Comparison between Resistograph Analysis with Physical Properties of the Wood of Brazilian Native Tree Species

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ABSTRACT

There is just little information about the technological aspects of the wood of Brazilian native tree species, which limits their suitable use. The objective of this study was to evaluate the resistograph amplitudes of the wood from six native tree species in different wood density classes, and correlate them with their wood densities to demonstrate the efficiency of this nondestructive technique. The results of the resistograph analysis divided the species into three classes. Analyses of basic and bulk densities of their wood showed statistically significant differences among the evaluated samples that divided them into four classes. The comparison of resistograph method and observed densities showed only a slight difference among the density classes. Therefore, it was found in this study that resistograph analysis may be used for explaining wood properties as well as achieving satisfactory correlations with their actual values, especially the physical properties of species with high wood density.

Keywords: nondestructive method, density, Brazilian species.

1. INTRODUCTION

A significant challenge facing modern societies is the need to become sustainable, in other words, regarding the needs and rational use of natural resources. Many natural resources have been continuously explored and exploited by our society over the years, including forests. In South America, the Brazilian Atlantic Forest biome merits special attention, as its associated ecosystems covering an area of 1.1 million km^2, approximately 13% of the Brazilian territory (Ribeiro et al., 2009), which is "home" to a significant portion of the world's biological diversity.

To achieve the rational use of natural resources by society, in particular forestry resources, it is necessary to invest in science and technology for discovering new marketable species, as well as strategies for their sustainable exploitation. The first step in this process is to determine the technological behavior of the wood of different tree species, which can help one to plan their potential uses. However, there is little information on the link between the scientific data and technological properties of the wood from Brazilian native tree species. Among these properties, the physical ones play a particularly important role because they determine the quality of the wood and its utilization in forestry activities.

Among wood parameters, density is an index of quality that is highly valued by researchers and forest improvers due to the proven heritability and ease of evaluation, which can help to determine the potential uses of woods (Wu et al., 2010). To evaluate this characteristic, several nondestructive methods, without causing harm to it or its potential use, have been developed and applied.

The resistograph is an ideal device for describing the variation in the radial profile of wood by drilling into it, which is related to its hardness and density (Kahl et al., 2009; Acuña et al., 2011; Chen & Guo, 2016). Specifically, the resistance of the wood to be drilled depends on its density.

The analysis performed by the resistograph equipment evaluates the resistance posed by the wood against a small diameter rod that enters at a certain drilling speed. A graph of the distance traveled inside the trunk by the amplitude of the resistance imposed on the drill rod is then generated, with this amplitude then being correlated with the density of the wood (Eckard et al., 2010; Acuña et al., 2011; Rinn, 2012; Couto et al., 2013). This resistance can also detect local internal defects, cracks and decay (Jasiénko et al., 2013; Tannert et al., 2014; Zhang et al., 2015).

In recent years, few studies have been carried out on the use of resistograph analysis as a tool to be correlated with wood density values, with the aim of determining potential uses for native tree species in Brazil. Thus, the objective of this study was to demonstrate the effectiveness of this nondestructive methodology (i.e. using the resistograph device) to explain the relationship between the technological behaviors of wood and its physical properties (i.e. density).

2. MATERIAL AND METHODS

2.1. Description of the study area

The research materials for this study came from one homogeneous experimental plantation, established for the purpose of timber production, located inside the Vale Natural Reserve in Linhares, Espírito Santo state, Brazil. This reserve is one of the few and most relevant remnant areas of the Brazilian Atlantic Forest biome, which is a little more than 21 thousand ha in size and important for the maintenance of wildlife (flora and fauna) and its conservation. The reserve contains homogeneous plantations of native tree species ranging from 17 to 31 years old and includes more than 100 native species of the Atlantic Forest, originating from seeds of the matrix reserve. After performing a census of the area, six species were chosen (Table 1) and these selected species have been expected to have distinct wood densities based on data classification found in the literature (IPT, 1985), two species with wood of low density; two species with wood of medium density; and two species with wood of high density.

According to this classification, the woods with density lower than 0.50 g/cm^3 are classified as low density, 0.50 to 0.72 g/cm^3 as medium density and woods with density upper to 0.72 g/cm^3 are classified as heavy density.

Ninety trees were selected for study, divided among these six species, with 15 trees used per species (Table 1). Three trees were harvested per species, and the first 2.1-m long log was taken from each tree. Thus,

Table 1. Basic density of the species analyzed in this study.

