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Longitudinal variation of wood basic density of *Inga marginata* and *Chrysophyllum gonocarpum*

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Abstract
The wood basic density is one of the main physical properties of wood and is correlated with several other characteristics of this material. Thus, this study aimed to evaluate the longitudinal variation of wood basic density of *Inga marginata* Willd. and of *Chrysophyllum gonocarpum* (Mart. & Eichler) Engl. The three trees of each species were shown in a fragment Seasonal Deciduous Forest Alluvial and, after cutting, were measured and cubed by the Smalian's method. For the determination of wood basic density, discs were removed in positions the 0.1 m of the base, 25, 50, 75 e 100% of the commercial height and diameter to height of 1.30 m above the soil. The results indicated that both the wood *Inga marginata* as the *Chrysophyllum gonocarpum* presented variation of wood basic densityin the bottom-up sense, where the highest values of this characteristic were observed in the base with decreasing trend until top the trees. The mean wood basic density of each species was 0.574 and 0.575 g.cm^{-3} for *Inga marginata* and *Chrysophyllum gonocarpum*, respectively.
Key words: Ingá-feijão; Aguaí-da-serra; Native species; Wood quality.

Variação longitudinal da massa específica básica da madeira de *Inga marginata* e *Chrysophyllum gonocarpum*

Resumo
A massa específica básica é uma das principais propriedades físicas da madeira e está correlacionada com várias outras características desse material. Assim, esse estudo teve por objetivo avaliar a variação longitudinal da massa específica básica da madeira de *Inga marginata* Willd. e de *Chrysophyllum gonocarpum* (Mart. & Eichler) Engl. As três árvores de cada espécie foram amostradas em um fragmento de Floresta Estacional Decidual Aluvial e, após o corte, foram medidas e cubadas pelo método de Smalian. Para a determinação da massa específica básica foram retirados discos nas posições a 0,1 m da base, 25, 50, 75 e 100% da altura comercial e no diâmetro à altura de 1,30 m do solo. Os resultados indicaram que tanto a madeira de *Inga marginata* e quanto a de *Chrysophyllum gonocarpum* apresentaram variação da massa específica básica no sentido base-topo, onde os maiores valores dessa característica foram observados na base com tendência decrescente até o topo das árvores. A massa específica média de cada espécie foi 0,574 e 0,575 g.cm^{-3} para *Inga marginata* e *Chrysophyllum gonocarpum*, respectivamente.
Palavras-chave: Ingá-feijão; Aguaí-da-serra; Espécies nativas; Qualidade da madeira.

Introduction

The *Chrysophyllum gonocarpum* (Mart. & Eichler) has great dispersion of Rio Grande do Sul to the south of Bahia and Goiás - Brazil, features heavy wood being used for firewood, charcoal and making rustic furniture (Lorenzi 2002). *Inga marginata* Willd. It has natural occurrence in northeastern Argentina (South America) to Costa Rica (Central America), features light wood and is used for production of firewood and charcoal can be used for pulp and tannin extraction (10 to 15% in the bark) (Carvalho 2006).

Knowledge of the wood basic density (WBD) of wood of these species is scarce. The WBD can be considered as the combination of their different cell types and reflects the amount of ligneous material per unit volume or, of mode inverse, the volume of empty spaces inherent to wood (Peres et al. 2012).

By being one of main technological parameters, the WBD is excellent indicator of wood properties (Vale et al. 2009), due to its relation to other various characteristics, such as rupture strength, shear etc., and also be easily determined (Lima and Garcia 2005; Washusen et al. 2005; Mattos et al. 2011; Eloy et al. 2013). Thus, indicates the feasibility of its use in various purposes, the WBD is important because it is a characteristic amenable to genetic improvement and considered highly inheritable (Lopes and Garcia 2002; Trautenmüller et al. 2014).

The variations of WBD found in forest species is due to the differences in the anatomical structure of the wood and, in smaller proportions, the amount of extractive substances present per unit volume. These variation happen because, primarily, the age of the tree, genotype, site quality, climate, geographical location (Alzate et al. 2005; Washusen et al. 2005; Trevisan et al. 2007; 2012a; 2012b) and according to the growth rate (Rezende et al. 1998).

The variability of WBD of hardwood can be given per four variation models, (I) where uniformly decreases with height, (II) decreasing until the middle of bole with accrual up to the top, (III) growing from base to top, but not having an definite standard and (IV) not presenting variation according to height (Downesand Raymond 1997).

