Effect of provenances on wood properties of ***Balfourodendron riedelianum***

Efecto de las proveniencias en propiedades de la madera de *Balfourodendron riedelianum*

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Abstract

Wood is comparatively more conservative than other parts of trees, such as leaves, which present greater phenotypic plasticity. We studied the effect of seed origin on annual increment, physical-mechanical properties and anatomical characteristics of *Balfourodendron riedelianum* wood in a homogeneous plantation (Luiz Antônio Experimental Station (LAES)) from three natural provenances (Gália and Bauru in São Paulo State and Alvorada do Sul in Paraná State, Brazil).

Because genotypic information is a determinant of wood formation, trees were expected to develop wood structure based on their provenances. Our results demostrate that variations in volume, properties and wood anatomy were influenced by provenance. Alvorada do Sul trees showed lower growth in volume and higher strength and homogeneity, compared to Gália and Bauru. Typical radial pattern was not observed for most characteristics, except modulus of elasticity and fiber length in Gália and compression parallel to the grain in Bauru that increased towards the bark. Based on the latter characteristc, *B. riedelianum* wood in a homogeneous planting has class C40 mechanical strength, as indicated for use in medium-sized structures, light civil construction and the manufacture of furniture.
Keywords: annual increment, guatambú, pau marfim, radial variation, strength class, tropical wood.

Resumen

La madera es comparativamente más conservadora que otras partes de los árboles, como las hojas, que presentan una mayor plasticidad fenotípica. Se estudió el efecto del origen de la semilla sobre el incremento anual, las propiedades físico-mecánicas y las características anatómicas de la madera de *Balfourodendron riedelianum* en una plantación homogénea (LAES) de tres procedencias (Gália y Bauru en Estado de São Paulo y Alvorada do Sul en Estado de Paraná, Brasil). Debido a que la información genotípica es un determinante de la formación de la madera, se esperaba que los árboles desarrollaran una estructura de madera basada en sus genética de las procedencias. Los resultados de este estudio demuestran que las variaciones en volumen, propiedades y anatomía de la madera fueron influenciadas por la procedencia. Los árboles de Alvorada do Sul mostraron menor crecimiento en volumen y, por lo tanto, mayor resistencia y homogeneidad, en comparación con Gália y Bauru. El patrón radial típico no fue observado para la mayoría de las características, excepto el módulo de la elasticidad y la longitud de la fibra en Gália y la compresión paralela al grano en Bauru que aumentó en dirección a la corteza. Con base en esta última característica, la madera de *B. riedelianum* en plantación homogénea tiene una resistencia mecánica de clase C40, tal como se indica para su uso en estructuras medianas, construcción civil ligera y fabricación de muebles.

Palabras clave: incremento anual, guatambú, pau marfim, variación radial, clase de resistência, madera tropical.

Introduction

Plants, like all living beings, have the ability to adapt to different demands of the environments. Wood is comparatively more conservative than other parts of trees, such as leaves, which present greater phenotypic plasticity. We know that genotypic information is a determinant of wood formation. Therefore, it is expected that trees with different provenances, though growing in the same place (different from seed origins), will still develop wood structure based on the genetic information from environmental origin conditions (Longui *et al*., 2011). To test this idea, we studied the effect of seed origin on annual increment, physical-mechanical properties and anatomical characteristics from three provenances of *Balfourodendron riedelianum* wood growing together in Luiz Antônio, Brazil. *B. riedelianum* (Engler) Engler (Rutaceae), 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, Groppo, & Dias, 2017). The species also occurs in Argentina and Paraguay, and the major threat arises from overexploitation of timber and deforestation. Accordingly, it has been identified as “endangered” (International Union for Conservation of Nature and Natural Resources – IUCN, 1998).

Timber produced in a sustainable manner on a worldwide scale is of great interest in order to reduce the pressure on native forests. Over the last decades, a large supply of commercial timber has come from the Brazilian Amazon Forest (Zenid *et al.*, 2009), but such harvesting has endangered the conservation of this biome. Thus, to avoid the predatory wood cutting, consumption should be deliberate, and production should be acquired from companies able to prove tree origin through a management plan and the necessary documentation to comply with pertinent forestry laws (Zenid *et al.*, 2009). This same concern should be adopted for timber from all Brazilian biomes. Thus, research that enables producers to comply with these conditions is essential.

