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EFFECT OF ANATOMICAL AND CHEMICAL STRUCTURE IN THE PERMEABILITY OF "AMAPÁ" WOOD

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ABSTRACT: This paper aimed to study the permeability to air and liquid, in the longitudinal direction of "amapá" wood (*Brosimum parinarioides* Ducke), originating from the Amazon Forest. Furthermore, the influence of anatomical and chemical characteristics in the permeability of the wood was investigated. For this study, samples were collected from three trees, in the state of Pará, Brazil, and submitted to permeability test, anatomical characterization, and chemical analyses. The permeability to the air of the "amapá" wood was estimated at $63.7 \cdot 10^{-9}$ $m^3 \cdot [m \cdot (N \cdot m^{-2}) \cdot s]^{-1}$ and to the liquid was $2.07 \cdot 10^{-9}$ $m^3 \cdot [m \cdot (N \cdot m^{-2}) \cdot s]^{-1}$. There were low correlations between air and liquid permeability and the anatomical features.

EFEITO DA ESTRUTURA ANATÔMICA E QUÍMICA NA PERMEABILIDADE DA MADEIRA DE AMAPÁ

Palavras chave:
Lei de Darcy
Fibras
Fluxo de ar e líquido
Brosimum parinarioides
Vasos

RESUMO: Objetivou-se, com este trabalho, estudar a permeabilidade ao ar e ao liquido no sentido longitudinal na madeira de Amapá (*Brosimum parinarioides* Ducke) oriunda da floresta amazônica. Além disso, identificar a influência das características anatômicas e químicas na permeabilidade dessa madeira. Foram coletadas no Estado do Pará - Brasil, três árvores de Amapá, das quais corpos-de-prova foram retirados e submetidos aos ensaios de permeabilidade, caracterização anatômica e análise química. A permeabilidade ao ar na madeira de Amapá foi de $63{,}7 \cdot 10^{-9}$ $m^3 \cdot [m \cdot (N \cdot m^{-2}) \cdot s]^{-1}$ e ao líquido de $2.07 \cdot 10^{-9}$ $m^3 \cdot [m \cdot (N \cdot m^{-2}) \cdot s]^{-1}$. Ocorreram baixas correlações entre a permeabilidade ao ar e ao líquido e as características anatômicas.

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INTRODUCTION

There are many forest species in the Amazon forest with the potential to replace the demand for traditional timbers. However, few studies have been conducted with these tropical species, in order to evaluate their technological characteristics. According to Zangiacomi and Rocco Lahr (2007), little information is available on the potential use of the so-called alternative species for replacing the traditional ones. Surely, the availability of other woods would reduce pressure on those endangered ones.

In the States of Amazonas and Pará, "amapá" wood (*Brosimum parinarioides* Ducke) is used for manufacturing veneers, plywood, packaging, toys, furniture, decorative panels, lumbers and others (MAINIERI; CHIMELO, 1989) and despite having many applications, research on "amapá" wood is still scarce.

The study on anatomical, physical and chemical characteristics of "amapá" wood can result in knowledge about the technological behavior of this species and the influence of these traits in its products.

The vessels are responsible for the propagation of flows in hardwoods, such as "amapá" wood (SIAU, 1971), by which they inter-communicate through structures called perforation plates. Wood permeability is an important indication of the displacement of fluids within the plant (ENGLAND; ATTIWILL, 2007). It is affected by the proportion of heartwood and sapwood. Additionally, other anatomical factors which affect the permeability are number, amount and diameter of the vessels (COMSTOCK; CÔTÉ, 1968; SIAU, 1984).

In pulping, preservation and drying processes, the flow of liquids or gases through the wood structure is important, since these are greatly affected by the ease with which the fluids move through the internal spaces in the wood, under static or dynamic pressure gradient (RAYIRATH; AVRAMIDIS, 2008). Thus, studies on the air and liquid permeability of alternative timbers, such as "amapá", are necessary.

