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Physical and Mechanical Properties of Juvenile Wood of *Anadenanthera peregrina* (L.) Speg. from Thinning

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Abstract: Reducing the rotation period through thinning and changing planting spacing can influence the technological properties of wood, with little attention paid to the effects of these variables on the raw material, which limits its processing in the wood sector. This work aimed to evaluate the physical and mechanical properties of wood from *Anadenanthera peregrina* juveniles thinned in three planting spacings (3 m × 3 m, 4 m × 4 m, and 5 m × 5 m). The physical properties in the base-top and pith–shell directions and the mechanical properties of the samples were evaluated. The results indicate better technological properties for wood with larger spacings. The physical properties showed decreasing trends in the base-top direction and increasing trends in the pith-bark direction, with a distinct trend in the degree of collapse. The average basic density of the different planting spacings varied between 0.47 g cm^{-3} and 0.63 g cm^{-3}. The mechanical properties obtained for the 4 m × 4 m spacing were superior to those of the other spacings. Wood from young *A. peregrina* is an alternative for industrial processing, as wood from higher planting densities is more suitable for purposes that require resistance and rigidity.

Keywords: red angico; silvicultural management; wood technological characterization

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1. Introduction

Discussions about the technological properties of wood have become frequent due to the versatility and high potential for use of the material, with the intrinsic characteristics of wood being factors that influence its quality, which makes it necessary to have approaches that help in the correct choice of the material. These choices allow inferences about possible industrial applications and lead to more efficient use of the raw material, thus promoting the appreciation of different species that are still little recognized by the timber sector.

There are several existing approaches to wood characterization, with the generally applied methods being those that enhance industrial use, such as physical and mechanical properties [1], which are used to estimate the stiffness and resistance of wood when adult, which contributes to the generation of products with greater added value [2].

However, although the characterization of mature wood is a common practice and of greater industrial interest, research has advanced with the aim of characterizing wood that is still young, which tends to diversify the use of the raw material, making it more competitive in the wood sector.

Young wood is defined as the secondary xylem formed during the early life of the tree [3,4], being produced close to the pith of the tree and presenting intrinsic properties considerably different from those of adult wood, where this refers to wood that has tracheid's stabilized growth [5], with density, tracheid length, cell wall thickness, cellulose content, strength, and stiffness being greater when compared to young wood [6].

When young, wood has smaller and shorter fibers, thinner fiber walls, larger microfibril angles, higher lignin content, lower density, and lower strength than adult wood, which leads to the depreciation of the raw material since it presents undesirable and disadvantageous properties for its application [7–11].

However, despite its limited application in different segments, the study of the properties of wood that is still young tends to elucidate the performance of different species, promoting their use during their initial phase and enabling the processing of material from interventions applied to planting. Tree thinning is one common practice.

Thinning is an activity that aims to reduce competition between trees by removing some individuals from the stand. This enables an increase in wood production with less competition between the remaining trees, resulting in varied benefits to the forest [12].

This practice can be applied to better utilize trees that would be lost due to natural mortality and the growth of remaining trees [13,14], with other advantages attributed to improving forest vitality and biodiversity.

Despite being a common practice of application in forests, little is known about the performance of this activity on the properties of wood, which makes new paths for the insertion of young wood resulting from this method unfeasible, thus generating inadequate disposal of wood from species that are little or already recognized industrially, including red angico wood (*Anadenanthera peregrina* (L.) Speg.).

Red angico wood has commercial potential; as a result, adult trees of this type have good resistance and rigidity, and at the same time, they have great durability and easy workability [15–17], even for energy use [18] and carbon stock [19].

This species is known toto easily adapt to different environments, and its adult trees can reach heights of between 14 and 22 m, with its trunk characterized by being short, not very cylindrical, and which can vary between 40 and 80 cm in diameter [15]. In relation to this wood, when mature, the species has a resistant heartwood that is hard to cut and durable under natural conditions, in addition to presenting excellent conditions for adhesion and accepting finishes with paints and varnishes [20,21].

