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ORIGINAL ARTICLE

Wood properties of 32-year-old *Peltophorum dubium* wood from two seed provenances planted in Luiz Antônio - SP, Brazil

Propriedades da madeira de *Peltophorum dubium* aos 32 anos de idade, oriunda de duas procedências de sementes plantadas em Luiz Antônio - SP, Brasil

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Abstract

We studied *Peltophorum dubium* (Spreng.) Taub. (Fabaceae) wood, popularly known in Brazil as canafístula, from two different provenances planted in Luiz Antônio – SP, Brazil. The study aimed to characterize variations between and within provenances in the radial direction in the trunk of *Peltophorum dubium* trees based on average annual increment, anatomical analyses, as well as physical-mechanical properties of the wood. Thirty randomly selected trees, 15 from each provenance were collected at 32 years of age for analysis of wood properties. The provenances differed only in ray density. The wood of *P. dubium* varied radially and, in general, followed the typical anatomical pattern of variation, having longer and wider vessel elements with lower cell density, along with longer fibers with thicker walls close to the bark. Alvorada do Sul - PR (AS) and Bauru - SP (BA) provenances presented the highest values for most of the properties in the region close to the bark; however, these values were not always significantly different from the other positions. *P. dubium* wood falls into resistance class C20, the lowest among the resistance classes in angiosperms, as defined by NBR 7190 ABNT. We conclude that *P. dubium* is highly adaptable to many locations and that consistency in the quality of its wood can be kept between provenances.

Keywords: Canafístula; Pith-bark variation; Wood density; Wood strength; Wood anatomy.

Resumo

A madeira de *Peltophorum dubium* (Spreng.) Taub. (Fabaceae), popularmente conhecida no Brasil como canafístula, de duas diferentes procedências plantadas em Luiz Antônio – SP, Brasil foi estudada. O objetivo principal foi caracterizar as variações entre procedências e no sentido radial do tronco de árvores de *Peltophorum dubium* por meio da determinação do incremento médio anual, análises anatômicas e propriedades físicas e mecânicas da madeira. Trinta árvores selecionadas aleatoriamente, 15 de cada procedência foram coletadas aos 32 anos para análise das propriedades da madeira. As procedências diferiram apenas na frequência dos raios. A madeira de *P. dubium* variou radialmente e em geral seguiu o padrão típico de variação: em termos anatômicos com elementos de vasos mais longos e largos e com menor densidade das células, além de fibras mais longas e com paredes mais espessas próximos da casca. A procedência Alvorada do Sul - PR (AS) e Bauru - SP (BA) apresentaram para a maioria das propriedades os maiores valores na região da proximidade da casca, no entanto, nem sempre, esses valores foram diferentes significativamente das outras posições. A procedência Alvorada do Sul - PR (AS)

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apresentou os maiores valores nas propriedades na região próxima da casca e em alguns casos sem diferença para a posição intermediária. A madeira de *P. dubium* foi classificada na classe de resistência C20, a mais baixa entre as classes de resistência definidas nas angiospermas pela NBR 7190 da ABNT. Concluímos que *P. dubium* tem alta adaptabilidade em diferentes locais e que a consistência na qualidade de sua madeira pode ser mantida entre procedências.

Palavras-chave: Canafístula; Variação medula-casca; Densidade da madeira; Resistência da madeira; Anatomia da madeira.

INTRODUCTION

Wood is an excellent building material by combining several qualities, such as strength and aesthetics. It also incorporates considerable carbon in its structure, preventing it from accumulating in the atmosphere, which is crucial in the current climate change scenario (Brashaw & Bergman, 2021). Native forests have met the demands of the forest sector for many years, but the misuse of these forests has brought to bear strong national and international pressure to restrict the use of native wood, which, in any case, is scarce. This can be directly attributed to the climatic effects of forest extraction, burning and deforestation. Meanwhile, the demand for forest products remains high. Therefore, in order to minimize environmental damage, forests have seen an increase of exotic species planted in Brazil (Medeiros et al., 2020).

The cultivated tree industry provides society with more than 5,000 bioproducts, such as paper packaging, fabric, books, diapers, laminate floors and wooden furniture, among many others. Present in more than a thousand municipalities in Brazil, the cultivated tree sector drives local economies and generates direct and indirect jobs and an income effect, generating 2.8 million opportunities throughout Brazil (Indústria Brasileira de Árvores, 2022). Cultivation and research of exotic species have increased in Brazil, and today, consequently, knowledge about the forestry and management of exotic species has increased, especially for *Eucalyptus* and *Pinus*. At the same time, however, knowledge about the forestry of some native species has gone wanting. In addition, growers have little incentive for breeding programs and cultivation of some native Brazilian species (Bertolini et al., 2015).

For the optimal use of wood, irrespective of species or planting system, it is necessary to certify its quality, which, according to Savidge (2003), is defined as the degree of excellence in relation to the intended application. Absent an exact measurement of quality, it is possible to establish some physical indicators of wood quality and, hence, its most appropriate use, especially in tropical countries with high biodiversity of timber species (Zenid et al., 2009).

Wood quality for specific purposes is largely conditioned by its anatomical features that directly affect physicomechanical properties and their variations along the trunk (Henin et al., 2018). Therefore, the correct use of a material is associated with its characteristics, and this is just as true for wood, making it essential to know its variations relative to performance in different applications (Paes et al., 2010).

Knowledge about growing tree species with the quality required to meet building standards is necessary for the expansion of forest-based industry, which, in turn, will ensure a low-cost, safe and less environmentally harmful way to generate jobs and income (Farias & Melo, 2020). Some native species have rapid growth combined with high wood productivity, making it essential to understand the silviculture of these native species for their eventual application in the wood industry for such purposes as energy and extraction of by-products (Bertolini et al., 2015).