The growth of WBD can be the result of increased of cell wall thickness of fibers or an increase in the proportion of the fibers in relation to the proportion of vases. In inverse way, an increase in the proportion of vases, with or without a decrease in cell wall thickness leads to decreased WBD (Eisfeldet al. 2009).

With this, the use of wood as raw material may only occur from the adequate knowledge of its properties (Klock et al. 2004). For being a heterogeneous organic element, composed basically of cellulose, hemicelluloses, lignin and extractives, shows versatility of uses to obtain a series of products, such as plywood, MDF, paper and wood for construction.

In this sense, the present study has the objective to evaluate the longitudinal variation of wood basic density the

Inga marginata Willd. and *Chrysophyllum gonocarpum* (Mart. & Eichler) Engl.

Material and methods

For the present study were used three trees of each species, which had average diameter 14.0 (± 3.1) and 16.5 (± 2.0) cm the DBH (diameter at breast height - 1,3 m above the ground), in *Inga marginata* and *Chrysophyllum gonocarpum,* respectively. These was in a fragment located in the county of Iraí (RS - Brazil), at area Federal University of Santa Maria - UFSM, centered on the coordinates 27º13'35.31" South and 53º18'59.06" West.

The regional climate is subtropical very humid, with precipitation annual average between 1.700 and 1.900 mm and average temperature between 20 and 23ºC (Rossato 2014) and soil can be classified as neosol regolithic eutrophic (Santos et al. 2013).

To study the WBD were removed discs with approximately two centimeters thick, the following positions bole: 0.1 m (base), 25, 50, 75 and 100% commercial height (defined by minimum stem diameter equal to five centimeters) and diameter at breast height (DBH). In the field, the disks were placed in plastic sacks and transported to Forest Products Technology Laboratory (FPTL) UFSM-FW where were labeled and divided two symmetrically opposed wedges, containing parts of heartwood and sapwood.

The wooden wedges were submerged in water, where remained until reach constant weight. For obtaining WBD (Equation 1) of each wedge, was determined, first, the saturated volume, using the method of hydrostatic balance, described by Vital (1984). The dry mass was obtained by leaving the samples in a greenhouse the ± 103°C until reach constant weight.

The volume was calculated by Smalian's method, collecting diameters without bark in the relative positions where withdrew the discs sample, was measured the length of each section and calculated the volume of each section (v_i), thus, the commercial volume (v_{5s}) each tree is result the sum of the five sections.

For the analysis of WBD along the bole, the data sampled by relative position were submitted to regression analysis. These were processed by package "*Statistical Analysis System*" (SAS 1993), in which it was, first, applied the procedure *Stepwise* regression modeling. The model was definite by Equation 3. The WBD, at each position on the trunk it was determined by the average of values of the two wedges. Then, were calculated the weighted according to the volume of each tree (Equation 2).

$$\rho_b = Mo/Vu \quad (1)$$

Where:
pb = wood basic density, g.cm^{-3};
Mo = dry weight in a greenhouse (103°C) g;
Vu = volume saturated, cm^3.

$$\rho_{bpond} = ((((\rho_{b0\%} + \rho_{bDBH})/2)*v_1) + (((\rho_{bDBH} + \rho_{b25\%})/2)*v_2) + (((\rho_{bi} + \rho_{bi+1})/2)*v_i)) / v_{5s} \quad (2)$$

Where:
$\rho_{b\ pond.}$ = WBD on the total volume without bark, g.cm^{-3};
$\rho_{b"i"}$ = basic density in the position "i", g.cm^{-3};
v_1, v_2, v_i = volume without bark corresponding to two successive positions, m^3;
v_{5s} = commercial volume without bark, m^3.

$$\rho_b = f\ (P;\ 1/P;\ P^2;\ 1/P^2;\ \ln P;\ 1/\ln P;\ \sqrt{P}) \quad (3)$$

Where:
ρ_b = Wood basic density, g.cm^{-3};
P = Relative position (bottom-up direction), %.

The best equation was selected based on the adjusted coefficient of determination ($R^2_{aj.}$), standard error of estimate (S_{xy}), value of F calculated and analyzing the distribution of residues in each variable in the model.