However, despite the important characteristics it possesses, there is no information available in the literature about the species wood when young, which has led to the depreciation and underutilization of the raw material, thus highlighting the need to generate scientific information to boost efficient processing. Nonetheless, we can expand the use of juvenile red angico wood and thus generate a new alternative for the timber market. To achieve this, it is necessary to characterize the wood while it is still young so that it serves as a reference for further studies and future applications, with the knowledge generated being a path to carrying out possible actions aimed at obtaining a raw material with desirable characteristics.

Due to the context and the importance of characterizing young wood, the present study aimed to evaluate the physical and mechanical properties of *A. peregrina* juvenile wood in the base-top and pith-bark directions, with the wood studied coming from thinning practices applied at different planting spacings.

2. Materials and Methods

2.1. Collection of Experimental Material

The material for this study was obtained from stands of the species *Anadenanthera peregrina* (L.) Speg, from an experimental plantation located in an area belonging to the Federal Institute of Espírito Santo, located in the district of Rive, municipality of Alegre, in the southern region of the State of Espírito Santo, Brazil. This area is named under the *Pilot Forest* project.

The climate of this region, according to the Köppen classification, is of the Aw type, marked by the occurrence of rainy summer and dry winter periods, with the average temperature and precipitation during the growth period of the trees being 23.9 °C and 1222 mm, respectively (based on data from the Automatic Meteorological Station, located in Rive, Alegre municipality, state of Espírito Santo, Brazil, which were provided by the National Institute of Meteorology (INEMET)) [19,22].

Regarding the collection of trees, five individuals were selected resulting from selective thinning, applied in order to reduce competition between trees, with individuals collected from 3 m × 3 m, 4 m × 4 m, and 5 m × 5 m spacings at 90 months of age.

The collected trees were selected according to their diametric classes; wood disk were obtained from each spacing with average diameters of 29 cm ± 3.97, 41.9 cm ± 3.43, and 55.4 cm ± 7.76 (mean diameter ± standard deviation) (3 m × 3 m, 4 m × 4 m, and 5 m × 5 m, respectively) and 4 cm thick, according to the commercial height, considered when the bifurcation interrupted the stem continuity in the positions (0% (base), 25%, 50%, 75%, and 100% (top)) according to the methodology described by Martins et al. [23], in addition to an extra disk removed at the height of the diameter at chest height (DBH) (1.30 m from the ground) (Figure 1).