Given the difficulty of evaluating the permeability of the wood, this research can contribute to the knowledge of this physical characteristic, where publications that report studies on air and liquid permeability for hardwood timber, and more specifically of Amazon forest species, are rare.

The aim of this study was to assess the influence of anatomical and chemical characteristics of *Brosimum parinarioides* Duck (amapá) wood, on its longitudinal permeability to the air and liquid.

MATERIAL AND METHODS

Wood samples were obtained from three "amapá" trees (*Brosimum parinarioides* Ducke) of a natural forest belonging to CIKEL Brazil Verde S/A. This company has certification from the Forest Stewardship Council (FSC). It is located in Paragominas - Pará State, Brazil (3°57'S and 48°64'W). Two-meter long logs were removed from 40 meters high trees. The logs were sent to the company's sawmill where three planks 2000 mm long, 650 mm wide and 30 mm thick, of each tree, were cut for this study.

The heartwood samples, in the prismatic shape 0.26 meters long, approximately 25 mm of width and 25 mm thick, were lathed to acquire the cylindrical shape, with diameter of 20 mm.

Sample preparation

Samples were produced from the three planks of each tree (Figure 1). Then, the samples were maintained in a climatic room (temperature of 20°C ± 2°C and relative humidity of 60% ± 5%) until constant mass. After this stage, the sides of the samples were sealed with slow cure epoxy resin, to ensure only longitudinal flow. The samples returned to the climatic room for the cure of the resin and the stabilization of their mass. Seasoned, cylindrical samples were cut with a circular saw to standardize their dimension (20 mm in diameter x 50 mm long), according to the methodology for permeability (SILVA et al., 2008). 15 samples were produced from each plank, totalizing 45 samples per tree.

Permeability test

The apparatus for testing the permeability to atmospheric air was equipped with three rotameters, to measure air flow through the samples. Therefore, the samples were placed on a device, where at one end of the sample a flow meter was connected and, on the other end, suction was applied (BUFALINO et al., 2013; SILVA et al., 2008). The data of air flow, time (minutes) for flow to remain constant and its respective pressure were recorded.

The liquid permeability was conducted using a graduated pipette with a capacity of 50 ml, which replaced the rotameters. A set of stoppers were made, in which the sample was placed with a face for suction through a joint conical glass, and the other end of the sample was connected to the burette, as described by Silva et al.

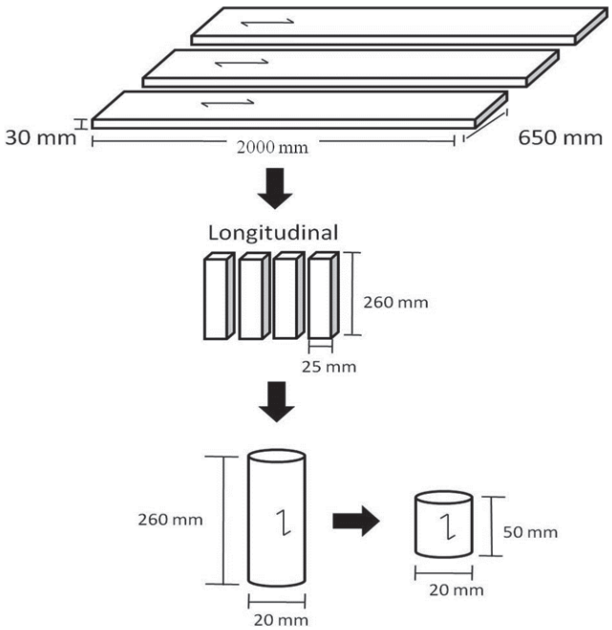

FIGURE 1 Sampling preparation for the experiment.
FIGURA 1 Preparação de amostras para o experimento.

(2008). The system was then submitted to suction. The time for 30 ml of distilled water to cross the sample was marked with a digital timer. After this stage, the pressure indicated on the gauge of the vacuum pump was measured.