In this context, we herein limit our reporting to *Peltophorum dubium* (Spreng.) Taub. (Fabaceae), a native, non-endemic, species in Brazil with geographical distribution in four Brazilian continental biomes of Caatinga, Cerrado, Mata Atlântica, and Pantanal to the northeast, Midwest, southeast and south, respectively (Silva et al., 2022). *Peltophorum dubium* has good resistance to cold, and it is used for the recovery of degraded areas, permanent preservation areas, afforestation and landscaping (Lorenzi, 2002). According to Carvalho (2002, 2003), *P. dubium* forestry is recommended homogeneous and in full sunlight. About 80% survival can be expected in plantations; however, growth in height, diameter and shape is heterogeneous. Branches can be pruned, improving tree stem quality and, consequently, added wood value.

This study aimed to characterize variations between and within provenances in the radial direction in the trunk of *Peltophorum dubium* trees based on growth characteristics and wood properties.

We asked i) if seed origin affects anatomical features and physicomechanical properties and ii) if radial variation in anatomical features affects physicomechanical properties. We also examined iii) the structural use (strength class) of *P. dubium* wood.

MATERIAL AND METHODS

Provenances of the seeds and planting area

In 1981, seeds from open-pollinated plants were collected in two natural populations (provenances) of *P. dubium* in the city of Alvorada do Sul (AS), state of Paraná, and city of Bauru (BA), state of São Paulo. Seedlings grown from seeds of trees growing together were planted in 1982 at the Luiz Antônio Experimental Station (LAES), city of Luiz Antônio, state of São Paulo (Figure 1A-B). Geographic location, climatic and soil data from the three areas were presented in Table 1. The plantation was established with six blocks in linear plots of six plants at a spacing of 3 m × 2 m (Figure 1C).

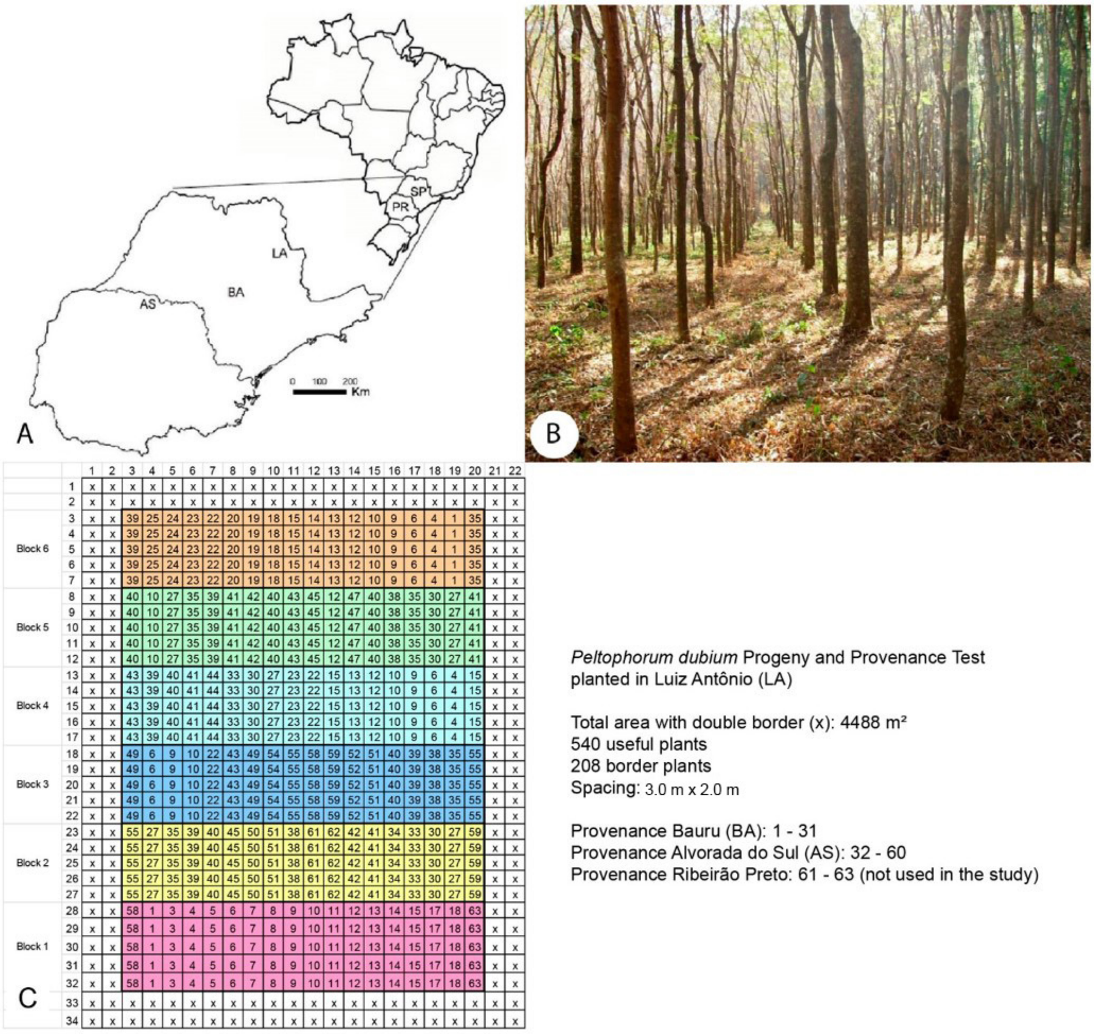

Figure 1. A. Location of planting area: Luiz Antônio - SP (LA) and areas where seeds were collected: Alvorada do Sul - PR (AS) and Bauru - SP (BA). B. Planting of *Peltophorum dubium* in Luiz Antônio Experimental Station. C. Outline and planting information.

Table 1. Geographic location, climatic and soil data in a homogeneous planting area (Luiz Antônio - SP) of 32-year-old *Peltophorum dubium* and two seed provenances (Alvorada do Sul - PR and Bauru - SP) of the species.