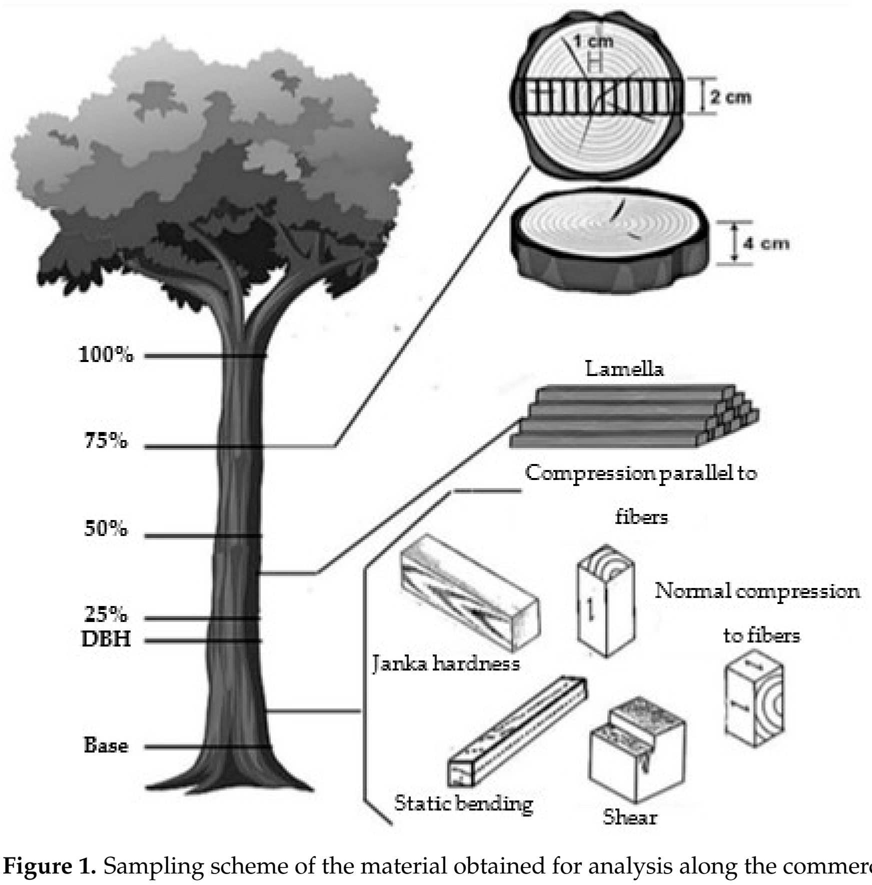

Figure 1. Sampling scheme of the material obtained for analysis along the commercial height and in the pith—-bark direction in *Anadenanthera peregrina* juvenile wood.

The collected logs were destined for an analysis of the mechanical properties (first logs), and the material was identified and stored in a place that was protected from the weather.

2.2. Determination of Physical Properties

For the analysis of the physical properties of wood from the collected disks, specimens were obtained at each radial centimeter, being identified according to the treatment and position of the tree. For the analysis of the basic density, linearity, and volumetric shrinkage, the specimens had their dimensions adapted due to the diametrical variation of the disk, having a dimensional pattern of 1.0 × 2.0 × 4.0 cm (thickness, width, and height, respectively) cut in radial, tangential, and longitudinal directions, respectively.

The anisotropic factor of the wood was determined by the values obtained through the relationship between the shrinkage in the tangential and radial directions (T/R).

To assess whether the samples would tend to collapse during the drying process, the thickness of the specimens was measured in the transversal direction [24] (Equation (1)):

$$DC = T_{max} - T_{min} \quad (1)$$

where DC: degree of collapse; T_{max}: maximum thickness, in mm; and T_{min}: minimum thickness, in mm.

After measuring the dimensions of saturated samples and weighing them, the samples were submitted to the drying process in an oven (Solab, SL-102/480, Piracicaba, SP, BR) with an initial temperature of 50 °C, gradually increasing 10 °C at each time until 103 ± 2 °C was reached, remaining at this temperature until constant mass. After drying, the samples were measured and weighed to obtain the dimensions and mass in the dry condition.

2.3. Determination of Mechanical Properties

The specimens for the analysis of mechanical properties were adapted due to the limited availability of material and to defects and drill attacks, being produced according to the American Society for Testing and Materials—ASTM D-143-22 [25]—with the exception of specimens for tests of resistance to compression parallel to the fibers that were produced according to the Brazilian Regulatory Norm—NBR 7190-3 [26]. The dimensions of the test specimens as well as the load applied to them are specified in Table 1.

Table 1. The dimensions of the test specimens for evaluating the mechanical properties of red angico wood.

Mechanical Properties	Dimensions (cm)	Speed of Applied Load
Compressive strength parallel to the fibers	2.5 × 2.5 × 7.5	10 MPa min^{-1}
Compressive strength perpendicular to the fibers	2.5 × 2.5 × 5.0	0.305 mm min^{-1}
Static bending strength	2.5 × 2.5 × 46.0	2.5 mm min^{-1}
Shear strength	5.0 × 5.0	0.6 mm min^{-1}
Janka hardness	5.0 × 5.0 × 15.0	6 mm min^{-1}

Fourteen replicates were obtained for each mechanical test for each different plant density spacing, totaling 168 samples. The specimens were stored in an air conditioning chamber (Eletrolab, EL011, São Paulo, SP, BR) with a temperature of 25 ± 2 °C and 65 ± 5% relative humidity, and were weighed periodically until stabilization. After stabilization, the mechanical tests were performed on a universal testing machine with a capacity of 100 kN and automatic data retrieval (EMIC, DL 10000, São José dos Pinhais, PR, BR).

2.4. Statistical Analysis

The physical properties were analyzed by means of simple linear regression expressed in a descriptive way through the use of Excel software (Microsoft®, Office Professional Plus, version 2016, Redmond, WA, USA) with the purpose of evaluating the behavior of the wood in the pith-bark and base-top directions, with a 95% significance.