Species	Basic density (g/cm³)	Source
Joannesia princeps Vell.	0.40-0.55	Lorenzi (1992), Silva & Lemos (2002)
Spondias venulosa (Engl.) Engl.	0.36-0.56	Lorenzi (1992), Rolim & Piotto (2018)
Copaifera lucens Dwyer	0.67	Rolim & Piotto (2018)
Astronium concinnum (Engl.) Schott	0.64-0.68	Santos et al. (2011)
Handroanthus serratifolius (Vahl.) S. O. Grose	0.70-0.98	Shimamoto et al. (2014)
Libidibia ferrea var. *parvifolia* Benth	0.81	Rolim & Piotto (2018)

it could be observed that 15 trees were selected for the nondestructive tests, and of these three trees were felled to produce material for destructive analysis. The logs were seed to the sawmill at the forestry institute of the Federal Rural University of Rio de Janeiro (*Universidade Federal Rural do Rio de Janeiro* (UFRRJ)), to provide material for destructive analyses performed on the *Laboratório de Processamento de Madeira* (LPM/UFRRJ) to evaluate the physical properties of the wood.

2.2. Resistograph analysis

The resistograph analysis was carried out using 15 trees per species by following the instruction manual included in the apparatus. With the aid of a Global Positioning System (GPS), two drillings were carried out on each individual tree in the north-south and east-west directions. Hence, 30 resistograph analyses were performed per species, and 180 resistograph analyses in total.

The main variable examined in this study was the resistograph amplitude measurements (RA%), which could be defined as a number representing the difficulty for the drill rod to drill through the wood. The perforation was standardized at 10 cm for each individual, of which the bark was estimated to represent 10% in later analyses of the results. The software used for resistograph analysis was the program Decom version 2.34c.

2.3. Evaluation of physical properties

After the primary wood processing of each log into boards, the boards that had the best orientation of their anatomical elements were chosen. The samples to be used for the analysis of density were then prepared according to the NBR 7190 standards (ABNT, 1997), and six samples were selected per board, resulting in 18 specimens per species.

The method chosen for using in the determination of basic density and bulk density (at 12% moisture)

was the gravimetric method. All specimens were measured and weighed in the green, saturated and dry conditions. With these data, it was possible to calculate the values of the basic density (Equation 1) and bulk density (Equation 2) of the wood of each individual and species as follows:

$$\rho_b = \frac{m_s}{V_u} \qquad (1)$$

where ρ_b = basic density (g/cm³); m_s = dry weight of the sample at 103 ± 2 °C (g); and V_u = volume of the test sample in the saturated state (cm³); and

$$\rho_{blk} = \frac{m_{(12\%)}}{V_{(12\%)}} \qquad (2)$$

where ρ_{blk} = bulk density at 12% moisture (g/cm³); $m_{12\%}$ = weight of the sample at 12% moisture (g); e $V_{12\%}$ = volume of the test sample at 12% moisture (cm³).

2.4. Comparison between results of nondestructive and destructive analyses

The data obtained met the requirements of normality and homogeneity for parametric tests. Therefore, analysis of variance (ANOVA) was performed to compare the differences of densities among the different species.

Based on the results of the above analysis, the coefficient of determination (R^2) of the relationship between the results of the nondestructive and destructive analyses of the resistograph amplitude with the physical properties of the individuals was calculated using a linear regression. This was performed to test the effectiveness of this nondestructive methodology in explaining the technological behaviors of the wood.

3. RESULTS AND DISCUSSION

3.1. Resistograph amplitude analysis

In Figure 1, the relation of the resistograph behavior to the drilling length can be seen. The resistograph amplitudes of the species analyzed and the results

of the Tukey HSD test comparing the means among species are shown in Table 2. The results of the analysis of the resistograph amplitude allowed the species examined to be divided into three distinct classes. *Libidibia ferrea* var. *parvifolia* (Mart. ex Tul.) L. P. Queiroz showed a resistograph amplitude value that was much and significantly higher than that of the other species, and thus being in a higher density class when compared to them. *Handroanthus serratifolius* (Vahl) S. O. Grose, *Copaifera lucens* Dwyer and *Astronium concinnum* Schott ex Spreng. had the same density class. *Astronium concinnum* was placed in the lowest density class, along with *Spondias venulosa* (Engl.) Engl. and *Joannesia princeps* Vellozo.

The study concerning technological behaviors of wood using the resistograph device is relatively new, especially in Brazil, where only a few studies have been done over the last decade with wood from Brazilian trees (Table 3) to verify their potential use in various applications.

Comparing the results found in this study with those in the literature, it could be stated that the characteristic of the wood of Brazilian native trees matches its physical properties. Therefore, denser wood has higher resistograph amplitude, and in the same way, wood with lower density presents smaller resistograph amplitude.