Area and Geographic Location	Luiz Antônio (21°40'S, 47°49'W)	Alvorada do Sul (22°46'S, 51°13'W)	Bauru (22°18'S, 49°03'W)
Köppen Climate Classification	Cwa	Cfa	Cwa
Mean precipitation (mm)*	1340	1368	1296
Mean temperature (°C)*	23.5	22.1	22.5
Mean minimum temperature (°C)	16	16	17.2
Mean maximum temperature (°C)	30	28.4	27.8
Altitude (m)	550	320	530
Soil type and characteristics**	Dark Red Latosol. Medium texture, clayey or very clayey. High fertility. Low water-holding capacity.	Red Nitosol. Clay texture to very clayey. Medium to high fertility. High water-holding capacity.	Red Argisols. Medium texture to course. Low fertility. Low water holding-capacity.

* Sistema de Informação Hidrológicas / Agência Nacional de Águas (2017) for data of mean annual precipitation and temperature from January 1975 to December 1985. ** Zanatto et al. (2013) for data of Luiz Antônio. Almeida et al. (2011) for data from Bauru. Bhering et al. (2007) for data from Alvorada do Sul.

Mean annual increment of the forest

In 2014, we evaluated all plantation trees in Luiz Antônio (227 from Alvorada do Sul seeds and 244 from Bauru seeds, totaling 471 trees). The diameter at breast height, 1.3 m from the ground (DBH), was measured with a caliper, and height was measured with a Vertex IV hypsometer. Using DBH and height values, the volume was calculated based on the formula proposed by Higuchi (1978), Vtree = 0.210 + 0.259 x $(DAP)^2$ x HT, developed for species *Peltophorum dubium*. Then, the volume per hectare was calculated according to spacing (3 m x 2 m) by multiplying the number of plants by the average tree volume as Vhectare = 1665 * Vtree, and, finally, mean annual increment was calculated by dividing volume per hectare by age of planting, 32 years, as MAI = Vhectare / 32. Observation in the calculation of the volume of the trees, a correction factor was used in function of the mortality rate of the plantation.

Sampling for physicomechanical properties and anatomical features

We cut 30 randomly selected trees, 15 from each provenance. A trunk log of 1.3 m was removed from the base of each tree, and a central plank was cut to obtain specimens for physico-mechanical properties and anatomical characteristics. Three radial positions were established: i) the nearest part of trunk center, which was designated as pith; ii) a middle position; and iii) a position close to the bark, which was designated as bark. A specimen was taken from each position to determine the physical, mechanical properties, and anatomical features (Figure 2).

Quantification of heartwood and sapwood of the disks

Peltophorum dubium wood is characterized by presenting reddish heartwood, so heartwood and sapwood percentages were initially evaluated by visual observation from trunk base (Figure 2) disk surfaces, and relative area calculations were done with a ruler.

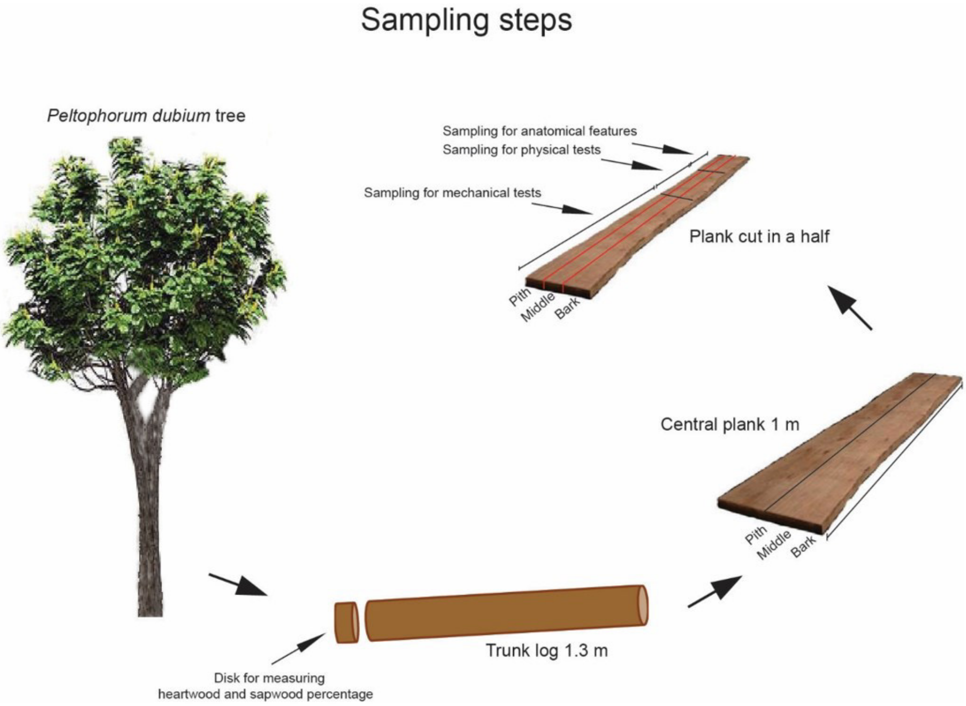

Figure 2. Schematic illustration of sampling for determination of heartwood and sapwood percentage and specimens' origin to determine the physical-mechanical tests and anatomical features.

Wood physical properties

Wood density at 12% EMC was determined, according to standard NBR 7190 (Associação Brasileira de Normas Técnicas, 1997) with an adaptation in the dimensions of the specimen of 2 cm x 2 cm x 3 cm were conditioned at constant temperature (21°C) and moisture content (65%). In these conditions, mass was determined using an analytical balance, and volume was calculated by the product of their dimensions, as obtained with a micrometer.

Basic density was determined by the ratio between dry mass and saturated volume. Specimens (5 cm x 3 cm x 2 cm) were immersed in water and considered saturated when they presented constant mass during monitoring in the laboratory. Subsequently, specimen's saturation volume was obtained by the hydrostatic balance method and were dried in an oven at 105 °C ± 2°C to obtain the dry mass. Wood basic density was calculated by the relationship between dry mass and saturated volume in accordance with Brazilian standard ABNT NBR 11941 (Associação Brasileira de Normas Técnicas, 2003), with an adaptation in the dimensions of the specimen.