In this context, the Instituto Florestal de São Paulo, Brazil, has promoted studies with several native forest species with economic potential, e.g., from of provenance and progeny tests, base populations and seed orchards to *ex situ* conservation and production of seedlings for decades (Gurgel Garrido, Faria, Cruz, & Palomo, 1997). Among the studied species, we highlight *B. riedelianum*, which has ornamental use, as well as use for reforestation (Durigan, Figliolia, Kawabata, Garrido, and Baitello, 1997). Based on its excellent wood quality, Paula and Alves (2007) report that *B. riedelianum* wood has long been used in civil construction, carpentry, furniture manufacture and other applications. Despite the importance of *B. riedelianum* for logging purposes, we have little knowledge about the effects of large-scale cultivation and no detailed information on productivity, cultivation techniques, or the growth and development of a natural genetic variant available for breeding. Thus, as described above, our study with provenance tests in adult age (30 years age) and considering silvicultural and wood traits, represents a unique opportunity to increase such knowledge by collecting seeds from three natural populations and in a homogeneous plantation.

Objectives

This study proposal was to estimate effect of provenances on tree volume, volume per hectare and mean annual increment of *B. riedelianum*. To determine variations in properties and anatomy in function of provenances and radial variation. Finally, to characterize physical-mechanical properties to know wood strength and strength class. In this way, providing information for farmers interested in planting *B. riedelianum*.

Materials and methods

Provenances of the seeds and planting area

In 1983, seeds from open-pollinated plants were collected in three natural populations (provenances) of *B. riedelianum* in the states of São Paulo and Paraná municipalities, Gália, Bauru, and Alvorada do Sul. Seedlings were grown up from seeds planted in 1984 at the Luiz Antônio Experimental Station (LAES), in municipality of Luiz Antônio. Geographic location, clima and soil data from the four areas are presented in table 1. The plantation was established in six blocks in linear plots of six plants at a spacing of 3 m × 3 m (Gurgel-Garrido *et al*., 1997).

Table 1. Geographic location, climatic and soil data in provenance test of *B. riedelianum* (Gália-SP, Bauru-SP and Alvorada do Sul-PR) at 30 years old in municipality of Luiz Antônio-SP.

Area and Geographic location	Luiz Antônio (21º40’S, 47º49’W)	Gália (22º17’S, 49º33’W)	Bauru (22°18’S, 49°03’W)	Alvorada do Sul (22º46’S, 51º13’W)
Köppen climate classification	Cwa	Cwa	Cwa	Cfa
Mean precipitation (mm)*	1340	1395	1296	1368
Mean temperature (ºC)*	23.5	22.0	22.5	22.1
Mean minimum temperature (ºC)	16	15.6	17.2	16

Mean maximum temperature (ºC)	30	28.5	27.8	28.4
Altitude (m)	550	650	530	320
Soil type and characteristic**	Dark Red Latosol. Medium texture, clayey or very clayey. High fertility. Low water holding capacity.	Red Yellow Latosol. Medium texture. Low fertility. Low water holding capacity.	Red Argisols. Medium texture to course. Low fertility. Low water holding capacity.	Red nitosol. Clayy texture to very clayey. Medium to high fertility. High water holding capacity.

* Sistema de Informação Hidrológicas /Agência Nacional de Águas [ANA] (2017), Data of mean annual precipitation and temperature from January 1975 to December 1985.

** Data of Luiz Antônio, Gália, Bauru, and Alvorada do Sul were reported by Zanatto, Leonel, Thomaziello, and Oliveira (2013), ESALQ-USP (2006), Almeida, Toniato, and Durigan (2011), and Bhering *et al*. (2007), respectively.

