
Tucum	68.4		21.7
Buriti	65–71		21–27
Tururi	74.1	12	31.1
Sisal	65–67	12	9.9
Curaua	71–74	9.9–21	7.5–11

The values for the other fibers were obtained from literature [34]

Table 2 Elongation, tenacity, and Young’s modulus values for tucum (*Astrocaryum chambira* Burret) and for fibers from other species of recognized textile employability [20, 35]

Fiber	Elongation (%)	Tenacity (cN/ Tex)	Young’s modulus (N/ Tex)
Tucum	6.57	37.4	8.3
Sisal	2.5	39.7	12.4
Jute	1.9	38.9	17.9
Hemp	1.8	55.6	19.4
Flax	3.0	45.5	15.5
Cotton	5.0	34.9	5.8

do Tucum” (Tucum Yarn) is a traditional knowledge passed from generation to generation. It can be divided into four stages: collecting the leaves, removing the fiber (which is referred as “linen” by them), combing and pulling the “linen” and spinning the yarn (Fig. 8) [14, 37].

A basic characterization of this handcrafted yarn is shown in Table 3.

It is an interesting strong yarn, with a rustic appearance, what is expected since it is a handmade product. However, it is worth noting that despite the tucum yarn be manufactured in this way (employing own hands or a simple wood spindle), the torsion is fairly regular.

3.9 The *A. chambira* fiber and the traditional communities

The following Table 4 summarizes the information of the main studies found in the literature about *A. chambira* fibers employed by Amazonian communities, such as the country in which the research was carried out; how the palm tree is popularly called in that region; the studies’ aim and an example of craft products made with this fiber.

Traditional knowledge of extraction, spinning and the handicraft manufacturing, as well as the economic and emotional importance of this fiber for such communities are the most exploited points by the authors [1–7].

The knowledge of Amazonian biodiversity and natural resources is part of the culture of forest peoples [14].

The direct dependence of traditional communities on the environment constitutes a modality of the relationship between society and nature [37]. It is a relation considered of low environmental impact, which could therefore, propitiate the conservation of the biological diversity [38, 39]

In this sense, faced with the actual environmental crisis, the way of life and the knowledge of these populations have been listed as important instruments for environmental conservation [40].

4 Conclusion

The leaves of the palm tree scientifically known as *Astrocaryum chambira* are a source of vegetal fiber used by several traditional communities to make handicrafts and other utensils. The studies report the processes of extraction, processing and spinning of the fiber, present products made with it and some approach aspects of management practices and sustainable use of the palm.

However, no previously study presents a physical and chemical characterization of the fibers of *Astrocaryum chambira* Burret. In this way, its main characteristics were determined, namely: 90 ± 12 cm fiber length; 1.510 ± 0.007 g/cm³ density; $10.0 \pm 0.34\%$ regain; 80.3% index of crystallinity; TGA; DTG and DSC profiles with estimated values of holocellulose (68.4%) and lignin (21.7%); and tensile tests resulting in: 37.4 ± 5.6 cN/Tex tenacity; $6.6 \pm 0.4\%$ elongation; 8.3 ± 1.0 N/Tex Young’s Modulus. About its tensile properties, a similarity was observed with sisal fiber (also a leaf fiber), which could orientate future application researches.

In SEM microscopies with EDS analysis, it was possible to find siliceous bodies (phytoliths) along the longitudinal surface of the fiber. Silica is not a rare element in palms or other plants; it was also found in the leaves of the palm *Oenocarpus Mart.* (Arecaceae), for example.