Volumetric shrinkage was obtained from the same samples as those used for basic density (Associação Brasileira de Normas Técnicas, 1997). Samples were saturated in water, their dimensions measured with a caliper (accuracy = 0.001mm), taking three measurements per direction, and then oven-dried at 105 ± 3°C, followed by determination of the dry volume of each sample. Volumetric shrinkage, as a percentage, is the difference between saturated and oven-dried volume divided by saturated volume.

The Anisotropy index (AI), Performance (PE) and volumetric variation (ΔV) of *P. dubium* wood were determined using Equations 1, 2, and 3 respectively. These factors are important, as they help in the destination of wood.

$$AI = \frac{\varepsilon r,3}{\varepsilon r,2} \quad (1)$$

$$PE = \frac{\varepsilon r,2}{\varepsilon r,3 * \Delta V} \times 100 \quad (2)$$

$$\Delta V = \frac{saturated\ volume - Dry\ volume}{Dry\ volume} \quad (3)$$

Where: AI = Anisotropy index, Ɛr, 2 = radial retraction (%), Ɛr, 3 = tangential retraction (%), PE = performance, ΔV = volumetric variation.

Wood mechanical properties

We carried out the following tests: shear strength parallel to grain, compression strength parallel to grain, modulus of elasticity and rupture in bending. Tests were performed in a computer-controlled 300 kN electromechanical testing machine. Strains were evaluated using a standard mechanical strain gauge extensometer (accuracy of 0.001 mm). Mechanical tests were performed according to (Associação Brasileira de Normas Técnicas, 1997). We used a loading speed of 2.5 MPa/min (shear strength) and 10.0 MPa/min (compression and bending). Initial results of strength and elastic properties (modulus of elasticity) were corrected to EMC (12%) using a conversion coefficient of 3% (of variation per 1% of MC variation) for strength properties and 2% for elastic properties. In Brazilian standard NBR 7190 (Associação Brasileira de Normas Técnicas, 1997), the characteristic value of compression strength parallel to the grain is used to classify wood in the system of strength classes, guiding the choice of the most suitable species for structural projects (Eufrade Junior et al., 2015).

Wood anatomical analyses

Samples (1.5 cm^3 blocks) were softened in boiling water and glycerin (4:1) for approximately 1h. Transverse and longitudinal sections 12-15 µm in thickness were cut using a sliding microtome. Sections were bleached with sodium hypochlorite (60%) and washed thoroughly in water. We prepared permanent slides according to Johansen (1940). Sections were double-stained with aqueous 1% safranin and aqueous 1% astra blue (1:9). We mounted slides permanently in synthetic resin (Entellan®). Measurements followed the recommendations of the IAWA Committee (International Association of Wood Anatomists Committee, 1989). Quantitative data are based on at least 25 measurements for each feature from each tree, thus fulfilling statistical requirements for the minimum number of measurements.

Data analyses

We initially undertook descriptive statistical analyses 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 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, a parametric analysis of variance (one-way analysis of variance (ANOVA)) was performed. When a significant difference was observed, Tukey's test was used to identify pairs of significantly different means. We analyzed radial variation within the same tree (pith, middle and bark). We also analyzed the three radial positions together, and thus comparing the provenances (Alvorada do Sul-PR e Bauru-SP). In comparisons between the two locations, we used the *t* test.

RESULTS

Growth and mean annual increment of the forest

No difference was observed between the two provenances for tree dimensions and mean annual increment (Table 2).

Table 2. Growth data and mean annual increment in seed provenance test (Alvorada do Sul - PR and Bauru - SP) of 32-year-old *Peltophorum dubium* in a homogeneous planting area (Luiz Antônio - SP)

Variables	Provenances	
	Alvorada do Sul - PR	Bauru - SP
DBH (cm)	11.0 (15.9 a) 20.5	12.5 (15.6 a) 21.0
Commercial height (m)	2.2 (8.1 a) 14.1	1.5 (7.5a) 12.6
Total height (m)	12.7 (16.9 a) 23.3	10.1 (15.9 a) 20.6
Tree volume (m^3)	0.210 (0.264 a) 0.562	0.210 (0.255a) 0.544
Volume per hectare (m^3ha^{-1})	440.7	424.8
Mean annual increment ($m^3ha^{-1}year^{-1}$)	13.77	13.27

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.

Heartwood and sapwood percentage

No statistical difference in heartwood and sapwood percentage was noted between provenances. We observed a higher percentage of sapwood than heartwood by taking average values between the two provenances (Figure 3).

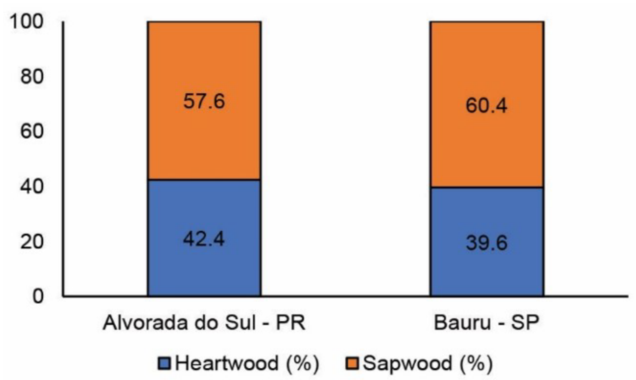

Figure 3. Percentages of heartwood and sapwood of 32-year-old *Peltophorum dubium* from two seed provenances (Alvorada do Sul - PR and Bauru – SP) planted in Luiz Antônio Experimental Station.

