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

Carlos Eduardo Silveira da Silva¹, José Henrique Camargo Pace¹, Fernando José Borges Gomes¹, Paulo César Leal de Carvalho¹, Claudia de Azevedo Reis¹, João Vicente de Figueiredo Latorraca¹, Samir Gonçalves Rolim², Alexandre Monteiro de Carvalho¹

¹Universidade Federal Rural do Rio de Janeiro – UFRRJ, Seropédica/RJ, Brasil
²Symbiosis Investimentos, Porto Seguro/BA, Brasil

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,
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 sent 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:

\[
\rho_b = \frac{m_s}{V_u}\]  

where \(\rho_b\) = basic density (g/cm\(^3\)); \(m_s\) = dry weight of the sample at 103 ± 2 °C (g); and \(V_u\) = volume of the test sample in the saturated state (cm\(^3\)); and

\[
\rho_{blk} = \frac{m_{12\%}}{V_{12\%}}\]  

where \(\rho_{blk}\) = bulk density at 12% moisture (g/cm\(^3\)); \(m_{12\%}\) = weight of the sample at 12% moisture (g); and \(V_{12\%}\) = volume of the test sample at 12% moisture (cm\(^3\)).

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

---

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

| Species                        | Basic density (g/cm\(^3\)) | 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)                       |
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.

#### 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) b        |
| *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 ($\rho_b$) and bulk ($\rho_{blk}$) densities (at 12% moisture) of the wood of the species studied, listed in descending order.

| Species                              | $\rho_b$ (g/cm$^3$) | $\rho_{blk}$ (g/cm$^3$) |
|--------------------------------------|---------------------|-------------------------|
| *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 ($\rho_b$) and bulk densities ($\rho_{blk}$). Values in the table are the $R^2$ values of comparisons between RA and density.

| Species                              | $RA^*\rho_b$ | $RA^*\rho_{blk}$ |
|--------------------------------------|--------------|------------------|
| *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.

ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) Brasil – Finance Code 001

SUBMISSION STATUS

Received: 27 mar., 2019
Accepted: 27 nov., 2019

CORRESPONDENCE TO

Carlos Eduardo Silveira da Silva
Departamento de Produtos Florestais, Universidade Federal Rural do Rio de Janeiro – UFRJRodovia BR 465, Km 07, CEP 23890-000, Seropédica, RJ, Brasil
e-mail: c.eduardo_silveira@yahoo.com.br

FINANCIAL SUPPORT

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

REFERENCES

Acuña L, Basterra LA, Casado MM, López G, Ramón-Cueto G, Relea E, et al. Application of resistograph to obtain the density and to differentiate wood species. *Materiales de Construcción* 2011; 61(303): 451-464.

Associação Brasileira de Normas Técnicas – ABNT. NBR 7190:1997: Projetos de Estruturas de Madeira. Rio de Janeiro: ABNT; 1997.

Carrasco EVM, Pereira NCS, Alves RC. Estimativa da densidade aparente, resistência à compressão e módulo de elasticidade da madeira por meio do resistógrafo. *Revista Construindo* 2013; 5(1): 45-51.
Chen Y, Guo W. Mechanical properties evaluation of two wood species of ancient timber structure with nondestructive testing methods. BioResources 2016; 11(3): 6600-6612. http://dx.doi.org/10.15376/biores.11.3.6600-6612.

Couto AM, Trugilho PF, Neves TA, Protásio TP, Sá VA. Modeling of Basic Density of wood from Eucalyptus grandis and Eucalyptus urophylla using nondestructive methods. Revista Ceres 2013; 19(1): 27-34.

Dias DC, Colodette JL, Thiersch CR, Leite HG, Gomide JL. Uso da técnica de resistografia e de variáveis dendrométricas na modelagem da densidade básica de povoamentos clonais de Eucalyptus. Revista Ciência Florestal 2017; 27(2): 609-619. http://dx.doi.org/10.5902/1980509827746.

Eckard J, Isik F, Bullock B, Li B, Gumpertz M. Selection efficiency for solid wood traits in Pinus taeda using time-of-flight acoustic and micro-drill resistance methods. Forest Science 2010; 56(3): 233-241.

Glass SV, Zelinka SL. Moisture relations and physical properties of wood. In: Glass SV, Zelinka SL. Wood handbook: wood as an engineering material. Madison: U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory; 2010.