The data of the physical and mechanical properties were evaluated according to the following assumptions: (a) homogeneity of variance (Cochran test, $p < 0.05$) and (b) normality of experimental errors (Shapiro–Wilk test, $p < 0.05$) with SPSS software (Statistical Package for the Social Sciences, version 22.0, Armonk, NY, USA).

The assumptions were met, and the analysis of variance ($F < 0.05$) was performed based on a completely randomized design (DIC), composed of three treatments (planting spacing), for the technological properties of the wood. In cases where there was a significant difference in the analysis of variance, the means test was applied (Tukey, $p < 0.05$). The analysis of variance and test of means were performed in the Sisvar program (Version 5.6, Lavras, MG, BR) [27].

3. Results

3.1. Physical Properties of Wood

When correlating the behavior of the physical properties of *Anadenanthera peregrina* juvenile wood with height, there was a tendency towards a decrease in the basic density and shrinkage (radial, tangential, and volumetric) in the studied spacings (Figure 2A–D).

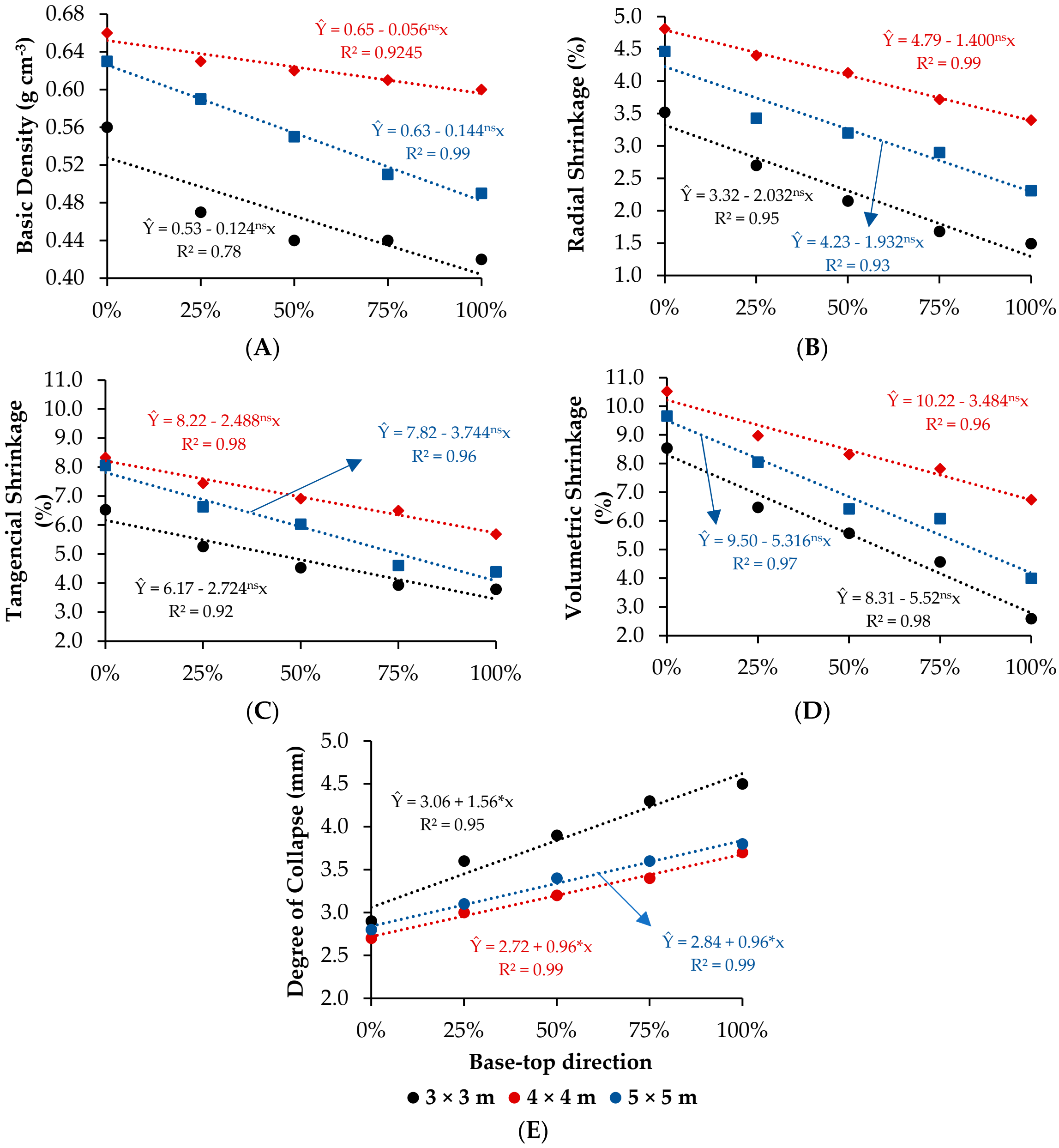

Figure 2. Average behavior of variation in physical properties studied for *Anadenanthera peregrina* juvenile wood at different planting densities in the base-top direction of the trees. ^{ns}: not significant by regression ANOVA ($F > 0.05$); *: significant by regression ANOVA ($F < 0.05$).

Regarding the behavior of the degree of collapse (Figure 2E) in *A. peregrina* wood, it was possible to observe that it increased in the base-top direction and that the analysis of variance was significant ($F < 0.05$) as a function of tree height, showing that the independent variable exerted an influence on the dependent variable.

The degree of collapse obtained was classified as moderate at the base for presenting values below 3 mm and severe along the trunk due to its values ranging from 3 mm to 6 mm, as described by the literature [24].

The mean values of *A. peregrina* density ranged between 0.47 g cm^{-3}, 0.63 g cm^{-3}, and 0.56 g cm^{-3} (3 m × 3 m, 4 m × 4 m, and 5 m × 5 m, respectively), being classified as low density wood (≤0.50 g cm^{-3}) and medium density wood (0.50–0.72 g cm^{-3}) according to the classification of Muñiz and Coradin [28]. Therefore, there are generally higher densities for wider spacings. This will allow the wood to be used in different things, such as particle boards and the application of solid wood in furniture, for example.