Wood physicomechanical properties

In AS, basic and apparent density were higher in the bark and smaller in the pith. In BA, density gradually increased towards the bark. The average of three positions for each provenance did not show significant difference for both densities. Volumetric shrinkage was higher in intermediate and bark positions in both provenances. The anisotropy index obtained indicates that the pith position wood is more stable in both provenances, although no significant difference was identified with the other positions, when considering the mean values between them (Table 3).

Shear parallel to the grain was higher in intermediate and bark positions in AS and increased toward the bark in BA, but with no difference in the intermediate position. Higher compression parallel to the grain values were observed in bark in AS, but did not differ radially in BA. MOE and MOR values were higher in intermediate and bark positions in both provenances. No differences between the means of the three radial positions were observed in any mechanical properties in either provenance (Table 3). Values of characteristic resistances based on compression parallel to the grain are presented in table 4.

Table 3. Physicomechanical properties of the wood of 32-year-old *Peltophorum dubium* in a homogeneous planting area (Luiz Antônio - SP) and two seed provenances (Alvorada do Sul - PR and Bauru - SP).

Radial position	ρbas (g cm^{-3})	$\rho_{12\%}$ (g cm^{-3})	VS (%)	AI	PE	f_{v0} (MPa)	f_{c0} (MPa)	MOE (MPa)	MOR (MPa)
Alvorada do Sul - PR									
Pith	0.45 c	0.54 c	8.85 b	1.33 b	8.75 a	11.99 b	32.89 b	6192 b	54.82 b
Middle	0.52 b	0.63 b	10.13 a	1.79 a	5.23 b	13.66 a	34.16 b	7719 a	67.22 a
Bark	0.55 a	0.65 a	10.58 a	2.02 a	4.11 b	13.97 a	37.68 a	7331 a	68.16 a
Mean	0.51 A	0.61 A	9.85 A	1.71 A	6.03 A	13.21 A	34.91 A	7081 A	63.40 A
Bauru - SP									
Pith	0.43 b	0.57 b	8.62 b	1.10 c	10.86 a	11.38 b	32.80 a	5701 b	56.17 b
Middle	0.51 a	0.63 b	9.90 a	1.71 b	4.86 b	12.59 ab	34.14 a	7090 a	65.80 a
Bark	0.52 a	0.68 a	11.13 a	2.05 a	4.40 b	13.25 a	33.81 a	7716 a	68.22 a
Mean	0.49 A	0.63 A	9.88 A	1.62 A	6.70 A	12.40 A	33.58 A	6836 A	63.39 A

ρbas= basic density; ρ12 = apparent density at 12% moisture content; VS = volumetric shrinkage; AI = anisotropy index; PE = Performance; fv0 = shear parallel to the grain; fc0 = compression parallel to the grain; MOE = modulus of elasticity; MOR = modulus of rupture. Mechanical properties data at 12% moisture content. The difference among radial positions is represented by lowercase letters, while uppercase letters represent comparison between provenances. In the same column, distinct letters differ statistically ($P < 0.05$) by Tukey's test.

Table 4. Characteristic resistances of 32-year-old *Peltophorum dubium* in a homogeneous planting area (Luiz Antônio - SP) and two seed provenances (Alvorada do Sul - PR and Bauru -SP).

Radial position	Alvorada do Sul (MPa)	Bauru (MPa)
Pith	26.9	29.4
Middle	29.7	30.9
Bark	36.2	30.5
Mean	30.93	30.27

Anatomical analyses

Radially, we observed longer vessel elements in intermediate and bark positions for both provenances. Wider vessels occur in intermediate and bark position in AS, but only in bark in BA. Both provenances have higher vessel density in pith position (Figure 4). The average of three radial positions showed no difference between the two provenances. Ray height did not differ radially in three positions in AS, while in BA, higher rays occurred in pith. Both provenances presented wider rays in intermediate and bark position. In AS, higher ray frequency was observed in pith and bark positions, but no difference in BA (Figure 4). When comparing the mean of the three positions, height and width of rays did not differ between provenances, while the most frequent rays were observed in BA. Longer fibers with thicker walls occurred in intermediate and bark positions in both provenances. Mean values did not differ in both provenances for two fiber variables (Table 5).

