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Properties of an Amazonian vegetable fiber as a potential reinforcing material

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ABSTRACT

The jacitara palm (*Desmoncus polyacanthos* Mart.) is widely used by the artisans of the Amazon Basin region of Negro River, Brazil, and is known to provide excellent fiber characteristics and appearance. However, there is a lack of technical/scientific information about this important vegetable fiber. The objective of this study was to evaluate the main properties of jacitara fibers for their future technological application as reinforcement in composites. Anatomical, ultrastructural, chemical, physical and mechanical tests were performed. The coefficient of rigidity, fraction wall, Runkel index and aspect ratio results showed the potential of the jacitara fibers as reinforcement in composites. The range of the microfibrillar angle of the fibers was 12.8–16.5°. The average contents of cellulose, hemicellulose, lignin, extractives and mineral components were 66.9%, 18.4%, 14.7%, 11.6% and 1.8%, respectively. Fibers extracted from the bottom or from the medium part of the jacitara stem showed higher modulus of elasticity (1.9 GPa and 1.7 GPa, respectively) and tensile strength (74.4 MPa and 70.6 MPa, respectively) than that extracted from the upper part. The properties of the jacitara fibers are in the same range of other lignocellulosic materials. The experimental results in the present work contribute to the widespread use of the jacitara fibers as a source of raw material that may be used to engineered composites and new materials for different applications in the near future.

1. Introduction

Vegetable lignocellulosic macrofibers are widely available from annual plants in most developing countries. They present several interesting advantages, particularly their low real (1.3–1.5 g/cm^3) and apparent density (0.4–1.5 g/cm^3), high specific stiffness (1.1–80.0 GPa) and strength (0.1–3.0 GPa), biodegradability, their renewable character, their low processing energy in the case of chopped natural fibers, and their availability everywhere at modest cost and in a variety of morphologies and dimensions (Davies et al., 2011; Jarabo et al., 2012). For example, fibers from monocots presents average fiber lengths and width varying from 1.1 to 2.7 mm and 8 to 30 μm respectively (Ilvessalo-Pfäffli, 1994). In general these fibers are narrow, thick-walled, accompanied by thin-walled fibers with varying shapes of fibers ends (tapering, oblique and blunt).

All these properties make the vegetable lignocellulosic fibers convenient materials for matrix reinforcement, such as polymeric composites or fiber-cement applications, as witnesses the significant number of recent reviews and special issue publications (Peijs and Baillie, 2003; Savastano Jr. and Warden, 2005; Belgacem and Gandini, 2008; Sabu and Pothan, 2008; Savastano Jr. et al., 2010).

Vegetable fibers can be classified according to their origin: from phloem or liber (e.g. jute and malva), from leaves (e.g. sisal and curauá), from seeds (e.g. cotton), from fruit (e.g. coconut), from grass and reed (e.g. palm trees, rice and corn) and from xylem or woody material. Among the vegetable fibrous species, the most used and studied in Brazil are the *Eucalyptus* genus (mostly used as cellulose Kraft pulp), as well as bamboo (Guimarães Jr. et al., 2010), sugar cane bagasse, sisal and coconut coir husk fibers (Motta and Agopyan, 2007; Savastano Jr., 2000; Savastano Jr. and Warden, 2005; Savastano Jr. et al., 2010).

A prior knowledge of the morphology, chemical composition, and physical and mechanical properties of the vegetable fibers is essential for evaluation of their potential for different applications, of their capacity for a later industrial upscaling or for assessing

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the highest reinforcing potential of the fibers (e.g. improving their interaction with the composite matrix).

Jacitara (*Desmoncus polyacanthos* Mart.) is a very common palm species (Arecaceae family) native from Amazon Basin region of Negro River, Brazil. The stem fibers of jacitara are widely used by traditional Amazonian communities for production of handicraft utensils and instruments widely commercialized in South America, and also play an important cultural role for local communities. The jacitara stem has similar morphology and quality to the Asian rattans (*Calamus* spp.), which are species of great importance to the rattan and furniture industry, worldwide known by the quality of their fibers. However, there is a general lack of technical and scientific information about the jacitara palm fibers. Therefore, the objective of this study was to identify the main fiber morphological characteristics, the chemical composition, the physical and mechanical properties of the jacitara stem fibers, with the aim of exploring new applications for this Amazonian species.

2. Experimental

2.1. Material

The jacitara (*D. polyacanthos* Mart.) stems were collected in the district of Novo Airão, Amazonas State, Brazil. The usable length of the collected stems was obtained from the plant stem close to the ground and below the crown of each individual leaf. Samples for anatomical/morphological characterization were taken at five different height positions of the usable jacitara trunks: bottom (0%), 25%, medium (50%), 75% and top (100%), as depicted in Fig. 1.

