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MEAN ANNUAL INCREMENT, WOOD DENSITY AND VESSEL DIAMETER OF 42-YEAR-OLD *Balfourodendron riedellianum* AND *Peltophorum dubium* IN A HETEROGENEOUS PLANTING[1]

INCREMENTO MÉDIO ANUAL, DENSIDADE DA MADEIRA E DIÂMETRO DOS VASOS DE *Balfourodendron riedellianum* E *Peltophorum dubium* EM PLANTIO HETEROGÊNEO COM 42 ANOS DE IDADE[1]

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ABSTRACT – The knowledge of wood from potentially producing species is desirable to propose the expansion of such product through plantations, thereby avoiding the illegal exploitation of wood in native forests. To this end, we evaluated mean annual increment, wood density and vessel diameter of *Balfourodendron riedelianum* and *Peltophorum dubium* in a heterogeneous planting at 42 years of age. We selected these species because they belong to different successional groups; *B. riedelianum* is late secondary and *P. dubium* is a pioneer species. We aimed to determine and then compare growth characteristics and to relate them to wood density and vessel diameter. *P. dubium* presented a higher mean annual increment compared to *B. riedelianum*, and this difference was directly related to successional group. These differences were also related to structural variations, in which *B. riedelianum* presented smaller vessel diameter compared to *P. dubium*, as well as denser wood, either by the slower growth, the consensus line of reasoning, or, alternatively, climax and high longevity species tend to have denser wood, while pioneer species have lower density when compared to other successional groups. For timber producers requiring high productivity with a faster cycle, *P. dubium* is the indicated species. On the other hand, if a producer prefers denser and more strength wood, albeit with slower cycle, then *B. riedelianum* is indicated. It was revealed that species can be planted together, allowing a longer cycle with the wood supply in different periods and with different characteristics.

Keywords: canafístula; pau-marfim; native planting; wood volume.

RESUMO - O conhecimento da madeira de espécies potencialmente produtoras é desejável para propor a ampliação da oferta deste produto em forma de plantios a fim de evitar a sua exploração ilegal de madeira de florestas nativas. Avaliamos o incremento médio anual, densidade e diâmetro dos vasos da madeira de *Balfourodendron riedelianum* e *Peltophorum dubium* em um plantio heterogêneo aos 42 anos de idade. Selecionamos essas espécies por pertencerem a diferentes grupos sucessionais, sendo *B. riedelianum,* uma secundária tardia e *P. dubium,* uma pioneira. Objetivamos determinar e comparar características de crescimento e relacioná-las com a densidade e diâmetro dos vasos da madeira. Nossos resultados demostram que *P. dubium* apresentou maior incremento médio anual do que *B. riedelianum*, sendo essa diferença relacionada diretamente ao grupo sucessional. Adicionalmente tais diferenças estão relacionadas às variações estruturais, com vasos de menor diâmetro em *B. riedelianum* comparada a *P. dubium*, e madeira mais densa em *B. riedelianum*, quer seja pelo crescimento mais lento, linha de raciocínio mais empregada atualmente ou por uma proposta alternativa, em que espécies climácicas ou longevas tendem a apresentar madeira mais densa, enquanto que espécies pioneiras possuem madeira mais leve comparada à outros grupos sucessionais. Se um produtor madeireiro deseja maior produtividade, com ciclo mais rápido a espécie indicada seria *P. dubium*, enquanto que se a escolha for por madeira mais densa e resistente, embora com ciclo mais longo a indicação é *B. riedelianum*. Ressaltamos que as espécies podem ser plantadas juntas permitindo um ciclo mais longo com a obtenção de madeiras em diferentes períodos e com características distintas.

Palavras-chave: canafístula; pau-marfim; plantio de nativas; volume de madeira.

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1 INTRODUCTION

Although laws authorizing logging in certain areas, illegal logging in Brazil and in several Amazonian countries is common. The illegal logging occurs in different forest areas and for various aspects, e.g., false licenses, exploitation of any commercially valuable tree, regardless of which trees are protected by law, cut in quantities greater than the quotas allowed by law, cut outside areas of forest concession and cutting within conservation units and indigenous lands (WWF, 2018).