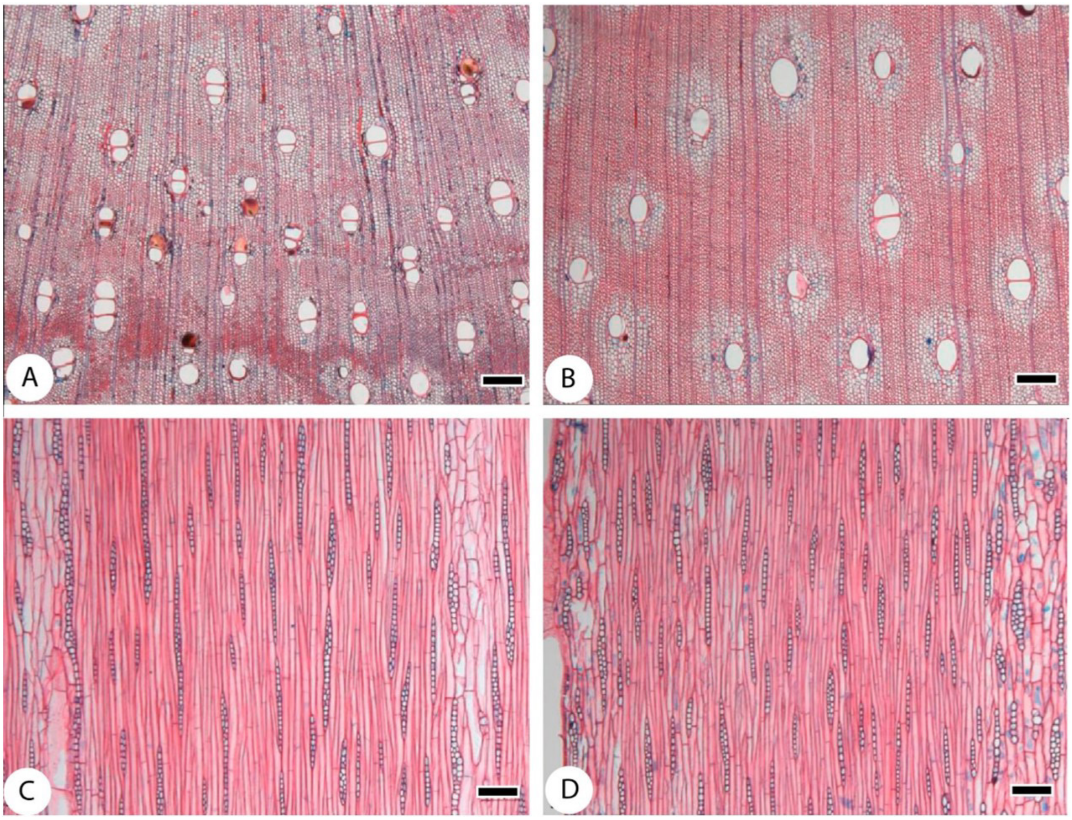

Figure 4. *Peltophorum dubium* wood anatomy of Alvorada do Sul - PR provenance. A-B transverse sections from region near the pith and near the bark, respectively. Scale bar = 200 µm. C-D tangential sections from region near the pith and near the bark, respectively. Scale bar = 100 µm.

Table 5. Anatomical features of 32-year-old *Peltophorum dubium* in a homogeneous planting area (Luiz Antônio - SP) and two seed provenances (Alvorada do Sul - PR and Bauru - SP).

Radial position	VEL (μm)	VD (μm)	VF (nº mm^{-2})	RH (μm)	RW (μm)	RF (nº mm)	FL (μm)	FWT (μm)
Alvorada do Sul - PR								
Pith	288 b	100 b	7.75 a	207 a	15 b	8.9 a	846 b	3.11 b
Middle	327 a	116 a	5.14 b	202 a	19 a	8.4 b	975 a	4.11 a
Bark	336 a	116 a	5.64 b	206 a	20 a	8.9 a	978 a	3.87 a
Mean	317 A	111 A	6.18 A	205 A	18 A	8.7 B	933 A	3.70A
Bauru - SP								
Pith	292 b	103 b	7.89 a	224 a	16 b	8.9 a	820 b	2.90 b
Middle	332 a	110 b	5.36 b	197 b	20 a	9.0 a	965 a	3.90 a
Bark	331 a	119 a	5.44 b	203 b	21 a	9.2 a	976 a	3.00 a
Mean	318 A	111 A	6.23 A	208 A	19 A	9.0 A	920 A	2.27 A

VEL = vessel element length; VD = vessel diameter; VF = vessel frequency; RH = ray height; RW = ray width; RF = ray frequency; FL= fiber length; FWT = fiber wall thickness. Difference among radial positions is represented by lowercase letters, while comparison between provenances is represented by uppercase letters. In the same column, distinct letters differ statistically ($P < 0.05$) by Tukey's test.

DISCUSSION

Growth and mean annual increment of the forest

The lack of variation between provenances showed that seed origin did not influence tree volume. In the present study, we found a mean value of 13.6 m^3 ha^{-1} $year^{-1}$ for mean annual increment. In an experiment with seven-year-old *P. dubium* and the same spacing (3 x 2 m), also, in Luiz Antônio, an average annual increase of 19.6 m^3 $ha^{-1}year^{-1}$ was reported (Carvalho, 2003). The difference in studies may be related to age, 32 years in the present study. This result can be explained by faster growth in the first years of life. According to Carvalho (2003), a fast-growing species has productivity higher than 14 m^3 ha^{-1} $year^{-1}$. Accordingly, after studying 100 native species, authors of the present study highlight that *P. dubium* is among the 32 considered fast growing. As shown above, our values are close to the reference value.

In addition, tree mortality was low, 12.24% for AS and 9.28% for BA; thus, *P. dubium* combines fast growth with low mortality rate. According to Köhler et al. (2001), typical values of average mortality rates in primary rainforest trees are 1% to 2% per year, but a significantly higher rate for pioneer species. Thus, the mortality rate was lower for AS at 0.38% and for BA at 0.29% per year.

Peltophorum dubium wood is mainly used in civil construction, such as beams, rafters, slats, doorframes, windows, floors, ceilings and partition walls (Carvalho, 2003). The consumption of Amazonian sawnwood by civil construction in the state of São Paulo in 2001 was 1,783,300 m^3, showing that *P. dubium* from reforestation has the potential to provide sawnwood for industrial use and its residues can be used to manufacture panels and energy (Sobral et al. 2002). According to Zenid et al. (2009), a growing interest has been the use of mechanical or chemical wood processing residues in the production of panels within the principle of reuse, or even recycling, of materials. Modes et al. (2012) state that *P. dubium* wood particles, when bonded with a formaldehyde tannin adhesive, produced sheets with excellent technological characteristics, making this species an alternative source for panel production. In addition, *P. dubium* has good calorific value (4755 kcal kg^{-1}), showing that this species has good potential for energy biomass and, thus, a possible destination for these residues.

Quantification of heartwood and sapwood

Peltophorum dubium presented a higher proportion of sapwood (58.96%) when compared to heartwood (41.04%). Pereira et al. (2013) reported on wood used in construction or furniture production, as is the case of *P. dubium*. They found a higher heartwood percentage than sapwood, whereas the present study did not; possibly explain by the age of trees studied. That is, with advancing age, it is possible that the heartwood ratio becomes larger than that of sapwood.

In practice, most sapwood is removed during cutting of sideboards at the sawmill, but this material could be used. According to Vieira (2003), in Rio Grande do Sul, *Eucalyptus* sideboards are used as external cladding walls (kiosks, sheds and other constructions). The author also mentions that sideboards are low value-added products owing to their faster degradation, but that they can be used in a way that avoids loss. In addition, as mentioned in the previous item, *P. dubium* wood presented excellent results in the assembly of panels and has potential as energy biomass (Modes et al., 2012), which would be an alternative for material otherwise discarded during cutting and processing.