Mean annual increment

In 2015, dbh - diameter at breast height, of about 1400 trees was measured with caliper, and height was measured with a hypsometer Vertex IV. From dbh and height values the volume was calculated based on the formula proposed by Higuchi (1978). The equation used was

$$\text{Volume} = 0.063 + 0.255 \times \text{Diameter} \times \text{Height} \quad (1)$$

Then, the volume per hectare was calculated considering the spacing (3 m × 3 m) and the number of plants. The number of plantas was multiplied by the average tree volume. Finally, the volume per hectare and year was calculated by dividing volume per hectare by age of planting (30 years).

Sampling for physical and mechanical properties and anatomical features

We cut 36 randomly selected trees, 12 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 physical and mechanical properties and anatomical characteristics. Three radial positions were established:

the nearest part of trunk center, which was designated as pith, a middle position, and a position close to the bark, which was designated as bark.

Apparent density (D_{12})

Apparent density was determined in acclimatized specimens by the ratio of their mass and volume at the current moisture content (MC). We used the model proposed by Rezende, Escobedo, and Ferraz (1988) based on the study of Kollmann and Côté (1968) to obtain the value to nominal 12% equilibrium moisture content (EMC) (D_{12}) (see Eq. 1). The density of the model used at any moisture content ($D_{u\%}$, ranging from 0% to 25% MC) is relative to the density at 0% MC (D_0). Then, D_{12} was calculated from D_0 using the two equations:

$$D_{u\%} = D_0\,(1 + 0.01_{u\%})\left(1 - \frac{0.0084_{u\%}D_0}{1+0.28D_0}\right) \quad (2)$$

$$D_{12\%} = \frac{1.12D_0 + 0.2007D_0^2}{1+0.28D_0} \quad (3)$$

Mechanical tests

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 eletromechanical testing machine. Strains were evaluated using a standard mechanical strain gauge extensometer (accuracy of 0.001 mm).

Mechanical tests were performed according to NBR 7190 (Associação Brasileira de Normas Técnicas [ABNT] 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 the EMC (12%) using a conversion coefficient of 3% (of variation per 1% of MC variation) for strength properties and 2% for elastic properties.

In the Brazilian standard NBR 7190 (ABNT, 1997), the characteristic value of compression strength parallel to grain is used to classify the wood in the system of strength classes (Table 2), and it guides the choice of the most suitable species for structural projects.

Table 2. Strength classes and characteristic values for hardwoods at 12% MC, based on the NBR 7190.

Hardwoods					
Classes	$\sigma_{c\|,k}$ (MPa)	$\sigma_{s,k}$ (MPa)	$E_{c\|,m}$ (MPa)	D_b (g cm^{-3})	D_{12} (g cm^{-3})
C20	20	4	9500	0.500	0.650
C30	30	5	14500	0.650	0.800
C40	40	6	19500	0.750	0.950
C60	60	8	24500	0.800	1.000

$\sigma_{cl,k}$ = Compression parallel to the grain. $\sigma_{s,k}$ = volumetric shrinkage. $E_{cl,m}$ = modulus of elasticity. D_b = basic density. D_{12} = apparent density.

Anatomical analysis

We cut small portions of wood from each sample for maceration using Franklin's method (Berlyn and Miksche, 1976). Wood fragments were stained with aqueous safranin and mounted temporarily in a solution of water and glycerin (1:1). Samples of 2 cm^3 were softened in boiling water and glycerin (4:1) for 1 h to 2 h. From these samples, transverse and longitudinal sections 18-25 µm in thickness were obtained with a sliding microtome. Sections were bleached with sodium hypochlorite (60%), washed thoroughly in water, and stained with 1% safranin (Johansen, 1940). Measurements followed the recommendations of the IAWA Committee (IAWA, 1989). Quantitative data are based on at least 25 measurements for each characteristic from each tree, thus fulfilling statistical requirements for the minimum number of measurements.

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, a parametric analysis of variance (one-way analysis of variance [ANOVA]) was performed. When a significant difference was observed between radial positions and provenances, Tukey's test was used to identify pairs of significantly different means. We analyzed the radial variation within the same tree and also three radial positions together comparing the provenances. Pearson's correlations between variables and variables with radial position were carried out.