Gouvêa AFG, Trugilho PF, Gomide JL, Silva JRM, Andrade CR, Alves ICN. Determinação da densidade básica da madeira de Eucalyptus por diferentes métodos não destrutivos. Revista Árvore 2011; 35(2): 349-358. http://dx.doi.org/10.1590/S0100-67622011000200019.

Instituto de Pesquisas Tecnológicas – IPT. Madeira: o que é e como pode ser processada e utilizada. São Paulo: IPT; 1985. p. 1-189. (Boletim ABPM: no. 36).

Jasiénko J, Nowak T, Hamrol K. Selected methods of diagnosis of historic timber structures - principles and possibilities of assessment-. Advanced Materials Research 2013; 778: 225-232. http://dx.doi.org/10.4028/www.scientific.net/AMR.778.225.

Kahl T, Wirth C, Mund M, Böhnsch G, Schulze E-D. Using drill resistance to quantify the density in coarse woody debris of Norway spruce. European Journal of Forest Research 2009; 128(5): 467-473. http://dx.doi.org/10.1007/s10342-009-0294-2.

Kretschmann DE. The influence of juvenile wood content on shear parallel, compression, and tension perpendicular to grain strength and mode I fracture toughness of loblolly pine at various ring orientation. Forest Products Journal 2008; 58(7/8): 89-96.

Logsdon NB, Calil C Jr. Influência da umidade nas propriedades de resistência e rigidez da madeira. Cadernos de Engenharia de Estruturas 2002; 18: 77-107.

Lorenzi H. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Vol. 1. Nova Odessa: Editora Plantarum Ltda; 1992. 368 p.

Oliveira BRU, Latorraca JVF, Tomazello M Fo, Palermo GPM, Carvalho AM, Pastro MS. Microdensitometria de raios X aplicada na determinação da variação da densidade do lenho de árvores de Eucalyptus grandis W. Hill. Revista Scientia Forestalis 2011; 40(93): 103-112.

Ribeiro MC, Metzger JP, Martensen AC, Ponzoni FJ, Hirota MM. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. Biological Conservation 2009; 142(6): 1141-1153. http://dx.doi.org/10.1016/j.biocon.2009.02.021.

Rinn F. Basics of micro-resistance drilling for timber inspection. Holztechnologie 2012; 53(3): 24-29.

Rolim SG, Piotto D. Silvicultura e tecnologia de espécies da mata atlântica. Belo Horizonte: Editora Rona; 2018. 160 p.

Santos CM, Lima IL, Longui EL, Remeiro D, Zanatto ACS, Morais E, et al. A densidade básica e características anatômicas variam radialmente na madeira de Astronium graveolens Jacq. (Anacardiaceae). Revista do Instituto Florestal 2011; 23(2): 191-201.

Shimamoto CY, Botosso PC, Marques CM. How much carbon is sequestered during the restoration of tropical forests? estimates from tree species in the Brazilian Atlantic Forest. Forest Ecology and Management 2014; 329: 1-9. http://dx.doi.org/10.1016/j.foreco.2014.06.002.

Silva CESS, Xavier CN, Santos PV, Carvalho AM, Latorraca JVF, Brancalion PHS. Estimativa da densidade da madeira em árvores vivas de Cedrela fissilis Vell. através de resistografia. Revista Scientia Forestalis 2017; 45(113): 139-144. http://dx.doi.org/10.18671/scifior.v45n113.13.

Silva DB, Lemos BS. Plantas da área verde da Super Quadra. Brasília: Embrapa Recursos Genéticos e Biotecnologia; 2002. 147 p.

Tannert T, Anthony R, Kasal B, Kloiber M, Piazza M, Riggio M, et al. In situ assessment of structural timber using semi-destructive techniques. Materials and Structures 2014; 47(5): 767-785. http://dx.doi.org/10.1016/s11527-013-0094-5.

Wu S-J, Xu J-M, Li G-Y, Risto V, Lu Z, Li B, et al. Use of the pilodyn for assessing wood properties in standing trees of Eucalyptus Clones. Journal of Forestry Research 2010; 21(1): 68-72. http://dx.doi.org/10.11676/s11527-010-0011-5.

Zhang J, Xu QF, Xu YX, Zhang M. Research on residual bending capacities of used wood members based on the correlation between non-destructive testing results and the mechanical properties of wood. Journal of Zhejiang University - Science A (Applied Physics & Engineering) 2015; 16(7):541-550.