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ORIGINAL ARTICLE

Age of segregation of Brazilian sycamore wood from two different physiographic regions

Idade de segregação da madeira de plátano proveniente de duas distintas regiões fisiográficas

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ABSTRACT: The manufacture of wooden pieces with appropriate properties according to each type of use requires a great knowledge about their variability, especially in the radial direction. The present study aims to determine the age of segregation between juvenile and mature woods of sycamore (*Platanus* x *acerifolia*) wood by the radial variation of its basic density. Sycamore trees were randomly selected in two physiographic regions of the southern Brazil, namely Central Depreciation and Hill Top northeast. To determine density, the volume of the saturated samples was measured by the buoyancy method and the dry mass was obtained by weighing after drying in an oven at 103 °C. Sycamore wood segregated at distance between 11 cm and 16 cm from the pitch, corresponding to the 12th and 15th growth rings. The density presented significant variability when compared between regions and/or juvenile and mature woods.

RESUMO: *A fabricação de peças de madeira com propriedades apropriadas de acordo com cada tipo de utilização exige um grande conhecimento da sua variabilidade, especialmente na direção radial. O presente estudo teve como objetivo determinar a idade de segregação da madeira juvenil e adulta de plátano (Platanus x acerifolia) por meio da variação radial de sua densidade básica. As árvores de plátano foram selecionadas aleatoriamente em duas regiões fisiográficas do sul do Brasil, chamadas Depressão Central e Encosta Superior Nordeste. Para determinar a densidade, o volume das amostras saturadas foi avaliado pelo método de flutuação e a massa seca foi obtida por pesagem após secagem em estufa a 103 °C. A madeira de plátano segregou a uma distância entre 11 cm e 16 cm da medula, correspondente a anéis de crescimento entre o 12º e o 15º. A densidade apresentou variação significativa quando comparada entre regiões e/ou entre os lenhos juvenil e adulto.*

KEYWORDS
Basic density
Wood quality
Juvenile wood
Mature wood

PALAVRAS-CHAVE
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Madeira adulta

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1 Introduction

Sycamore (*Platanus x acerifolia* (Ait.) Wild) trees are find in Europe and the USA in large scale due to their quick vegetative propagation and elevated drought resistance. The specie was taken to southern Brazil with the Italian colonization (during the 19th century) in the mountain and upland regions of the state and presented good adaptation to local climatologic conditions. Currently, sycamore tress are cultivated in small and private sites and their wood is mostly used in the bent furniture industry (Gatto et al., 2007).

As other wooden species, the sycamore wood is marked by its heterogeneity, thus presents many anatomical characteristics that may lead to variations in physical and mechanical properties. In addition to the aforementioned mechanisms, other exogenous factors can be considered sources of variation for its properties. This way, for a suitable sampling and correct wood quality evaluation, it is critically important to consider the reliability of the selecting method.

In choosing the most adequate woods for a specific application, density is the most important technological property. This physical property can be useful to classify the various types of wood (Alteyrac et al., 2005; Nugroho et al., 2012). Thus, the demarcation between juvenile and mature woods shall be considered a method for wood classification in function of radial position.

Peres et al. (2012) highlighted the importance of estimating the age of wood demarcation in order to improve silvicultural management techniques. According these authors, the knowledge about the beginning age of mature wood production allows the optimization of a thinning process in order to suppress juvenile wood production, which presents lower quality. From the technological standpoint, the age of segregation of a specie provides a tool in order to interfere in aspects such as the incidence of drying defects, physical and mechanical properties of wood, the cellulose pulping yield and paper's quality (Delucis et al., 2014).

Some authors, while examining distinct hardwoods, noted similarities in the distribution of their anatomical properties and adopted a method that generates two regression lines to demarcate the beginning of mature wood by considering the fiber length as the principal variable (Loo et al., 1985; Gatto et al., 2013; Palermo et al., 2015). This criterion was analogously used considering the density (Peres et al., 2012; Lourençon et al., 2013) and the modulus of elasticity in bending (Delucis et al., 2015).

Among the various interactions involving density, the literature emphasizes the knowledge about the origin of the trees (Delucis et al., 2014). In this context, based on parameters such as climatological data and soil constitution, the Brazilian territory is classified in different physiographic regions.

Regardless of factors like genetic heritability, hormone production, seed origin, and silvicultural management, the wood quality is strongly affected by the planting area, especially due to soil depth and drainage, amount and pattern of yearly soil moisture availability, and frequency and nature of common and occasional winds and storms (Evert, 2006). In a second place, the presence of competing vegetation, and some types of animals, insects and microorganisms can also damage the trees. Therefore, different species might present woods with different qualities in relation to these external conditions, which is dependent of their adaptation to the environment.