Armed with knowledge of wood from potentially producing species, it is possible to propose the expansion of such product through plantations in the state of São Paulo, thereby avoiding the illegal exploitation of wood in native forests. Rational cultivation of timber species can contribute to combating illegal wood trade from other states, as well. According to Zenid et al. (2009), in past decades, the largest wood supply used in São Paulo came from the Amazon Forest, but without proper vigilance of exploitation and without compliance with current legislation. Although studies in commercial plantations are more developed and suitable for reforestation, studies with native species are essential. Thus data about growth, as well as wood properties and structure, are essential for selection of profitable species from the point of view of producers.

Mean Annual Increment - MAI is a fundamental factor impacting the choice of species. According to Blanchez (2010), MAI is the volume of wood produced in one hectare of forest during a year. To calculate the increment of a tree plantation, the total volume is divided by forest age. Other essential data are gained from knowledge about wood quality, in particular, density, which is defined as the ratio of mass to volume (Glass and Zelinka, 2010). Density is used to estimate mechanical properties (Hoadley, 2000). Additionally, it is anatomical structure that determines wood properties. Thus, between wood cells, vessels are responsible for conducting water, and several studies have reported vessel plasticity in adapting to climatic conditions (McElrone et al., 2004; Meinzer et al., 2010; Fan et al., 2012), especially precipitation and soil water retention capacity. Furthermore, vessel dimensions directly affect wood density since vessel lumen represents empty spaces that do not contribute to mass and, consequently, to wood density.

To study the aforementioned characteristics and especially for genetic conservation, the Forestry Institute of São Paulo State has been promoting studies with several species with economic potential for decades, performing provenance experiments, progeny tests, provenance x progeny tests, base population and seed collection areas for ex situ conservation and production of seedlings of several species (Gurgel-Garrido, 1997).

Between the studied species over the years, we highlight *Balfourodendron riedelianum* Engl. - Rutaceae (pau marfim) and *Peltophorum dubium* (Spreng.) - Taub. - Fabaceae (canafistula). *B. riedelianum*, popularly known as pau marfim or guatambú, is a native, nonendemic species of Brazil with geographical distribution in midwestern, southeastern and southern Brazil, as well as the Cerrado and Atlantic Forest (Pirani et al., 2017). *P. dubium* is also a native species, not endemic to Brazil, with geographical distribution in northeastern, midwestern, southeastern and southern Brazil, as well as the Caatinga, Cerrado, Atlantic Forest and Pantanal (Silva et al., 2017).

According to Lorenzi (2002), both species are used for ornamental purposes and landscaping projects. Although the use of these woods has diminished because of the greater availability of Amazonian woods, they have historically been used over time for many applications. *B. riedelianum* wood presents excellent quality, and as such, it is used in civil construction, woodworking, furniture making, decorative laminates, wooden blocks and wainscoting (Mainieri and Chimelo, 1989). The species is also used in reforestation of riparian forests (Durigan et al., 2002). *P. dubium* produces high-value, economical wood used, for instance, in civil construction for beams, rafters, windows, door frames, floors, ceilings, railway sleepers, as well as furniture making, naval and military construction, and woodworking (Reitz et al., 1978; Carvalho, 2003).

The present study evaluated mean annual increment, wood density and vessel diameter of two timber species of interest, *Balfourodendron riedelianum* and *Peltophorum dubium*, in a heterogeneous planting at 42 years of age. Our objective was to determine and compare growth characteristics and to correlate them with wood density (physical property) and vessel diameter (anatomical feature) since these variables are related to mechanical strength (density) and hydraulic conductivity (vessel diameter). Because

B. riedelianum and *P. dubium* are important for logging purposes, it is essential to establish tree growth information, as well as wood properties and characteristics that increase the knowledge of these native species and contribute to planting decisions and correct use. Accordingly, in this study, some tree growth characteristics and their potential effect on wood density and vessel diameter are evaluated. We selected these species because they belong to different successional groups; *B. riedelianum* is late secondary (Durigan and Nogueira, 1990), and *P. dubium* is a pioneer species (Lorenzi, 2002). Thus, we sought to interpret growth (MAI), wood density values and vessel diameter in species classified into different successional groups