The tangential shrinkage was higher than the shrinkage in the radial direction, ranging from 3.79% to 8.33% and 1.49% to 4.81%, respectively.

The anisotropy coefficient increased from the base to the top for woods obtained in the 3 m × 3 m spacing (range: from 1.86 to 2.54), with the analysis of variance being significant ($F < 0.05$) as a function of tree height. For the 4 m × 4 m and 5 m × 5 m plant density spacings, the regression was not significant ($F > 0.05$), making it impossible to estimate the anisotropic factor in the base-top direction for woods of these plant density spacings.

The average values of the anisotropy coefficient for the 4 m × 4 m and 5 m × 5 m plant density spacings are similar; both are considered to have medium stability and be of satisfactory quality (1.6 to 2.0). The wood of the 3 m × 3 m plant density spacing has similar anisotropy until the 25% height, tending after this position to present medium instability (2.0 to 2.5), according to the Klitzke [29] classification.

The analyses performed on the diameter at breast height (DBH) disks demonstrated the same superior behavior of the physical properties in the larger plant density spacing, with the exception of the degree of collapse, which was greater in the 3 m × 3 m spacing. The basic density obtained was 0.49 g cm^{-3}, 0.65 g cm^{-3}, and 0.60 g cm^{-3} (3 m × 3 m, 4 m × 4 m, and 5 m × 5 m, respectively), with these values being lower than those of the base disks.

The same result was observed for linear shrinkage, volumetric shrinkage, and anisotropic factor, thus maintaining the decreasing trend of these phenomena as the height of the tree increased.

The equations (Figure 2) demonstrate a negative linear relationship between physical variables as a function of tree height, which is caused by the heterogeneity of the wood. Although the coefficient of determination (R^2) is high for some physical properties, the non-significant regression ($F > 0.05$) does not make it possible to estimate the variables in the base-top direction.

The trend observed for the physical properties of *A. peregrina* wood in the pith-bark direction presented an opposite behavior to the results observed in the base-top direction (Figure 3). The analysis of variance was significant ($F < 0.05$) for basic density and shrinkage (radial, tangential, and volumetric) and non-significant ($F > 0.05$) for the degree of collapse as a function of position inside the disk.