Results and discussion

The average values for WBD *Inga marginata* and *Chrysophyllum gonocarpum* and ranged from 0.596 to 0.515 g.cm^{-3} and 0.593 to 0.544 g.cm^{-3}, in the sense base top, respectively (Table 1). The WBD weighted based on the commercial volume of the bole without peel was found 0.574 and 0.575 g.cm^{-3} for *Inga marginata* and *Chrysophyllum gonocarpum*, respectively. The WBD of *Inga marginata* found in this study is higher than the values found in the literature, which range from 0.400 to 0.500 g.cm^{-3} (Carvalho 2006). As for the *Chrysophyllum gonocarpum*, the WBD values are smaller than 0.780 g.cm^{-3} cited by Lorenzi (2002).

Table 1. Wood basic density average per position sense longitudinal and wood basic density weighted for the commercial of the bole volume not shelled for trees *Inga marginata* and *Chrysophyllum gonocarpum*.

Species	Position on the sense base-top						$\rho_{pond.}$ (σ)
	0.1 m	DAP	25%	50%	75%	100%	
Inga marginata	0.596	0.587	0.583	0.566	0.555	0.515	0.574 (±0.030)
Chrysophyllum gonocarpum	0.593	0.586	0.584	0.562	0.554	0.544	0.575 (±0.016)

Where: $\rho_{pond.}$ = Wood basic density weighted for the bole volume without bark, g.cm^{-3}; σ = standard deviation, g.cm^{-3}.

Analyzing the WBD weighted and the relative positions, it is observed that between 25% and 50% of the height of the tree are the positions that more approached the weighted average this characteristic for the species *Inga marginata* and *Chrysophyllum gonocarpum*. Trautenmüller et al. (2014) cite that for *Cordia americana* the height of 50% and *Alchornea triplinervia* the strip of the DBH to 50%, are the heights that more represent the WBD weighted.

For the species *Eucalyptus saligna*, *Eucalyptus grandis* (Souza et al. 1986), *Trichilia claussenii* and *Calyptranthes tricona* (Trautenmüller et al. 2015) and *Acacia mangium* (Vale et al. 1999) the height of 25% has the best correlation as the WBD arithmetic mean. But, the height of 25 and 50% also boast good relationship with WBD arithmetic mean, for three species of gymnosperms *Araucaria angustifolia*, *Pinus elliottii* e *Pinus taeda* (Mattos et al. 2011). The regression equation selected by the procedure *Stepwise* to estimate the longitudinal variation of WBD *Inga marginata* (Equation 4), had a coefficient of variation equal to 5.5%; adjusted coefficient of determination of 0.41 and standard error of the estimate of 0.032 g.cm^{-3} (Table 2).

$$\rho_b = 0.59045 – 0.00000733*P^2 \quad (4)$$

Where:
ρ_b = Wood basic density, g.cm^{-3};
P = Relative position (sense base-top), %.

The regression equation to estimate the longitudinal variation WBD of *Chrysophyllum gonocarpum* (Equation 5) had a coefficient of variation equal to 3.6%; determination coefficient of 0.43 and a standard error of estimate of 0.020 g.cm^{-3} (Table 2). The values of WBD in function of the relative position base-top sense, estimated for the species *Inga marginata* and *Chrysophyllum gonocarpum* through the models described earlier can be seen in Figure 1A and 1B.

$$\rho b = 0.59388 – 0.00051993*P \quad (5)$$

Where:
ρb = Wood basic density, g.cm^{-3};
P = Relative position (sense base-top), %.

Table 2. Analysis of variance of the regression of wood basic density *Inga marginata* and *Chrysophyllum gonocarpum* according to the relative position.

------------- *Inga marginata* -------------			----------- *Chrysophyllum gonocarpum* -----------		
SV	MS	F	SV	MS	F
Equation	0.0126	12.72*	Equação	0.00567	13.65*
Error	0.0009905		Error	0.00041542	

Where: SV = source of variation; MS = mean square; F = F value; * significance level at 5%.