The physiographic region known as Central Depression occupies an area of 54,000 Km^2 in the state of Rio Grande do Sul. In this region, gondwana sediments predominate in the soil, with average high and low temperatures at 25 and 14 °C respectively, and an average annual rain precipitation of 1,600 mm (Brasil, 1973). The Hill Top northeast covers an area of 7,600 Km^2 in Rio Grande do Sul with mountainous terrain. With geologic formation composed by basaltic sediments, the referred region shows average low a high temperatures at 15 and 23 °C and an annual rain precipitation of 1,800 (Brasil, 1973).

Considering the mentioned issues, the present study aims to determine the demarcation age of juvenile and mature woods of the sycamore from two distinct physiographic regions of the state of Rio Grande do Sul, i.e. Central depression and Hill Top northeast, considering the variation of density in the radial direction.

2 Materials and Methods

Ten 50-70 years old trees were felled in two different physiographic regions belong to Rio Grande do Sul state, namely Central Depression and the Hill Top northeast. The selected tress presented at least 30 cm diameter and right form (shape), i.e. straight and cylindrical trunk, absence of bifurcation and good phytosanitary status. Moreover, trees located at the extremities of the planting area or at sloping ground were also avoided, according the procedure described in ASTM D 5536-95 (ASTM, 2010).

Following the tree harvesting, discs with 2 cm of thickness at DBH were produced. From each disc a slat from the central position was obtained, without cardinal orientation, centered on the pith and oriented considering the axial direction of the tree. The obtained material was taken to the Forest Products Laboratory (FPL) of the Federal University of Santa Maria (UFSM), where the central slats were sectioned centimeter by centimeter in the pith to bark direction. The final products were the produced samples of the wood with dimensions of 1.0 x 1.0 x 2.0 cm (radial, tangential and longitudinal directions, respectively), shown in Figure 1.

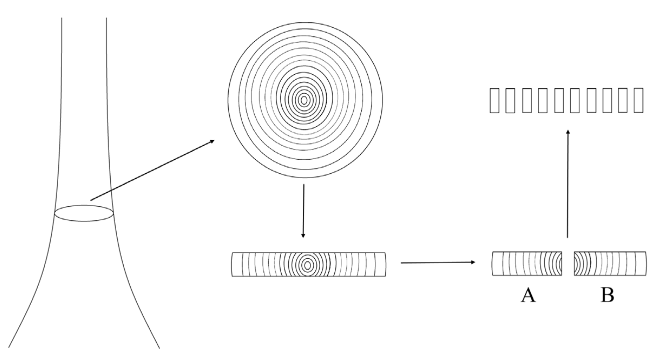

Figure 1. Scheme for the collection and preparation of samples. Where: A and B are wooden parts from each side of the central slat.

Figura 1. Esquema para a coleta e preparação das amostras. Onde: A e B são peças de madeira selecionadas de cada lado da bagueta central.

For the density measurement, the samples were firstly saturated with water in order to achieve constant mass. The volume was measured using the buoyancy method. Samples were then oven dried at 103 °C until constant mass, measured in an analytic balance (resolution of 0.01g). The calculation of basic density was performed considering the ratio between the anhydrous mass (m_a) and the saturated volume (V_s). Due to the reduced thickness of the growth rings, the samples were produced to contain a minimal number of these units, while still allowing for the density measurement.

In order to determine the zones belong to both the juvenile and mature woods for each physiographic region, a linear regression model was produced for the ascendant part of the graph "density versus radial position", with points beginning from the pith. Then, another model was generated for the stabilized part of the data, that followed the former part of the data, with points up to the bark. These two zones were defined visually, and the segregation point was the intersection between the two plotted regression lines extrapolated, as described in the literature (Lourençon et al., 2013; Delucis et al., 2014). Therefore, this point can also be defined as the point where the Y-axis value is equal for the two mathematical model.

In addition, polynomial regression models were produced to verify the variability in the basic density in the radial direction, from pith to bark. The models were analyzed based on the following parameters: coefficient of determination (R^2), average standard error (S_{YX}), calculated F-Value and confidence level.

Factorial analysis of variance was performed in order to verify the behavior of basic density considering the types of wood (juvenile and mature) and physiographic regions as the sources of variation. In the cases described as rejected null hypotheses, the average tests were performed with a 95% of confidence level.