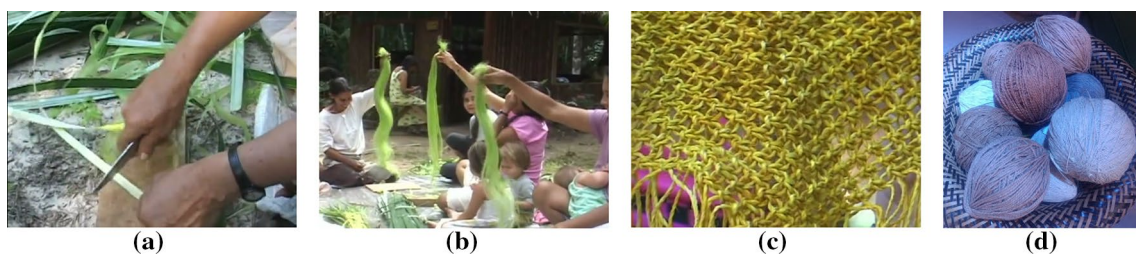


Fig. 8 Tucum fiber: **a** obtention from grown palm leaves [14, 34]; **b** processing of obtained fibers [14, 34]; **c** macrame fabric [14, 34, 36]; **d** authors’ photo

Table 3 Characterization of yarn made by Amazonian Brazilian community “Ceú do Jurua” from the fibers of tucum (*Astrocaryum chambira* Burret)

	Count number (Tex)	Tenacity (cN/Tex)	Elongation (%)	Z twist (t/m)	S twisting (t/m)
Average	317.70	19.62	7.02	308.20	174.50
SD	38.4	15.77	1.33	42,24	19.81
CV%	12.09	29.41	18.9	27.4	11,35

Table 4 Information gathered from previous studies addressing the fiber *A. chambira*





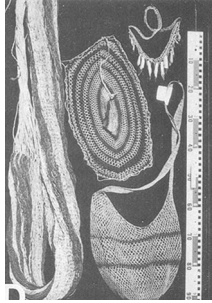

Country	Aim of the study	Popular name	Examples of handmade products made with <i>A. chambira</i>	Study
Colombia	Report the traditional use of <i>A. chambira</i> in the Colombian Amazon by indigenous communities in the municipalities of Leticia, San Martín Amacayacu, Nazareth, Puerto Nariño, Tarapaca and La Chorrera	Chambira or Cumare		[1]
Colombia	Summarize various plant fibers used for traditional crafts of the country	Chambira		[2]
Colombia	Propose guidelines for the management and sustainable use of nine species of the Colombian Amazon	Cumare		[3]
Peru	Approach the extraction, processing and production of handicrafts made with <i>A. chambira</i> fibers, as well as their economic aspects, in the community of Brillo Nuevo, Peru	Chambira		[4]

Table 4 (continued)

Country	Aim of the study	Popular name	Examples of handmade products made with <i>A. chambira</i>	Study
Peru	Approach the use of <i>A. chambira</i> fibers, focusing on sustainable use and the idea of conservation through use, in the community of San Jose	Chambira	–	[5]
Peru	Report the use of fiber <i>A. chambira</i> fibers in communities near Iquitos - Esperanza, Buena Vista, Chino, San Pedro and Blue Diamond	Chambira	–	[6]
Ecuador	Observe and report the four indigenous groups of the Ecuadorian Amazon which exploit the <i>A. chambira</i> fibers	Chambira		[7]
Brazil	Case study in a Brazilian traditional community approaching the processes of manufacturing the Tucum yarn (yarn made with <i>A. chambira</i> fibers)	Tucum		[14, 36]

The tucum yarn, manufactured by a Brazilian traditional community, presented strong mechanical properties and rustic appearance, but fairly regular torsion.

The fiber manipulation techniques are part of a traditional knowledge of several communities of Amazonian region. The worth recognition of a traditional knowledge could indeed be a form of the local biodiversity conservation, since the relation that these people have with nature involves respect, dependence and gratitude, which means that their management of the natural resources can be considered of low environmental impact. In this way, valuing a traditional knowledge of a population may be the same as keeping a species alive.

Not only the physical and chemical characteristics of the fiber must be considered when developing and studying an application, but in this specific case, the cultural aspects of the fiber are also much important. The traditional knowledge

of this people and their relationship with the nature and with the fiber must be respected, sustained and valued.

The results and discussions obtained here may be a database of the fibers from the leaves of *Astrocaryum chambira* Burret, helping future researches that will address its application potential, as an alternative textile fiber.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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