2 MATERIAL AND METHODS

2.1 Selection of species and planting

Seeds were collected in the state of São Paulo, Brazil, between May and July 1974. Although no exact collection sites were recorded, trees were selected from phenotypic characteristics of interest, such as vitality, form and health. Seedlings of five species (*Balfourodendron riedelianum*, *Cariniana legalis, Centrolobium tomentosum, Handroanthus vellosoi and Peltophorum dubium*) were produced and seeded in heterogeneous planting at the Luiz Antônio Experimental Station - LA (Cerrado), Luiz Antônio City, São Paulo (21°32′S, 47°42′W, elevation 648 m) (Figure 1).

The plantation was established in 1975 at a spacing of 3 × 2 m. The experimental design consisted of randomized blocks 5 x 6 (5 treatments x 6 blocks) in plots of 15 m x 18 m with 60 plants per plot and two borders (Figure 2). The planting was established to study the competition during tree growth, and these species were chosen because of their economic value for São Paulo State within the scope of forest studies in the experimental period (Gurgel Filho et al., 1974).

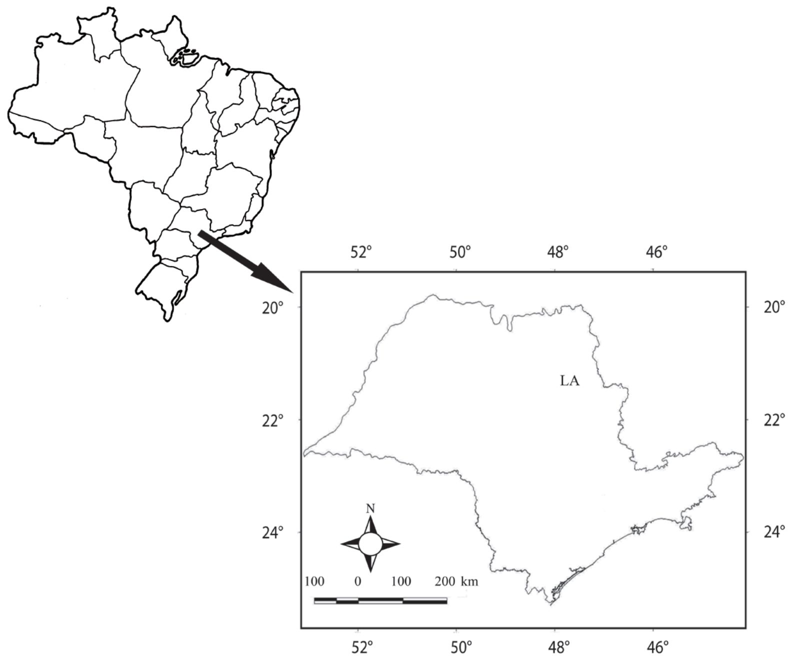

Figure 1. Location of the planting site in the Luiz Antônio Experimental Station- LA.

Figura 1. Localização da área de instalação do plantio na Estação Experimental de Luiz Antônio- LA.

Figure 2. Photographs of studied species. a. Overview of heterogeneous planting in the Luiz Antônio Experimental Station, b. *Balfourodendron riedelianum*, c. *Peltophorum dubium*.

Figura 2. Fotografias das espécies estudadas. a. Visão geral do plantio heterogêneo na Estação Experimental de Luiz Antônio, b. *Balfourodendron riedelianum*, c. *Peltophorum dubium*.

2.2 Mean Annual Increment (MAI)

All trees planted for both species, 158 from *Balfourodendron riedelianum* and 79 from *Peltophorum dubium*, were measured with a caliper, and height was measured with a Vertex IV hypsometer (Pacforest Supply Co., Springfield, OR). From DBH (diameter at breast height, 1.3 m from the ground) and height values, tree volumes were calculated based on the formula proposed by Higuchi (1978) who developed volumetric equations for commercial volume measurement for some Brazilian native species, including *B. riedelianum* and *P. dubium*. The equation used for *B. riedelianum* was Volume = 0.063 + 0.255 * Diameter * Height (Eq. 1), and for *P. dubium*, the equation used was Volume = 0.210 + 0.259 * Diameter * Height (Eq. 2). Then, the volume per hectare was calculated according to the spacing (3 x 2 m) by multiplying the number of plants by the average tree volume, and, finally, the volume per hectare per year was calculated by dividing volume per hectare by age of planting (42 years, 1975-2017).