Results and discussion

We observed larger dbh in Gália and Bauru, while tree height did not differ among the three provenances. Tree volume, volume per hectare and mean annual increment were higher in Bauru/Gália than Alvorada do Sul (Table 3).

Table 3. Silvicultural data and mean annual increment in provenance test of *B. riedelianum* (Gália-SP, Bauru-SP and Alvorada do Sul-PR) at 30 years old in municipality of Luiz Antônio-SP.

	Provenances		
	Gália	Bauru	Alvorada do Sul
dbh (cm)	6 (16.36a) 32	4 (16.48a) 32	4 (15.19b) 26
Height (m)	4 (16.24a) 26	2 (15.95a) 27	3 (15.64a) 23
Tree volume (m^3)	0.06 (0.18a) 0.58	0.06 (0.19a) 0.53	0.06 (0.16b) 0.41
Volume per hectare (m^3 ha^{-1})	209.62	213.90	185.18
Mean annual increment (m^3 ha^{-1} $year^{-1}$)	6.76	6.90	5.97

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 Tukey's test.

With the exception of shear parallel to the grain in Gália and Alvorada do Sul, compression parallel to the grain in Gália and MOE in Alvorada do Sul, the other wood properties varied from pith toward the bark in the three provenances (Table 4). Considering the average among three radial positions, Alvorada do Sul presented higher density and compression parallel to the grain. Shear parallel to the grain was higher in Alvorada do Sul with no difference compared to Bauru. Gália and Alvorada do Sul showed higher values of MOE and MOR, and in the latter Alvorada do Sul did not differ from Bauru (Table 4).

Table 4. Physical and mechanical properties in provenance test of *B. riedelianum* (Gália-SP, Bauru-SP and Alvorada do Sul-PR) at 30 years old in municipality of Luiz Antônio-SP.

Radial position	D_{12}	f_{v0}	f_{c0}	MOE	MOR
Gália					
Pith	0.87a	16.70a	44.89a	11801b	105.14b
Middle	0.83b	18.61a	47.66a	13180a	126.12a
Bark	0.82b	18.52a	47.53a	14226a	129.32a
Mean	0.84B	17.97B	46.68C	13056A	120.19AB
Bauru					
Pith	0.82b	17.55b	47.10b	10760b	104.54b
Middle	0.87a	18.12b	49.18ab	12464a	121.37a
Bark	0.83b	20.28a	51.73a	11819a	123.77a
Mean	0.84B	18.63AB	49.07B	11659B	116.56B
Alvorada do Sul					
Pith	0.90b	19.47a	50.56b	12622a	114.17b
Middle	0.92a	19.97a	54.11a	13514a	126.72a
Bark	0.88b	18.86a	53.68a	12955a	132.67a
Mean	0.90A	19.43A	52.77A	13942A	124.52A

D_{12} = apparent density at 12% moisture content (g cm^{-3}); f_{v0} = shear parallel to the grain (MPa); f_{c0} = compression parallel to the grain (MPa); MOE = modulus of elasticity (MPa); MOR = modulus of rupture (MPa). The difference between the radial positions is represented by lowercase letters, while the comparison between the provenances is represented by uppercase letters. In the same column, distinct letters differ statistically ($P < 0.05$) by Tukey's test.

Fiber diameter and wall thickness in Gália, vessel diameter and ray frequency in Bauru, and fiber width, diameter and wall thickness in Alvorada do Sul did not vary radially. The other anatomical characteristics showed variation (Table 5). Among provenances, shorter vessel elements occurred in Alvorada do Sul. Larger vessels were noticed in Bauru compared to the other two provenances. Gália showed less vessel frequency than other provenances. No variation was noted among provenances in ray height. Larger rays occurred in Gália, with no variation in Bauru. Higher ray frequency occurred in Gália. Fiber length increased gradually from pith to bark in Gália. It was longer in the middle position in Bauru and in middle and bark positions in Alvorada. Longer fibers occurred in Gália, with no difference to Alvorada do Sul. Larger fiber diameter occurred in Gália, with no difference to Bauru. Fiber wall thickness did not vary among the three provenances (Table 5).