Gas permeability

The gas permeability of the wood was determined following Darcy's law (equation 1), where Kg - gas permeability ($m^3 \cdot [m \cdot (N \cdot m^{-2}) \cdot s]^{-1}$); V - volume of the gas flow that goes through the species ($cm^3 \cdot s^{-1}$ or $m^3 \cdot s^{-1}$); L - sample length (cm or m); P - pressure (atm or $N \cdot m^{-2}$); ΔP - pressure difference (atm or $N \cdot m^{-2}$); t - time (s); A - cross-sectional area (cm^2 or m^2) and $\bar{P}$ - average pressure in the sample (atm or $N \cdot m^{-2}$).

$$Kg = \frac{VPL}{tA\Delta P\bar{P}} \quad [1]$$

Liquid permeability

The liquid permeability was also determined by Darcy's law, using the equation 2, where K - liquid permeability $m^3 \cdot [m \cdot (N \cdot m^{-2}) \cdot s]^{-1}$; V - volume of liquid flowing by the species ($cm^3 \cdot s^{-1}$ or $m^3 \cdot s^{-1}$); L - sample length (cm or m); t - time (s); A - cross-sectional area (cm^2 or m^2) and ΔP - pressure difference (atm or $N \cdot m^{-2}$).

$$K = \frac{VL}{tA\Delta P} \quad [2]$$

Anatomical characterization

After the air and liquid permeability tests, the anatomical analysis on the samples was done, to observe the effect of the anatomical elements in the permeability. Thus, samples were cut in the dimensions of 15 x 15 mm in tangential and radial planes, and 20 mm in the transverse plane, from the samples tested in the permeameter. The samples were softened, by cooking in water at 70°C during 24 hours. Then the samples were taken to cooking in nitric acid and distilled water, in the proportion 1:10 for 10 minutes, due to high resistance to cut in the cross-sectional samples.

The anatomical characters were described following the standards of the International Association of Wood Anatomists Committee - IAWA (1989) using an optical microscope, with increased ocular of 10x and objective between 2.5 to 100x, connected to the *Image Pro Plus* image analysis software.

The macerated material was prepared according to the method of Franklin (1945). 30 measurements were performed for the following parameters: vessel diameter (VD), vessel frequency (VF), fiber length (FL) and fiber width (FW). The wall thickness of the fiber (WT) was calculated by the difference between the fiber width and the lumen diameter, divided by two.

Chemical characterization

The wood was cut into wood chips and later into sawdust with a mill. The sawdust was then passed through sieves overlapping of 40 and 60 mesh, which used only the fraction that was retained on 60 mesh sieve. After this, the sawdust was stored in a climatic room (air temperature of 20°C ± 2°C and relative humidity of 60% ± 5%) until constant mass.

The analysis of the samples were performed according Associação Brasileira Técnica de Celulose e Papel - ABTCP (1974), to determine the solubility of extractives in cold water, hot water and soluble in alcohol-toluene. The soluble lignin content was determined with 1 g of sawdust, in the dry condition (0% moisture content) and 15 ml of sulphuric acid, all placed in a water bath for eight hours.

RESULTS AND DISCUSSION

"Amapá" wood properties

A summary of the chemical and anatomical characteristics and permeability of "amapá" wood are shown in Table 1.

TABLE 1 Chemical and anatomical characteristics of "amapá" wood and mean values of air and liquid permeability.

TABELA 1 Características químicas e anatômicas da madeira de amapá e valores médios da permeabilidade ao ar e ao líquido.