The trend of basic density and shrinkage (Figure 3A–D) in the three-plant density spacing showed an increase as it approached more peripheral regions of the disk; this behavior was deemed to be a reflection of the cell differentiation that occurs within the trunk.

With the trend observed for the basic density and radial, tangential, and volumetric shrinkage of *A. peregrina* wood in the pith-bark direction, it was possible to verify that there was a decline in the points closest to the bark.

The variance analysis for the anisotropy factor for wood obtained in the 3 m × 3 m spacing was not significant ($F > 0.05$) in the pith-bark direction. For wood obtained in the 4 m × 4 m and 5 m × 5 m plant density spacings, there was significance ($F < 0.05$), indicating that the anisotropic factor was influenced by these planting densities spacing as a function of the trunk diameter.

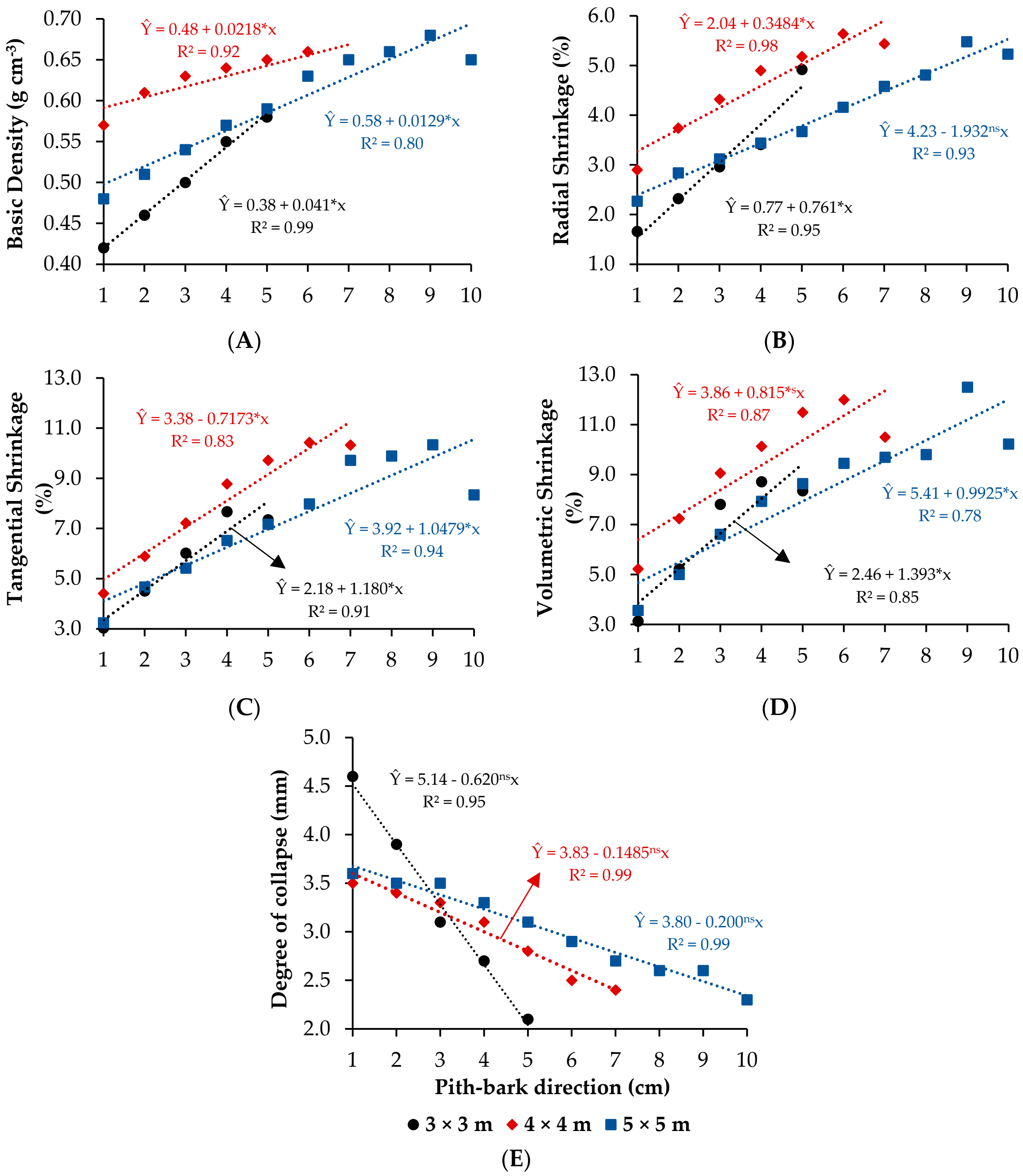

Figure 3. Average behavior of variation in physical properties studied for *Anadenanthera peregrina* juvenile wood at different planting densities in the pith-bark direction of the disk. ^{ns}: not significant by regression ANOVA ($F > 0.05$); *: significant by regression ANOVA ($F < 0.05$).

In the pith-bark direction, *A. peregrina* wood obtained in the 4 m × 4 m and 5 m × 5 m plant density spacings presents average stability, classifying the material as being of satisfactory quality. The wood from the 3 m × 3 m spacing was considered to have medium stability tending to instability, demonstrating that wood obtained from this spacing is more prone to the occurrence of defects.

Regarding the degree of wood collapse (Figure 3E), a decreasing behavior was observed in the pith-bark direction up to the most peripheral regions of the disk.

In general, the results of the physical properties in the base-top and pith-bark directions did not present significant changes in relation to the thinning applied toto the different planting spacings that could have influenced the trend of the analyzed variables, showing in this study that the thinning did not influence the technological properties studied for the assessed age.