2.3 Wood density and vessel diameter

Six 42-year-old trees were collected from an exploratory forest inventory. Tree height and diameter at breast height (DBH, 1.3 m from the ground) are shown in Table 1. From each tree, DBH discs were removed, and three equidistant samples close to the bark were cut from each disc.

This methodology produced 18 samples of each species and 36 samples in total for wood density and vessel diameter determination.

Table 1. Dendrometric data of six 42-year-old *Balfourodendron riedelianum* and *Peltophorum dubium* trees used to wood density and vessel diameter determination.

Tabela 1. Informações dendrométricas das seis árvores de *Balfourodendron riedelianum* e *Peltophorum dubium* aos 42 anos de idade usadas para a determinação da densidade da madeira e diâmetro dos vasos.

	Balfourodendron riedelianum		***Peltophorum dubium***	
Tree	Height (m)	DBH (cm)	Height (m)	DBH (cm)
1	18.4	16.8	15.0	22.3
2	18.9	17.4	19.5	26.8
3	16.9	15.1	16.4	23.7
4	19.6	18.2	12.9	20.2
5	20.4	19.2	14.9	22.2
6	17.0	15.2	16.1	23.4
mean	18.5	16.9	15.8	23.1

Wood density ($\rho 12$) was determined according to Glass and Zelinka (2010), evaluating the mass and volume at 12% Moisture Content - MC. Specimens of 3 x 2 x 2 cm were conditioned at constant temperature and MC (21°C and 65% MC, respectively), and under these conditions, mass was determined with an analytical balance. The volume was estimated with a caliper rule used to measure their dimensions.

For vessel diameter determination, wood pieces were boiled for 60 min in water: glycerin: alcohol (4:1:1) to soften the wood. Transverse sections 20 µm in thickness were cut using a sledge microtome. They were stained with a 1% aqueous solution of safranin and subsequently washed with water and mounted in water and glycerin (1:1) solution on slides (Johansen, 1940). The terminology followed the IAWA list (IAWA Committee, 1989). All vessel measurements were obtained using an Olympus CX 31microscope equipped with a digital camera (Olympus Evolt E 330) and image analyzer software (Image-Pro Plus 6.3).

2.4 Data analysis

We initially undertook descriptive statistical analysis and used Box Plot graphics to detect outliers. Thus, values 1.5 times higher than the 3rd quartile and values 1.5 times lower than the 1st quartile were excluded from the analysis. Normality tests were performed to check the distribution of data, and when a normal distribution was not observed, data were square root-transformed. Then, the t test was used to identify pairs of significantly different means.

3 RESULTS AND DISCUSSION

Tree height did not differ between the two species, but DBH and volume per tree were statistically higher in *P. dubium*. The volume per hectare and MAI also showed higher values for P. dubium compared to *B. riedelianum* (Table 2).

Table 2. Silvicultural data and mean annual increment of 42-year-old *Balfourodendron riedelianum* and *Peltophorum dubium.*

Tabela 2. Dados silviculturais e incremento médio anual de *Balfourodendron riedelianum* e *Peltophorum dubium* com 42 anos de idade.

	Balfourodendron riedelianum	*Peltophorum dubium*
Height (m)	5 (21.5a) 36	8 (20.5a) 36
DBH (cm)	6 (20.5b) 50	11 (27.9a) 52
Volume per tree (m^3)	0.09 (0.46b) 2.01	0.24 (0.76a) 2.63
Volume per hectare (m^3.ha-1)	769.36	1264.10
Mean annual increment (m^3.ha-1.year-1)	18.31	30/09/19

Minimum (mean) and maximum values for DBH, height and tree volume are presented. In the same row, distinct letters differ statistically ($P < 0.05$) by t test.