3 Results and Discussion

Based on the polynomial regression model (Table 1 and Figure 2), the basic density for both physiographic regions increases up to half of the radial section and then decreases

Table 1. Regression equations to estimate the density as a function of the radial position.

Tabela 1. Equações de regressão para estimar a densidade em função da posição radial.

Region	Ring		Equation	R^2	S_{yx}	F-ratio
A	12	a	$\rho = 0.5406 + 0.0079 \cdot p$	0.27	0.03	33*
		b	$\rho = 0.6254$	-	0.03	-
		e	$\rho = 0.5494 + 0.00650048 \cdot p - 1.258 \cdot 10^4 \cdot p^2$	0.36	0.03	62*
B	15	a	$\rho = 0.545484 + 4.8308 \cdot 10^3 \cdot p$	0.37	0.03	82*
		b	$\rho = 0.6525 - 1.7382 \cdot 10^3 \cdot p$	0.08	0.03	10*
		e	$\rho = 0.5372 + 7.8901 \cdot 10^3 \cdot p - 1.9221 \cdot 10^4 \cdot p^2$	0.43	0.03	97*
Both	12	a	$\rho = 0.5418 + 6.65833 \cdot 10^3 \cdot p$	0.26	0.03	65*
		b	$\rho = 0.6120$	-	0.01	-

Where: ρ= basic density ($g.cm^{-3}$); p= radial position (cm); A= Central depression; B= Hill Top northeast; a= first equation (ancestry points); b= second equation (stabilization points); e= the full extent of points; R^2= coefficient of determination; S_{yx} = standard error of estimate ($g.cm^{-3}$); F-ratio = valor de F calculated. * = significant at 1% error probability.

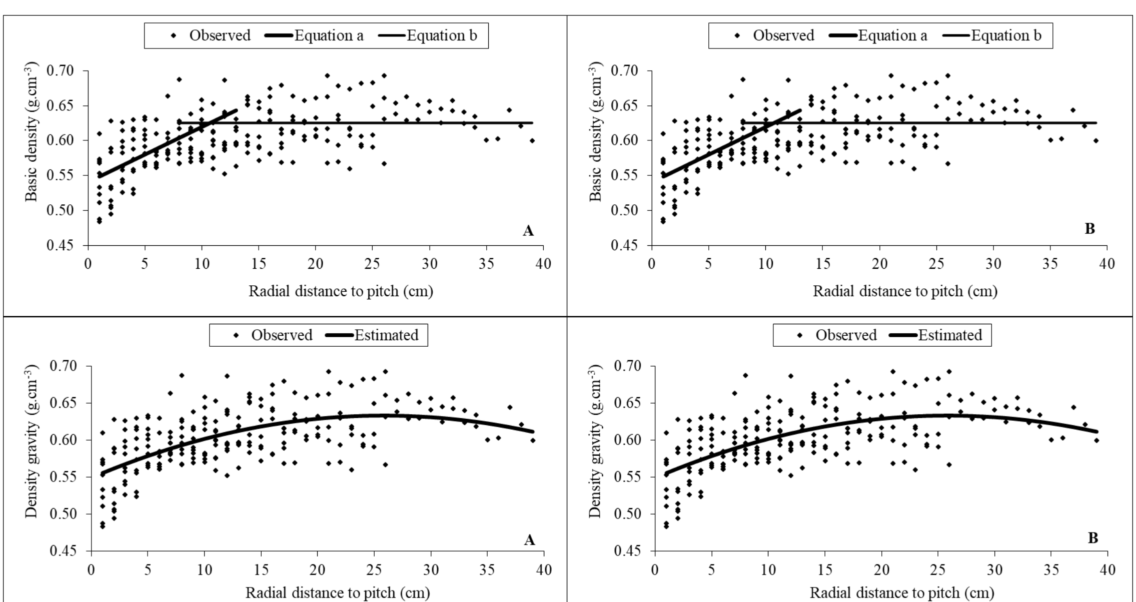

Figure 2. Variation of basic density in the pith-bark direction. Where: A = Central Depression; B = Hill Top northeast.

Figura 2. Variação da densidade básica no sentido medula-casca. Onde: A= Depressão central; B= Encosta Superior Nordeste.

slightly. For the Central Depression region, this increasing behavior occurs up to about 15 cm from the pith. On the other hand, for the Hill Top northeast region, increase of the related property occurs up to about 20 cm. For both regions, the basic density presents a decreasing behavior.