According to the equations (Figure 3), it is observed that the simple linear regression analysis was significant for most of the physical properties analyzed for *Anadenanthera peregrina* wood ($F < 0.05$) in the pith-bark direction, with the exception of the grade of collapse, indicating a positive relationship of physical characteristics as it approaches the more peripheral regions of the trunk.

Despite not being significant ($F > 0.05$), the results of the degree of collapse are important, as they demonstrate that there is no variation that promotes the incidence of this defect along the diameter of the tree.

The coefficient of determination (R^2) was high for all physical properties, demonstrating the precision and reliability of the statistical model used to estimate the variables of *A. peregrina* wood in the pith-bark direction.

3.2. Mechanical Properties of Wood

The average values of the mechanical properties of *A. peregrina* wood at 12% moisture are presented in Table 2. According to the results, it appears that there was a significant difference ($p < 0.05$) in the analyzed variables between the different plant density spacings.

Table 2. The mean values of the mechanical properties of *Anadenanthera peregrina* juvenile wood (12% moisture) at different plant density spacings.

Mechanical Properties							
			Static Bending		Janka Hardness		
Spacing	$f_{c0.m}$ (MPa)	$f_{v0.m}$ (MPa)	MOR (MPa)	MOE (GPa)	Axial Plan (MPa)	Radial Plan (MPa)	Tangential Plan (MPa)
3 m × 3 m	51.24 (2.21) c	13.06 (1.69) c	97.46 (18.88) c	10.46 (1.20) c	58.01 (9.25) c	43.08 (10.33) c	43.96 (10.41) c
4 m × 4 m	57.40 (4.48) a	19.06 (0.99) a	120.37 (10.77) a	13.32 (0.61) a	78.49 (5.07) a	71.54 (7.12) a	72.68 (7.41) a
5 m × 5 m	52.54 (3.00) b	15.97 (1.40) b	114.02 (13.07) b	11.74 (1.37) b	69.35 (9.18) b	59.39 (8.69) b	59.51 (13.89) b

$f_{c0.m}$ = compressive strength parallel to the fibers; $f_{v0.m}$ = shear strength; MOR = modulus of rupture; and MOE = modulus of elasticity. Means followed by the same letter in the column do not differ statistically from each other (Tukey, $p > 0.05$). The values in parentheses correspond to standard deviations.

We found that the best mechanical properties were obtained for the 4 m × 4 m spacing. It is also possible to verify that there was a close relationship between the basic density and the results of the analyzed mechanical variables, as the highest average values of strength were due to higher-density woods.