Valores mínimos (médios) e máximos para o DAP, altura e volume por árvore. Na mesma linha, letras distintas diferem estatisticamente ($P < 0,05$) pelo teste t.

Comparing other studies on mean annual increment, Gurgel Filho et al. (1982a, 1982b) reported a growth of 12 m^3.ha-1.year-1 for *B. riedelianum* and 14 m^3.ha-1.year-1 for *P. dubium* in a 26-year-old planting in the municipality of Santa Rita do Passa Quatro, state of São Paulo (no spacing information). Assad (2017) reported 6.90 m^3.ha-1.year-1 for *B. riedelianum* at 30 years (spacing of 3 x 3 m), while Galão (2017) reported 13.77 m^3.ha-1.year-1 for *P. dubium* at 32 years (spacing of 3 x 2 m), both in homogeneous plantations in Luiz Antônio, study site of the present report. Our values were 18.31 m^3.ha-1.year-1 for *B. riedelianum* and 30.09 m^3.ha-1.year-1 for *P. dubium* at 42 years. It should be noted the climatic and soil characteristics differ between Luiz Antônio and Santa Rita do Passa Quatro. Therefore, when compared to the data from Gurgel Filho et al. (1982a, 1982b), it is not surprising that our growth rate results would be quite different between the two species, especially given the 16-year difference in age between the two plantations. Thus, in *B. riedelianum*, we see a difference of about 2 m^3.ha-1.year-1 between our study and that of Gurgel Filho et al. (1982a, 1982b), whereas for *P. dubium*, the difference is twice. Compared with the data from Assad (2017) and Galão (2017), the values of the present study are higher. However, in fairly comparing this difference, some other factors must be considered, including age difference, which is higher in the present study, and spacing, which is lower in this study compared to that of Assad (2017) for *B. riedelianum*. Not much growth knowledge has accumulated for native species; therefore, in the present study, we used *Eucalyptus* data, for which smaller spacings are associated with higher volume production per hectare (EMBRAPA, 2018). Also, in the present study, trees grew in a heterogeneous planting. This is different from Assad (2017) and Galão (2017) whose data came from homogeneous plantations, again noting that *B. riedelianum* is late secondary and *P. dubium* is a pioneer species.

Such comparisons are important as the commercial interest of producers vary, and, of course, producers choose wood based on suitability for specific uses. According to Rossi et al. (2003), if wood volume per tree can be estimated, then the productivity of that plant population can be predicted. Compared to other tropical species, *B. riedelianum* and *P. dubium* are within the standards presented by Webb et al. (1984) and Wadsworth (1997), who noted that the productivity of tropical forests of short to medium rotation has a wide gradient ranging from 1-2 m^3 ha-1 year-1 to 25-30 m^3 ha-1 year-1. Thus, *P dubium* would be at the limit of this proposed gradient.

Balfourodendron riedelianum wood is denser and with smaller vessel diameter when compared to *P. dubium wood* (Figure 3).