Based on the intersection of the linear regression models, it is possible to assert that the basic density variation from the pith to the bark region did not present a pattern discordance, considering the physiographic regions of the selected trees for this study. For the Central Depression region, the segregation occurred at 11 cm from the pith, which corresponds to the 12th ring. On the other hand, for the Hill Top northeast region, the segregation occurred 16 cm from the pith, corresponding to the 15th growth ring.

Similarly to the present study, other authors that based on the radial variation of basic density also verified data distributions that enabled to observe the segregation of juvenile and mature woods (Gatto et al., 2012; Peres et al., 2012). In their study, Gatto et al. (2007) defined the point of demarcation of sycamore using the variation of anatomical parameters and verified that the phenomenon occurs at the 14th ring, which shows a similar result to the present study.

In general, the basic density is affected by many characteristics, such as anatomical: cell wall thickness, number of vessels, and fiber dimensions: chemical: quantity of each chemical compound, extractive and cellulose contents; genetic: seeds origin; and by exogenous factors such as climatic conditions, forest implantation and leading systems. It also varies as a function of the growth rate, original location, spacing, age, between genders, species and trees of the same species, along the basis to top and the pith to bark directions (Alteyrac et al., 2005; Wiedenhoeft, 2010).

The average value founded for basic density, without a distinction of the region and the type of wood, was 0.603 g.cm^{-3}. Based on factorial analysis of variance, the variability of basic density was verified considering the physiographic region (F=8.89; P= 0.0030) and the type of wood (F=111.38; P= 0). The interaction of the sources of variation was verified and presented no significance (F= 3.15; P= 0.0769). This way, the variation provided by different regions of trees does not present a relation with the variation provided by the type of wood (Table 2).

Based on the average tests, presented on Table 2, the density presented significant variance when compared between types of wood for both regions. On the other hand, only mature wood showed a significant difference when compared between regions, with wood from the Central depression presenting greater density than Hill Top northeast. Nevertheless, considering the similarity of the regions from the climatic standpoint, this difference can be attributed to the growth rate occurred due to P_2O_5 and K_2O highly concentrated in soils with gondwana sediments (Mani et al., 2016).

Similarly, Peres et al. (2012) and Gatto et al. (2013) founded significant variation of density between region of origin and types of wood. This way, with the contribution of the present work, the idea that the quality of the site and the wood variability in the radial direction can be reinforced as determinant factors to be studied, in order to determine possible uses of wood with great precision.

Table 2. Average basic density values.

Tabela 2. Valores médios de densidade básica.

Region	μ	
	Juvenile wood	Mature wood
Central depreciation	0.587 $_{(0.044)}$ a A	0.628 $_{(0.030)}$ b B
Hill Top northeast	0.583 $_{(0.032)}$ a A	0.612 $_{(0.028)}$ a B

Where: μ= average (g.cm^{-3}). Standard deviation (g.cm^{-3}) between parentheses. Means with the same lowercase letters in a column and uppercase letters on a line do not differ at 5% error probability according to Fisher's LSD test.

4 Conclusions

Sycamore wood segregated between 12 and 15 years. Its basic density average, without distinction of sources of variation, was 0.603 g.cm^{-3}. The basic density presented significant variation when compared between types of wood for both physiographic regions and between regions, except for juvenile wood. Therefore, for purposes where high quality are required of sycamore wood, it is suggested a planting plan with forecast for felling trees with a consolidated production of mature wood. In this sense, as planting area, Central depreciation is preferable than Hill Top northeast in order to obtain mature wood samples from this specie with better quality.

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Authors' contributions: Rafael de Avila Delucis wrote overall the manuscript, accounting literature review and conclusions made after the results analysis. Matheus Lemos Peres acted together Rafael in all these activities, since these two researchers are Post-Graduation students and they were colleagues during their respective master courses, wherein they belonged to the same research group. Matheus was crucial to elaborate all the text in English, since he has a wide knowledge about this. Rafael Beltrame supervised the Rafael and Matheus work's, guiding their efforts since the literature review until the final version of the manuscript. Indeed, Professor Rafael made the final edition of the text, to identify any possible mistake, as well as about terminological coherence, since he has wide experience in the wood science sector. Darci Alberto Gatto made all experiments during his doctorate course, and then, he invited all the other authors to help his for publishing this article. Clovis Roberto Haselein was the advisor of Darci during his doctorate course, contributing with a large intellectual helps in order to elaborate the whole work since the first ideas and proposals about the project.

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