Table 5. Anatomical features in provenance test of *B. riedelianum* (Gália-SP, Bauru-SP and Alvorada do Sul-PR) at 30 years old in municipality of Luiz Antônio-SP.

Radial position	VEL	VD	VF	RH	RW	RF	FL	FD	FWT
				Gália					
Pith	302b	48b	45a	215b	28b	7.0a	1128c	15.1a	4.7a
Middle	319b	51a	42b	216b	30a	7.0a	1257b	15.4a	4.7a
Bark	347a	49b	46a	235a	31a	6.5b	1325a	15.0a	4.7a
Mean	321A	50B	44B	221A	30A	6.8A	1240A	15.2A	4.7A
				Bauru					
Pith	290b	54a	45b	214a	28b	6.4a	1128b	15.1a	4.5b
Middle	324a	54a	44b	224a	30a	6.4a	1280a	14.2b	4.6ab
Bark	336a	53a	53a	227a	29ab	6.6a	1181b	15.3a	4.8a
Mean	312A	53A	47A	220A	29AB	6.4B	1193B	14.8AB	4.6A
				Alvorada do Sul					
Pith	284ab	47b	47ab	208b	28a	6.1a	1167b	14.6a	4.5a
Middle	306a	50a	45b	225a	29a	6.0a	1238a	14.5a	4.7a
Bark	299b	49ab	48a	219ab	29a	6.3a	1265a	14.5a	4.6a
Mean	295B	49B	46A	217A	28B	6.1C	1216AB	14.5B	4.6A

VEL = vessel element length; VD = vessel diameter; VF = vessel frequency; RH = ray height; RW = ray width; RF = ray frequency; FL fiber length; FD = fiber diameter; FWT = fiber wall thickness. Difference between 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.

Effect of provenance on growth

The increment difference among provenances may be associated with climate type and soil characteristics. Data in table 1 show that Alvorada do Sul (Cfa) has a different climate compared to other provenances and the planting area (Cwa), although precipitation and temperature means do not show much difference. It is possible that water holding capacity contributed to the results because Alvorada do Sul soil presents high water holding capacity, and plants were adapted to this condition, while in Gália, Bauru and Luiz Antônio, soil has low water holding capacity. Climate and soil differences may have influenced growth in this species, leading to a smaller increment in Alvorada do Sul compared to other provenances.

Consequently, lower growth in Alvorada do Sul, also described by Sebbenn, Freitas, Zanatto, Moraes, and Moraes (2007) for *B. riedelianum* in the same area as that of the present investigation, should be related to denser wood compared to Gália and Bauru. King, Davies, Nur Supardi, and Stan (2005), studying the relationship among tree growth, light absorption and wood density in Malaysian forests, reported a negative relationship between wood volume for a given biomass unit and its density. According to Harris (1981), faster growth of Gymnosperm or Angiosperm trees results in lower wood density. The growth of *B. riedelianum* is slow to moderate (Carvalho 2004). The highest volumetric productivities were mentioned by Garrido, Nogueira, and Garrido (1982) and Gurgel Filho, Moraes, and Garrido (1982) at 26 years old (12 m^3 ha^{-1} $year^{-1}$), nearly twice that of our study (Table 3). However, our values were higher than those in other studies, with younger trees, reported for southern and southeastern Brazil, e.g., Carvalho (2004), but in analyses of mean annual, other factors should be considered, such as spacing, soil type and age of planting.