3.2. Physical properties of wood

The results of the destructive evaluation of the physical properties (basic and bulk densities) of the wood of the six species studied are shown in Table 4.
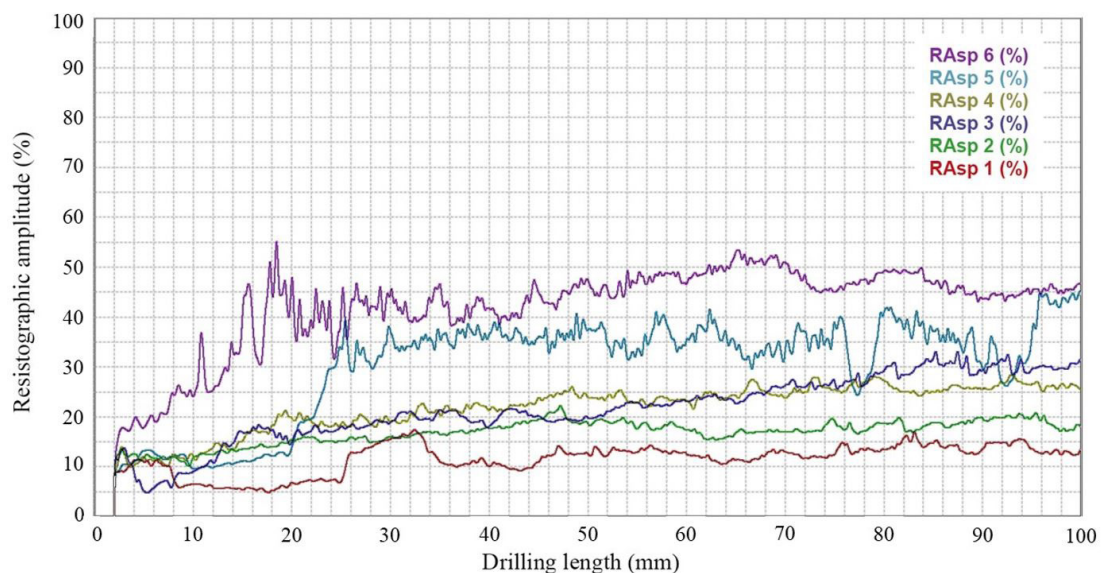
Figure 1. Graphic representation of the average technological characteristics of the woods of different species during resistograph drilling operation. RA = resistograph amplitude (%); sp. 1 = *Joannesia princeps* Vell.; sp. 2 = *Spondias venulosa* (Engl.) Engl.; sp. 3 = *Copaifera lucens* Dwyer; sp. 4 = *Astronium concinnum* (Engl.) Schott; sp. 5 = *Handroanthus serratifolius* (Vahl.) S. O. Grose; sp. 6 = *Libidibia ferrea* var. *parvifolia* Benth.

Table 2. Mean resistograph amplitude values of the analyzed species, listed in descending order.

Species	Resistograph amplitude (%)
Joannesia princeps Vell.	12.05 (± 1.8) c
Spondias venulosa (Engl.) Engl.	15.75 (± 2.9) c
Astronium concinnum (Engl.) Schott	17.87 (± 5.1) bc
Copaifera lucens Dwyer	21.33 (± 2.1) b
Handroanthus serratifolius (Vahl.) S. O. Grose	22.37 (± 1.2) b
Libidibia ferrea var. *parvifolia* Benth.	31.92 (± 1.9) a

Values in parentheses indicate the coefficient of variation for each mean; means with the same letter (a, b, c) were not significantly different statistically between species at a significance level of 5%.

Normality tests were performed on the data, and significant differences among the means for different species were found using Tukey's test (Table 4).

The results obtained can be interpreted as implying the existence of four distinct density classes for both basic and bulk densities. The highest density class included the species *L. ferrea* and *H. serratifolius*. These values reaffirm that these species present basic and bulk densities that can be considered high (heavy), as they were previously listed in the classification of Instituto de Pesquisas Tecnológicas (IPT, 1985).

The second class comprised the species *A. concinnum*, indicating that it had values of basic density considered medium, and bulk density considered high (heavy). The third class included *C. lucens*, which presented values of basic and bulk densities that characterize it as a species of medium wood density.

The fourth and last class included the species *S. venulosa* and *J. princeps*, which both presented values

of basic and bulk densities that characterize them as having wood of low density.

3.3. Comparison of the resistograph amplitudes with the density values

Table 5 shows the observed correlations between the results of the resistograph analysis and the densities (basic and bulk) of each species. The resistograph amplitude and basic density of all species were significant correlated. The species with higher density values showed stronger correlations between their resistograph amplitudes and both basic and bulk densities, with particularly high R^2 values found between their resistograph amplitudes and basic densities. This fact was highlighted by the high R^2 values found for the species *L. ferrea* (0.98), *H. serratifolius* (0.98) and *A. concinnum* (0.97).