2.2. Anatomy of the stem and fibrovascular bundles

The cross-section of the bottom of the jacitara stem was sectioned in a sliding microtome and using a type C razor blade steel. 10 μm thick slices were obtained. Staining of the sections was performed with safrablau (safranin 0.1% and astrablau 1%). Semi-permanent histological slides were observed in a Ken-A-Vision Model TT 1010 light microscope.

2.3. Fiber morphology

The separation of the anatomical elements (maceration) of the material extracted from the five height positions was performed using a method adapted from Franklin (1945). The macerated material remained in the oven at 60 °C until the complete individualization of the anatomical elements. Histological semi-permanent slides were prepared with the macerated material for measuring the following properties: overall fiber diameter (*fd*), lumen diameter (*ld*) and fiber length (*L*). Due to the absence of specific standard for monocots, the anatomical classification of the fibers was performed according to Coradin and Muñiz (1992) and International Association of Wood anatomists (IAWA Committee, 1989). Measurements of the dimensions of the fibers, as anatomical elements, were performed in a light microscope Ken-A-Vision Model TT 1010 with image analysis software (WinCeLL Pro, Regent Instruments Inc.). It was used around thirty measurements of fiber length, diameter and fiber lumen diameter, in each height position.

2.4. Anatomical parameters

From the values of overall fiber diameter (*fd*) and lumen diameter (*ld*) of the individualized fibers, it was calculated the anatomical parameters: wall thickness (WT), wall fraction (WF), coefficient of rigidity (CR), Runkel index (RI) and aspect ratio (AR). The wall thickness represents the average fiber cell wall thickness (Eq. (1)) while the wall fraction (Eq. (2)) indicates the volume occupied by the fiber wall in relation to the total fiber volume (Paula and Silva Jr., 1994). The coefficient of rigidity (Eq. (3)) and Runkel index (Eq. (4)) are used in the pulp and paper industry for checking the resistance of the fiber to the forces applied to the paper formation. The ratio of fiber length/fiber diameter, referred to as aspect ratio (Eq. (5)) consists of one parameter widely used to evaluate reinforcing fibers for composite materials and should be equal to or greater than 100 (Halpin and Kardos, 1976). These parameters provide useful information for evaluation of the potential of the vegetable fibers as reinforcement.

$$\text{WT}\ \ (\mu\text{m}) = \frac{fd - ld}{2} \tag{1}$$

$$\text{WF}\ \ (\%) = \frac{2 \times \text{WT}}{fd} \times 100 \tag{2}$$

$$\text{CR}\ \ (\%) = \frac{ld}{fd} \times 100 \tag{3}$$

$$\text{RI} = \frac{2 \times \text{WT}}{ld} \tag{4}$$

$$\text{AR} = \frac{L}{fd} \tag{5}$$

where *fd* is the overall fiber diameter (μm), *ld* is the lumen diameter (μm) and *L* is fiber length (μm).

2.5. Microfibrillar angle of the fiber

Microfibrils designate long flexible micro or nanofibers consisting of alternating crystalline and amorphous cellulose chains. According to Wimmer et al. (2002), the microfibrillar angle is one of the most important ultrastructural aspects of the fiber cell wall. The angle formed by microfibrils with the fiber axis is related to the strength of the individual cellulose fiber. The orientation of microfibrils toward the S2 layer can be associated with high tensile strength of the fiber. Lower values of microfibillar angle correlate with high tensile strength (Foelkel, 1977). The determination of the microfibrillar angle was carried out for fiber samples from the bottom (0%), medium (50%) and top (100%) positions of the jacitara plant (Fig. 1). The fractions of the stem at each position were sectioned at the tangential plane in a sliding microtome, using a type C razor blade steel. Each sample was composed of a mixture of histological sections with 10 μm thick, obtained from five different individuals of jacitara trunks. For dissociation of the anatomical elements the sections were soaked in a 1:1 (v/v) solution of hydrogen peroxide and glacial acetic acid at 50 °C for approximately 30 h, similarly to the procedures reported in Ribeiro et al. (2011). It was used a microscope with polarized light and a turntable with the scale ranging from 0 to 360°. Thirty fibers of each sample were measured for determination of the microfibrillar angle, following the methodology described by Leney (1981).

2.6. Chemical composition of the fibers

The contents of cellulose, hemicelluloses and lignin of the jacitara stems for chemical characterization (retained on the 60 mesh sieve) were obtained on the extractives-free samples, and they were determined according to the methodology described by Silva and Queiroz (2002). The determination of the extractives content and mineral/ash content followed the NBR 14853 (ABNT, 2010) and NBR 13999 (ABNT, 2003) standards, respectively.

2.7. Physical and mechanical properties

2.7.1. Thermal degradation

A representative compound sample of the jacitara fibers retained on the 270 mesh sieve was prepared for the