Anatomical differences are potential producers of variations in growth. Larger vessels were observed in Bauru, although in increment, Bauru did not differ statistically from Gália. Thus, higher growth of Bauru, especially compared to Alvorada do Sul, can be explained by higher potential of hydraulic conductivity which, as consequence, positively influences photosynthetic rate (Hacke, Sperry, & Pittermann, 2005). Larger vessels conduct water more efficiently than narrower ones. In addition, narrower and less frequent rays in Alvorada do Sul compared to the other two provenances may have also contributed to lower growth. This result can be explained by rays which primarily consist of parenchyma cells which can store starch. According to Costa, Callado, Coradin, and Carmello-Guerreiro (2006), *B. riedelianum* is mobilized for cambial reactivation after a period of dormancy. According to Carvalho (2004), *B. riedelianum* is a deciduous species. Therefore, the process of growth resumption is accelerated. From April to September, Luiz Antônio experiences a water deficit (Longui *et al*., 2011). Thus, a smaller volume and frequency of rays can be a competitive disadvantage in growth for Alvorada trees. Sebbenn, Freitas, Zanatto, Moraes, and Moraes (2009) reported faster growth and higher survival rate. Longui *et al*. (2011) observed wider rays, in provenance tests of *Gallesia integrifolia*, also planted in Luiz Antônio.

Studying the potential of native species (Brazilian) for the production of sawn wood, Silva (2013) reported that *B. riedelianum* has medium need of thinning and is suitable for planting in high silt content soils. Moreover, we found no data about the presence or content of silt in soils of studied areas. Silva (2013) did not indicate the potential production cycle for *B. riedelianum* (wood density 730 kg m^{-3}), but suggested about 45 years for *Hymenaea courbaril* (750 kg m^{-3})

and at 25 years for *Myroxylon peruiferum* (780 kg m^{-3}). In this context, we asked if *B. riedelianum* at 30 years of age would be ready for cutting. We emphasize that trees collected for the present study, presented dbh average ≈16 cm, but many trees were over 20 cm, and others reached dbh of 32 cm (Table 3). Although the tree trunk of *B. riedelianum* is usually straight, diameters found at 30 years old may not be suitable for cutting. Campbell (1999) reported that the ideal age for cutting can be determined by current annual increment (CAI), which measures how much the forest has grown in volume in the last year and mean annual increment (MAI), i.e., wood volume growing on one hectare of forest during one year on average since the forest has been planted. Campbell (1999) suggests that trees should be cut when CAI values are equal to MAI, when planting reaches the maximum wood volumetric production by area by year.

Radial variation

The most expected pattern pith-bark is an increase in density (physical property) and, consequently, an increase in mechanical properties since these are influenced by wood density, as well as an increase in fiber length and wall thickness, increase in vessel diameter and decrease in vessel frequency from pith to toward bark (Lachenbruch, Moore, & Evans, 2011; Hoadley, 2000; Baas, Ewers, Davis, Wheeler, 2004). It was observed a positive correlation between density and shear parallel to the grain (R = 0.99 and P = 0.03) and between MOR and fiber length (R = 0.99 and P = 0.04) in Alvorada do Sul. However, the expected pattern was not clearly noticed in *B. riedelianum* since a gradual increase was noted only in Gália for modulus of elasticity and in Bauru for compression parallel to the grain, both having positive correlations with radial position, as previously reported, in addition to fiber length, which gradually increased towards the bark in Gália. Other properties and anatomical characteristics did not show the typical radial pattern, as described by Lachenbruch *et al*. (2011).

In general, when considering the means values among properties in three radial positions, Alvorada do Sul presented more resistant wood when compared to Gália and Bauru. Also, values of density and compression in Alvorada were highest among the three provenances, while shear values did not differ from those of Bauru, and MOE and MOR values did not differ from those of Gália. Wood from Alvorada do Sul was the most homogeneous and absent of radial variation in six characteristics, including shear, MOE, width and frequency of ray, fiber diameter, and wall thickness. Gália did not vary in four variables, including shear, compression, fiber diameter and wall thickness. Bauru was the most heterogeneous wood, with no variation in three variables, all anatomical: vessel diameter, height and frequency of ray. Thus, Alvorada do Sul is the provenance with the highest value in properties and homogeneity, whereas Gália and Bauru provenances show the greatest mean annual increment.

Wood strength and Strength class

We did not find many studies about wood structure or physical and mechanical properties of *B. riedelianum*. Consequently, we compared the values of our study with those described by Mainieri and Chimelo (1989), Carvalho (2004) and Lima *et al*. (2011). The lack of studies about wood quality in a homogeneous plantation with determined age and spacings is a drawback since that is the information that farmers need in order to cultivate *B. riedelianum* for commercial purposes.