The species *J. princeps* (0.62) and *S. venulosa* (0.62) presented more satisfactory R^2 values when the

Table 3. Resistograph amplitude values of the wood of Brazilian trees found in the literature.

Species	Resistograph Amplitude (%)	Source
Clones of *Eucalyptus*	10.1-20.9	Gouvêa et al. (2011)
Cedrela fissilis Vell.	10.6	Silva et al. (2017)
Eucalyptus grandis	11.77	Couto et al. (2013)
Eucalyptus urophylla	12.99	Couto et al. (2013)
Hybrid clones of *Eucalyptus*	15.2	Dias et al. (2017)
Clones of *Eucalyptus*	23.9	Oliveira et al. (2011)

Table 4. Values of the basic (ρ_b) and bulk (ρ_{blk}) densities (at 12% moisture) of the wood of the species studied, listed in descending order.

Species	ρ_b (g/cm³)	ρ_{blk} (g/cm³)
Joannesia princeps Vell.	0.32 ± 0.02 d	0.41 ± 0.03 d
Spondias venulosa (Engl.) Engl.	0.34 ± 0.03 d	0.44 ± 0.03 d
Copaifera lucens Dwyer	0.55 ± 0.03 c	0.67 ± 0.04 c
Astronium concinnum (Engl.) Schott	0.64 ± 0.006 b	0.84 ± 0.07 b
Handroanthus serratifolius (Vahl.) S. O. Grose	0.80 ± 0.02 a	1.03 ± 0.01 a
Libidibia ferrea var. *parvifolia* Benth.	0.81 ± 0.02 a	1.08 ± 0.07 a

Means followed by the same letter did not significantly differ statistically at a significant level of 5%.

Table 5. Correlation of resistograph amplitude (RA) consisting of values of basic (ρ_b) and bulk densities (ρ_{blk}). Values in the table are the R^2 values of comparisons between RA and density.

Species	RA*ρ_b	RA*ρ_{blk}
Copaifera lucens Dwyer	0.55	0.70
Spondias venulosa (Engl.) Engl.	0.62	0.68
Joannesia princeps Vell.	0.62	0.32
Astronium concinnum (Engl.) Schott	0.97	0.80
Handroanthus serratifolius (Vahl.) S. O. Grose	0.98	0.71
Libidibia ferrea var. *parvifolia* Benth.	0.98	0.80

resistograph amplitude was compared with the basic density variable than did *C. lucens* (0.55).

It is important to mention that the species with lower values of basic density (*S. venulosa* and *J. princeps*) presented moisture contents of approximately 20%, while medium density species (*C. lucens* and *A. concinnum*) had an average value of 18.3%, and the heavy density species (*H. serratifolius* and *L. ferrea*) 16.3%. According to the work of Logsdon & Calil (2002), Kretschmann (2008) and Glass & Zelinka (2010), the physical and mechanical properties depend on the moisture content of the wood, being wood resistance tends to decrease when this content is high. However, the *C. lucens* wood was the only species that presented different characteristic according to this analysis, because even presenting a medium moisture content compared to the others, this species showed lower correlation with the basic density.

When analyzing the correlation between the resistograph amplitude and the bulk density (at 12% moisture), stronger correlations (higher R^2 values, explaining how well a regression line fits the data) were found for the species *L. ferrea* (0.80) and *A. concinnum* (0.80), followed by *H. serratifolius* (0.71), *C. lucens* (0.70), and *S. venulosa* (0.68), while *J. princeps* (0.32) had the weakest correlation between these variables.

Few previous studies have evaluated the correlation of the resistograph amplitude of wood with the actual wood density, and in the majority of cases such studies compared the RA% only with the basic density of the species, and were done on exotic species. Working with *Eucalyptus*, Gouvêa et al. (2011) found R^2 values ranging from 0.19 to 0.74. By researching native species, Carrasco et al. (2013) found the R^2 value equal to 0.86 between the RA% and the bulk density, and Silva et al. (2017) found the R^2 value equal to 0.55 for *Cedrela fissilis* Vellozo when evaluating the relationship between its RA% and basic density. Through this study, it was verified that there are still few studies that have used the resistograph method to analyze the physical properties of wood, with most of them being applied to the *Eucalyptus* genus and in essence, finding weak correlations.

4. CONCLUSIONS

The results of this study indicated that a nondestructive methodology using resistograph analysis may be used to estimate the potential uses of wood based on its density, as it could explain the technological behaviors of wood by achieving strong correlations with the wood's physical properties, more precisely those in species with higher wood density. Although the use of resistograph technology is recommended to assess the wood characteristics of live trees, more studies are necessary to optimize the use of this nondestructive technique with the aim of predicting wood density and suggesting potential technological uses for it.

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