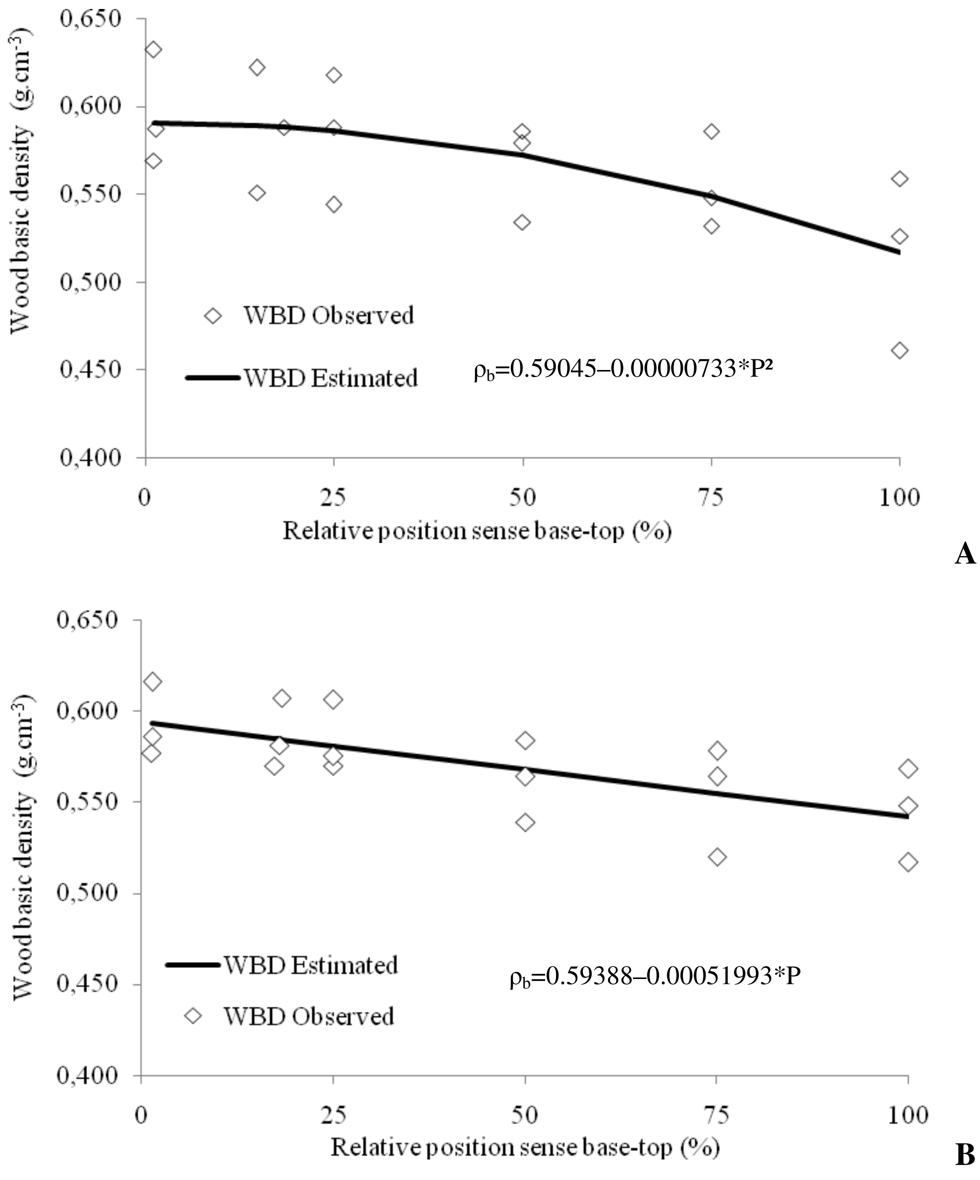

Figure 1. Variation in wood basic density of the trees *Inga marginata* (A) and *Chrysophyllum gonocarpum* (B) on function of the relative position in the sense longitudinal. Where: ME = wood basic density base, g.cm^{-3}.

In relation to longitudinal variation of WBD, this, presents statistical difference between the relative positions, with decreasing trend, where, adult wood and juvenile assist in variance the WBD. Compared with adult wood, juvenile wood differs by presenting a WBD lower, greater longitudinal contraction, greater angle microfibrilar, greater proportion of reaction wood, thinner cell walls, higher content of lignin, smaller transverse shrinkage, smaller percentage of autumnal wood, smaller cellulose content and less mechanical resistance (Latorraca and Albuquerque 2000; Melo et al. 2010).

Conclusion

In general, the two species shows the same model longitudinal variation of wood basic density, decreasing from base to top. The species *Inga marginata* and *Chrysophyllum gonocarpum* presented wood basic density averaged 0.574 and 0.575 g.cm^{-3}, respectively.

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