	Features	Mean	CV (%)
Chemical	Holocellulose (%)	63.3	2
	Lignin (%)	30.51	1
	Extractives (%)	5.31	17
	Ash (%)	0.88	15
Anatomical	Frequency of vessels (mm^2)	7	6
	Vessel diameter (μm)	161	9
	Fiber length (μm)	1,269	6
	Fiber wall thickness (μm)	4.7	13
	Fiber width (μm)	21.7	17
Permeability	Air: $m^3[m\ (N\ m^{-2})\ s]^{-1}$	63.7×10^{-9}	14
	Liquid: $m^3[m\ (N\ m^{-2})\ s]^{-1}$	2.07×10^{-9}	77

CV: Coefficient of variation

Chemical characteristics

The average holocellulose content in the "amapá" wood (63.3%, Table 1) agrees with those obtained by Browning (1963), who studied the holocellulose content of the amazon wood "pau mulato" (*Qualea dinizii*), "abiurara" (*Lucuma dissepala*), "breu branco" (*Protium heptaphyllum*) and "imbaúba" (*Cecropia juranyana*), and found values ranging from 69.3% to 73.8%. The values found in the chemical characteristics of "amapá" wood are close to those observed by Lima (2011), who studied the same species, but in other longitudinal position.

The average value of the lignin content (30.51%, Table 1) are consistent with the values determined by Miller (1999) and Sjostrom (1981), who observed lignin concentration ranging from 23 to 33%. Silva (2007), studying lignin content in hardwood, reported that timbers with high content of lignin present greater fluid passage. However, such a claim cannot be confirmed in this work.

The percentages of total extractives in the "amapá" wood (5.31%, Table 1) are consistent with those cited in the literature for Amazonian woods. Barbosa et al. (2007), studying antitermitic properties of crude extracts of wood and bark of species *Pouteria guianensis* and *Scleronema micranthum* found levels of extractives of 2.5% and 4.6%, respectively.

Milota et al. (1995) and Silva (2007) reported that the extractives content indicates that possibly there will be a barrier to the passage of fluids, mainly from the heartwoods. Thus, the extractives content of "amapá" wood may jeopardize impregnation with preservatives, as well as the movement of water during the drying process.

The ash content provides information about the amount of inorganic material within the plant. The average ash content in the "amapá" wood (0.88%, Table 1) is consistent with those cited in the literature, varying between 0.2% and 1% of the dry wood weight (MILLER, 1999; MORI et al., 2003). According to Silva (2007), an increase in ash content makes the wood more permeable to fluids.

Anatomical characteristics

Seven vessels per mm², with a mean diameter of 161 μm were found in "amapá" wood (Table 1). These values are close to those obtained by Mainieri and Chimelo (1989), who found for "amapá" wood a frequency of nine vessels per mm² and vessel diameter of 200 μm.

The total number of vessels per mm² and their diameter are extremely important, since these characteristics influence the wood permeability (COMSTOCK; CÔTÉ, 1968) and therefore wood impregnation and drying. When a reduction occurs in total vessels per mm², there is a compensation by increasing the diameter of these vessels (CRUZ, 2000). Thus, it is likely that "amapá" wood has a satisfactory water outflow during the drying and penetration of chemical preservatives, due to the frequency of their vessels, which are not blocked by tyloses.

The fiber dimensions of "amapá" wood (Table 1) are in agreement with similar studies on this species. For example, Mainieri and Chimelo (1989) evaluated the length and fiber width with results of 1160 μm and 23 μm, respectively, for "amapá" wood. The difference between the values of Table 1 and those of Mainieri and Chimelo (1989) was expected, since the trees come from native forest, with different ages and sites.

A matrix of Pearson correlation was computed for the assessment of the relationship between the anatomical features and permeability of the wood (Table 2).

A weak correlation (0.545) was found between fiber width and liquid permeability (Table 2). The frequency of vessels per mm² in "amapá" wood does not influence the liquid permeability because of the low correlation (-0,083). In general, the correlations were low. The highest correlations between variables were found for: fiber width x liquid permeability, and air permeability x liquid permeability.

TABLE 2 Pearson correlation between anatomical characteristics and permeability of "amapá" wood (Probability of 5%).

TABELA 2 Correlação da matriz de Pearson para características anatômicas e permeabilidade da madeira de amapá (Probabilidade de 5%).