Physicomechanical properties

Basic density of Alvorada do Sul wood was in absolute values higher in the three positions when compared to Bauru. Other studies have also found differences in density with respect to seed origin, e.g., Longui et al. (2011) who studied three different provenances of *Gallesia integrifolia* also planted in Luiz Antônio - SP. In general, densities were higher near the bark than in the pith, a pattern also reported by Lima et al. (2015) for 28-year-old *P. dubium*, and observed in other native Brazilian species, e.g., 24-year-old *Balfourodendron riedelianum* (Lima et al., 2011) and 15-year-old *Schizolobium parahyba* (Athanázio-Heliodoro, 2015).

In the present study, *Peltophorum dubium* wood showed mean values basic density and apparent density (12% of moisture content), respectively, from 0.430 (pith) to 0.530 g cm^{-3} (bark) and 0.550 (pith) to 0.660 gcm^{-3} (bark). Some authors like Vivian et al. (2010) found similar results by studying 10-year-old *P. dubium*. They found density of 640 kg m^{-3} at 12% humidity, but they did not provide precise information about position on the trunk or plant spacing, which are known to be two factors that interfere with density values. Lima et al. (2015) reported basic density of 28-year-old *P. dubium* in the same planting, 430 kg m^{-3} close to the pith and 500 $kg.m^{-3}$ close to the bark. Pith values did not differ from our values, while bark values were slightly higher. This small difference be related to the additional four years in the trees studied here (32 years).

Volumetric shrinkage is influenced by some variables, especially density with a strong positive relationship (Glass & Zelinka, 2021). In general, wood with high density has, proportionally, cells with thicker walls and lower lumen compared to wood of lower density. Thus, these woods retract and swell in greater proportion. Additionally, according to Glass & Zelinka (2021), the relationship between density and volumetric shrinkage must take into account the peculiarities of the microstructure, not just wall thickness and lumen diameter.

The samples close to the pith show less volumetric shrinkage than those located near the bark. This change may be associated with an increase in wood density, fiber length and cellulose content towards the bark (Ramkumar & Saravanan, 2022).

The anisotropy coefficient showed mean values of 1.21 close to the pith and 2.03 close to the bark (average of two provenances). According to the classification established by Czajkowski et al. (2020), this factor is considered excellent up to 1.50, normal between 1.50 and 2.00, and poor when higher than 2.00. Based on this evaluation, the wood close to the bark has a high coefficient of anisotropy, therefore, being a wood with little dimensional stability, this must be taken into account when using pieces of wood of this species, but other aspects must also be considered such as, the range of all other wood shrinkage indices. Vivian et al. (2010), studying 10-year-old *P. dubium*, found values of 1.94, close to the value we found in the bark region in 32-year-old trees. Pedroso & Mattos (1987) found a value of 2.84, showing more unstable wood than that in our study.

According to the presented results, it can be considered that the wood of *Peltophorum dubium* presented a good performance for both provenances, however the pith-bark variation was not very stable. This index accounts for wood quality through a low anisotropy factor associated with low volumetric shrinkage. The higher the index, the better the performance of the wood. Thus, the reverse behavior was expected, since its value is higher, the lower the volumetric shrinkage values (Athanázio-Heliodoro, 2015). Reinforcing what was mentioned above, for the anisotropy coefficient, based on the performance index, the wood next to the bark has lower quality when compared to the other two positions (middle and pith).

Shear value ranged from 11.68 MPa close to the pith to 13.61 MPa close to the bark. This resulted from a likely higher percentage of adult wood compared to juvenile wood (Wessels et al., 2014). Vivian et al. (2010) found values of 13.14 for *P. dubium* at 10 years old, and Pedroso & Mattos (1987) found values of 11.14 MPa.

Alvorada do Sul provenance presented higher compression parallel to the grain close to the bark when compared to BA. This difference is likely related to basic density and apparent density, which also differed in this trunk region for the two provenances. Glass & Zelinka (2021) claim that most variability of wood mechanical properties can be estimated based on density variation.

We found mean values of compression parallel to the grain of the 32.84 MPa close to the pith and 35.75 MPa close to the bark. Vivian et al. (2010), studying 10-year-old *P. dubium*, found a lower value for this same property, 30.3 MPa, but they did not provide information on plant spacing, a factor that can interfere with resistance. In a study with large trees, Pedroso & Mattos (1987) found values of 50.5 MPa, but we do not have information on age and spacing for comparison with our results. However, we can surmise that the species studied may have higher values of resistance to compression. The mechanical strength of *P. dubium* wood follows a trend found for other species, namely, that impact strength and static bending increase and decrease with the increase of wood moisture, indicating that exposure to adverse conditions of use will result in different behavior (Modes et al., 2012).

BA wood is more homogeneous with less variation from the pith to the bark, whereas AS wood is, radially, more heterogeneous. In AS, pith and middle region are classified as C20 and region close to the bark as C30; in BA, pith region is classified in class C20 and the other two regions as C30. Based on this assessment, trees with seeds from Bauru have a larger amount of wood with greater resistance when compared to trees with seeds from Alvorada do Sul. Wood that is more homogeneous may behave better in processing operations and reflect greater uniformity in other technological properties. However, we must consider that in the pith-bark variation, the classification of the wood ranged from C20 to C30, and this could be a problem for wood usage that is required to be as homogenous as possible. Wood with such characteristics can be applied for uses that require less physicomechanical variation (Eufrade Junior et al., 2015).

The provenances show higher MOE and MOR close to the bark and middle position. MOE ranged from 5947 MPa close to the pith to 7524 MPa close to the bark. Stangerlin et al. (2010) found MOE values for 10-year-old *P. dubium* of 5738.81 MPa, a value similar to that found in the pith of our study with 32-year-old *P. dubium*, which may be related to a greater amount of juvenile wood in this region and in the region studied by Stangerlin et al.