The density values this population are close to those reported by Mainieri and Chimelo (1989), 0.84 g cm^{-3} at 15% MC, but those authors did not mention the origin or age of *B. riedelianum*. Lima *et al*. (2011) studied the same planting of *B. riedelianum* at 24 years old and found a basic density of 0.60 g cm^{-3} (near the pith) to 0.65 g cm^{-3} (close to the bark), and Alvorada do Sul (0.66 g cm^{-3}), and Gália (0.64 g cm^{-3}) provenances did not show differences between them. Apart from the methodology for density determination which differed from that of Lima, it is related to the age of tree samples collected. Therefore, higher growth tree promoted a higher density for Alvorada do Sul compared to the other two provenances. According to Mainieri *et al*. (1983), *B. riedelianum* wood is classified as heavy wood since it has specific gravity between 750 - 950 kg m^{-3}. According to Brunelli, Leal, and Longo, (1997), *B. riedelianum* wood can be used to manufacture furniture, because its wood presents light coloration, nice appearance and appropriate mechanical strength. We noted little or no variation in color between heartwood and sapwood, which is characteristic of *B. Riedelianum*. According to Carvalho (2004), sapwood is white in color or slightly yellowish, while heartwood is white-yellowish straw, darkening to uniform pale yellow.

The results for shear parallel to the grain (16.70 MPa - 20.28 MPa, means) were higher than those reported by Mainieri and Chimelo (1989), who described 13 MPa for *B. riedelianum* green wood (above 20% moisture), but the age was not mentioned. In our study, the tests were performed with samples at 12% EMC, and it indicates dry wood. The values of mechanical properties are lower when determined in green woods, as seen in several species tabulated by Kretschmann (2010). The results for compression parallel to the grain (44.89 MPa - 54.11 MPa, means) were lower than those presented by Mainieri and Chimelo (1989) at 15% EMC (58.90 MPa), but since these did not have other information from the study cited above, it is not possible to establish a clearer comparison due to the facta that the present study used trees younger than those studied by Mainieri and Chimelo (1989).

According to NBR 7190 (ABNT, 1997), *B. riedelianum* wood falls into strength class C40, whereas the values of compression varied between 44.89 MPa to 54.11 MPa in the pith of Gália and middle position of Alvorada do Sul, respectively. Zenid *et al*. (2009) state that the use of strength classes eliminates the need to specify wood species regarding mechanical strength, but the mechanical properties should be known ahead of time in order to categorize a given species. Besides, knowledge of species is also essential when it is necessary to use wood that is naturally resistant or permeable to preservative solutions, or when it is necessary to know the workability and decorativeness of wood.

For modulus of elasticity (MOE) and modulus of rupture (MOR), Mainieri and Chimelo (1989) reported MOE of 11493 in green wood and MOR of 137 MPa at 15% moisture content. In this study values at 12% were higher for MOE (11659 MPa – 13942 MPa, means) and lower for MOR (116 MPa - 124 MPa). Here it is necessary to consider the difference in moisture content and the absence of other information from tree planting for woods which were tested and described by Mainieri and Chimelo (1989).

Conclusions

Variations in volume, properties and anatomy of wood occur among provenances. Alvorada do Sul shows lower growth in volume compared to Gália and Bauru. Alvorada do Sul wood presents higher strength and homogeneity than the other two provenances. Thus, Alvorada do Sul is the provenance with the highest value in properties and homogeneity, whereas Gália and Bauru provenances show the greatest mean annual increment.

Typical radial pattern, increase of the values from pith to the bark, is not observed for most wood characteristics, except MOE and fiber length in Gália and compression parallel to the grain in Bauru.

Based on compression parallel to the grain, 30-year-old *B. riedelianum* wood in a homogeneous planting has medium to high mechanical strength (reached a medium to upper strength class - C40), and as such, it is indicated for use in medium-sized structures and light civil construction, as well as the manufacture of furniture.

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