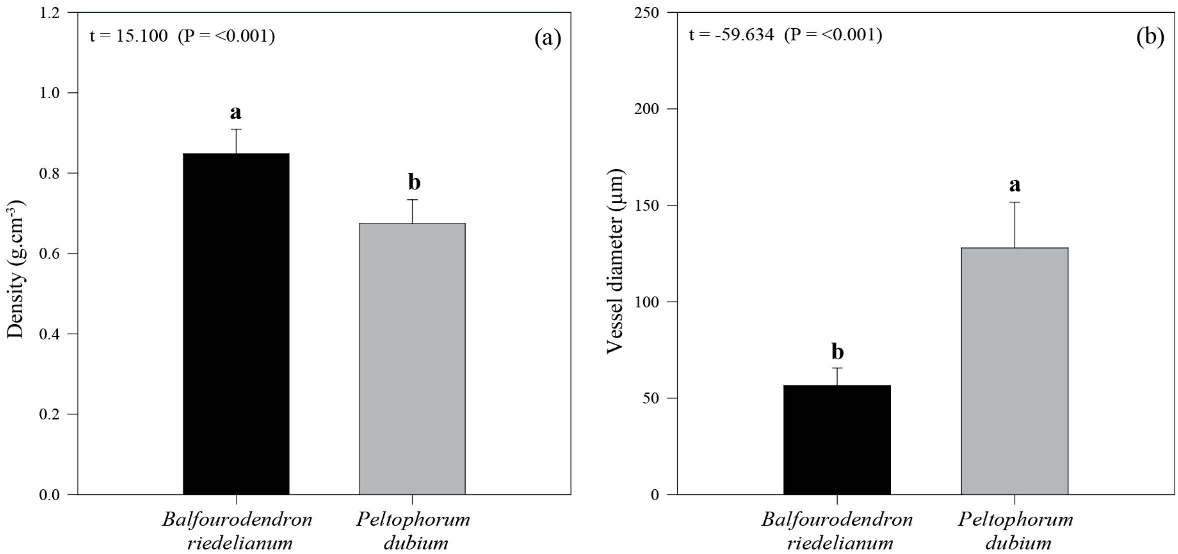

Figure 3. Variations of wood density (a) and vessel diameter (b) in *Balfourodendron riedelianum* and *Peltophorum dubium.*

Figura 3. Variações da densidade da madeira (a) e diâmetro dos vasos (b) em *Balfourodendron riedelianum* e *Peltophorum dubium.*

Variation in MAI between the two species should be attributed to the successional group. That is, since *P. dubium* is a pioneer species, it presents higher initial growth compared to *B. riedelianum*, a secondary species that grows more slowly and therefore presents higher density. In general, Muller-Landau (2004) reports that climax and high longevity species tend to have denser wood, while pioneer species have lower density when compared to other successional groups. In accordance with today's accepted consensus, Larjavaara and Muller-Landau, 2010); explain that wood density results from a compensation between resistance and cell construction economy. Thus, higher density gives greater strength, but at a higher construction cost. However, fiber length and wall thickness increase as the trunk increases radially (Larjavaara and Muller-Landau, 2010); therefore, a larger diameter trunk with low density wood can achieve greater strength with lower construction costs, as the cells grow faster, and less incorporation is observed in cell walls when compared to a thinner trunk with high density wood.

However, a newer approach proposed by Larjavaara and Muller-Landau (2010) holds that the advantage of high density is related to lower maintenance costs in terms of respiration, essentially because thinner trunks would have smaller surfaces with fewer parenchyma cells, i.e., live cells that breathe, unlike vessels and fibers that no longer have protoplasm in the adult tree and respectively perform the functions of water transport and mechanical support of the plant. According to Larjavaara and Muller-Landau (2010), such advantage would be important to tree species in the long term, which partly explains why they have denser wood than the pioneer species.

In addition, larger vessels of *P. dubium* confer a greater potential hydraulic conductivity compared to *B. riedelianum* with vessels of smaller diameter. Larger vessels are more efficient in water transport when compared to narrower vessels (Hacke et al., 2005). Although photosynthesis rate is also related to physiological processes and structural characteristics of leaves, differences in vessel diameters potentially lead to greater hydraulic conductivity efficiency and may interfere with the photosynthetic rate, causing *P. dubium* to show higher volume per tree than *B. riedelianum*.

4 CONCLUSIONS

Overall, our results show that *Peltophorum dubium* presents a higher mean annual increment when compared to *Balfourodendron riedelianum* and we assume that this difference is directly related to the successional group of each species, pioneer for *P. dubium* and secondary for *B. riedelianum*. This fact is also related to structural differences, with smaller diameter vessels in *B. riedelianum* in relation to *P. dubium*, and denser wood in *B. riedelianum*, either by slower growth by the accepted consensus reasoning, or, alternatively, as herein recommended, by lower maintenance costs in terms of respiration related to smaller surface. If a producer wants higher productivity with a faster cycle, *P. dubium* is the indicated species, whereas a producer who prefers denser and stronger wood, albeit with longer cycle, would choose *B. riedelianum*. Importantly, the study revealed that species can be planted together, allowing a longer cycle with the wood supply in different periods and with different characteristics.

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