MOR showed values from 55.49 MPa to 68.18 MPa, lower than values found by Stangerlin et al. (2010) of 77.38 MPa. Although all wood cells influence mechanical properties, perhaps the role of rays is the least explored. Although all wood cells influence mechanical properties, perhaps the role of rays is the least explored. According to Burgert & Eckstein (2001), close to the bark region, where we have a lower moisture content, the sapwood ray cells generally show secondary lignification of the cell walls, and when they are drier, they have a surprisingly high radial tensile strength. Furthermore, Wang et al. (2021) report that the longitudinal ray tensile strength in the pith region, which is wetter, is approximately half of that contained in the bark position, which is drier.

Wood anatomical analyses

The region near the pith has smaller cells with smaller diameters and thinner walls when compared to cells closer to the bark (Lachenbruch et al., 2011). The authors further state that production of juvenile wood results from the need for young cambium to mature before it can produce wood with more homogeneous cells and better physicomechanical properties, explaining cell variation along the radius. In *P. dubium*, it is possible to observe an increase in diameter and length of vessel, but a decrease in vessel density towards the bark. This same pattern was observed for other native species, as described in studies by Longui et al. (2009) with *Luehea divaricata*, Dünisch et al. (2004) with *Ilex paraguariensis*, as well as exotic species, as mentioned in Florsheim et al. (2009) for populations of *Eucalyptus dunnii* and Ishiguri et al. (2009) for *Paraserianthes falcataria*.

The current thinking is that rays play a central role in facilitating the coupling of inner bark and xylem. It is no longer thought that phloem and xylem are separate transport systems with exclusive functions (Pfautsch et al. 2015). Therefore, studying the radial variation of ray dimensions and frequency is essential to gain an understanding of the relationship among anatomy, physiology and plant adaptation to the environment.

In our study, two provenances had wider rays close to the bark and in the intermediate region, while ray frequency oscillated in AS, but did not differ in BA. Rays connect xylem and transport phloem along the entire vertical axis of the stem where they facilitate a bidirectional flux of water, as well as organic and selected inorganic substances, and play an important role in whole-tree hydraulic regulation (Pfautsch et al., 2015). Other authors have, however, found a lower ray frequency close to the bark, e.g., Urbinati et al. (2003) in *Terminalia ivorensis* and Lima et al. (2011) in *Cariniana legalis*. Other functional capabilities may explain this lower frequency since, in theory, more voluminous rays in greater frequency can confer an advantage to the plant by their capacity to store water and enhance xylem-phloem hydraulic regulation (Domec et al., 2006; Barnard & Bauerle, 2013).

Peltophorum dubium wood does not reach equilibrium relative moisture content for up to 40 days, which indicates that the drying process is slower than that of other species. This may have been influenced by the greater thickness and the higher fraction of the cell wall. The higher the cell wall values, the more difficult it is to remove permeated water, which accounts for close to 30% of wood moisture content, also known as the fiber saturation point (Eloy et al., 2021).

For fiber wall thickness, we found values of 3.01 μm close to the pith and 3.92 μm close to the bark. Lima et al. (2015), studying the same planting of *P. dubium* (different trees) at 28-year-old trees, found values of 3.40 μm and 4.23 μm, respectively, higher values than those observed in this study. The differences between these two studies were also noted for fiber length. Lima et al. (2015) reported fibers 812 μm in length close to the pith and 942 μm close to the bark, but in our study, the values were higher (823 and 976 μm, respectively). The variations found may be related to differences in tree diameters since the average trunk diameter (1.30 m) in Lima's study was 16.90 cm, but 15.80 cm in the present study. This difference in pith-bark variation in fiber length in trees of different diameters can be explained by the gradient. In larger diameter trees (16.90 cm), pith-bark variation ranged from 812 μm to 942 μm, a difference of 130 μm, between pith and bark, and in the case of the smallest diameter (15.80 cm), the range was from 823 μm to 976 μm, with a difference of 153 μm between positions. So, in smaller diameter trees, the variation is greater, and in larger diameter trees, the variation is smaller.

In both provenances, fiber length increased from pith to bark. This tendency to increase fiber length and stabilize after a certain point may be an indication of a change in the region from juvenile wood to adult wood (Lima et al., 2015). Since we did not analyze the relationship between growth rings and fiber length, we do not have the ages of each ring. However, in the two provenances, intermediate and bark values did not differ, suggesting that the wood can be considered mature from the intermediate region.

CONCLUSION

Growth characteristics (diameter, height and volume) did not differ significantly between the origins of *P. dubium*. Provenances differed only in ray density. Thus, we suggest that origin has no effect on the anatomy or physicomechanical properties of wood for this species, in cutting age and planting location.

The wood of *P. dubium* varied radially and, in general, followed the typical anatomical pattern of variation with longer and wider vessel elements and lower cell density, in addition to longer fibers and with thicker walls close to the bark.

In selecting matrices for wood use from these two provenances, both density and mechanical properties should be considered. The difference in density is small between the two sources, especially in the bark region. In general, while denser woods with higher values in mechanical properties can be found at Alvorada do Sul (AS), they are shown to more heterogeneous radially when compared to wood from the Bauru provenance. The greater thickness of the fiber wall found in Alvorada do Sul may have contributed to the difference in density found between the two sources.

According to the current technical standard, *P. dubium* wood is classified in resistance class C20, the lowest among the resistance classes defined in the norm for eudicots. However, in some positions, it showed values that can be classified as C30. Furthermore, based on other studies that reported higher values than ours, it is assumed that older woods can reach higher strength classes.

Based on the results of this research, it is possible to conclude that *Peltophorum dubium* has a good potential for several industrial uses that do not require much dimensional stability and do not have many restrictions in structural applications.

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