Features	FL	WT	FW	AP	LP	FV
AirPer	0.095	0.134	0.107	-	0.457	0.235
LiqPer	0.186	0.212	0.545	0.457	-	-0.083

FL: fiber length; WT: wall thickness; FW: fiber width; AP: air permeability; LP: liquid permeability; FV: frequency of vessels.

The comparison of correlations here obtained with other studies should be made carefully. The species, the sampling of the stem and the methodology used for the permeability test affects the results. Ahmed and Chun (2011) evaluated the penetration of the aqueous safranin, as a function of fiber length and vessel diameter, and found that the longitudinal length of the sample affected the flow of liquid, in wood of *Tectona grandis*. The methodology with safranine aqueous solution allows the observation of anatomical structures, with different colors in wood.

Permeability of wood

Air permeability

The value of longitudinal air permeability of "amapá" wood (Table 1) was higher than that found by Magalhães (2004) for *Pinus elliottii* Engelm var. *elliottii* wood, subjected to compression parallel to grain ($23.7 \cdot 10^{-9}$ $m^3 \cdot [m \cdot (N \cdot m^{-2}) \cdot s]^{-1}$). Also, Rice and Onofrio (1996) found longitudinal permeability for the timber of *Pinus strobus* equal to $22.5 \cdot 10^{-9}$ $m^3 \cdot [m \cdot (N \cdot m^{-2}) \cdot s]^{-1}$. However, Silva (2007), when studying the permeability of the heartwood of *Eucalyptus grandis*, obtained data around $30.6 \cdot 10^{-9}$ $m^3 \cdot [m \cdot (N \cdot m^{-2}) \cdot s]^{-1}$.

The values presented by the permeability of "amapá" wood are influenced by anatomical features, which is one factor that affects the permeability of the fluid in the timber. According to Comstock and Côté (1968) and Siau (1984), size, distribution, and number of conductor elements and mainly the presence and intensity of obstructions of these anatomical structures act differently in the different species.

Liquid permeability

The high value of the coefficient of variation (Table 1) of liquid permeability found in "amapá" wood, compared with air permeability, can be explained by the individual characteristics that were collected in a natural forest, which induces the formation of individuals more heterogeneous among themselves.

According to Silva (2007) this type of test has limitations on usage, and in this case, using distilled water, it will join the wood material quickly, drastically reducing the flow of liquid through the material. This occurs, according to Siau (1971, 1984), because wood is a hygroscopic material, with great affinity for water. This situation was observed during the execution of this work, which may also contribute to explain the low values of liquid permeability found for the species.

Another response on the low values of liquid permeability found in "amapá" wood was the elevated presence of extractives, which was 5.31%, that is, above the levels of extractives content for hardwood timber described by Browning (1963), ranging from 2% to 4%. The extractives are, according to Flynn (1995), Rice and Onofrio (1996), and Woo et al. (2005), natural barriers within the wood for liquid flow, especially in the heartwood. According to Wangaard and Granados (1967), the extractive can also be hygroscopic in nature, occurring as a reduction in the water flow. Possibly, the extractives present in "amapá" wood are hygroscopic in character. However, further studies are needed to confirm this hypothesis, since this is not part of this research.

CONCLUSION

The air permeability of "amapá" wood, in the longitudinal direction, was $63.7 \cdot 10^{-9}$ $m^3 \cdot [m \cdot (N \cdot m^{-2}) \cdot s]^{-1}$, while the liquid permeability was $2.07 \cdot 10^{-9}$ $m^3 \cdot [m \cdot (N \cdot m^{-2}) \cdot s]^{-1}$; the elevated extractives content can be in part responsible for the low liquid permeability; low levels of correlation between air permeability and fiber length (0.095), wall thickness (0.134) and fiber width (0.107) was found in "amapá" wood; low correlations between the liquid permeability and fiber length (0.186), wall thickness (0.212), fiber width (0.545) and vessel frequency (-0.083) was found in "amapá" wood.

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