According to the results on the modulus of elasticity and bending strength, the wood in the larger plant density spacing presented greater stiffness than the wood of *A. peregrina* shown in Table 3. In general, the results showed that the raw material evaluated in the present study can be better processed, leading to a more efficient use of wood from thinning practices applied at different planting spacings, thus expanding the possibilities of wood applications in the industrial sector, which will contribute to the exploration of young wood of different species.

Table 3. Mechanical properties of the genus *Anadenanthera* wood found in the literature.

Species	Age	Mechanical Properties	Result	Authors
Anadenanthera peregrina (L.) Speg.	Not identified	Compression parallel to the fibers (MPa)	58.35	Teixeira et al. [16]
		Shear (MPa)	15.10	
		Modulus of rupture in static bending (MPa)	118.17	
		Modulus of elasticity in static bending (GPa)	9.46	
		Axial hardness (MPa)	83.75	
		Radial hardness (MPa)	66.19	
		Tangential hardness (MPa)	67.96	
Piptadenia macrocarpa Benth ≈ *Anadenanthera colubrina*	Not identified	Compression parallel to the fibers (MPa)	72.50	Dias [30]
		Shear (MPa)	24.50	
		Modulus of elasticity in static bending (GPa)	16.50	
		Radial hardness (MPa)	144.60	
		Tangential hardness (MPa)	157.40	
Anadenanthera colubrina	Not identified	Compression parallel to the fibers (MPa)	44.00	Christoforo et al. [31]
		Shear (MPa)	15.00	
		Modulus of elasticity in static bending (GPa)	15.78	
		Radial hardness (MPa)	61.00	
		Tangential hardness (MPa)	70.00	

4. Discussion

The results show that the tangential shrinkage in the base-top direction was twice as high as the radial shrinkage; this aspect was associated with the anisotropic characteristics of the wood, which are influenced by the radius restrictions in the radial direction and by the different helical arrangement of microfibrils in the tangential and radial walls, promoting variations in the wood [32,33].

The results obtained for the trend of basic density and shrinkage in the pith-bark direction were also found by Ribeiro et al. [34] and Juizo et al. [35], who also observed an increase in the pith-bark direction in the basic density of the Australian Cedar and the density and shrinkage of the *Pinus patula* species. Additionally, Vidaurre et al. [6] corroborated the statements of the aforementioned authors, justifying the results based on the cellular differentiation that occurs between juvenile and adult wood, observed in the longitudinal and radial directions of the wood.

In relation to the trend obtained for basic density and radial, tangential, and volumetric shrinkage, it can be justified that the diametric differences of the disk promoted different numbers of repetitions. In addition, some specimens were excluded due to the presence of defects such as knots, cracks, and galleries resulting from drill attacks, which could compromise the results of the physical properties.

The wood collapse performance in the pith-bark direction was verified by Chafe [36] and Souza et al. [19], who stated that the differences existing in the radial positions generate a proportional increase in collapse as the green moisture increases and the basic density decreases.

In terms of resistance, the mean values presented different responses when compared to the values found in the literature for *A. peregrina* wood (Table 3).

We found that the results of mechanical properties by Teixeira et al. [16], with the exception of the modulus of elasticity, were higher than the values obtained for wood in the 3 m × 3 m and 5 m × 5 m spacings, with the values of the 4 m × 4 m spacing being close to those found for the species *A. peregrina* (L.) Speg.

In comparison to the results of the mechanical properties of the species *Piptadenia macrocarpa* Benth. ≈ *Anadenanthera colubrina*, we noted a greater resistance of the wood in relation to *A. peregrina*, which is justified by the higher density obtained for the species, which was 0.88 g cm^{-3}.

A. colubrina had lower mechanical strength [36] than the species in the present study, with the exception of the modulus of elasticity, which was greater than the three-plant density spacing, and the Janka hardness in the radial and tangential directions, which presented values higher than those obtained for the 3 m × 3 m and 5 m × 5 m plant density spacings, thus showing individual variability of the species.

Factors that stand out, such as position in the tree, moisture content, charge duration time, direction of load application, and anatomical structure of the wood, are aspects that generate variations in the mechanical properties of the material, thus reinforcing the importance of its study [37–41].

5. Conclusions

Anadenanthera peregrina juvenile wood demonstrated its potential for industrial use, highlighting the 4 m × 4 m plant density spacing for purposes that demand high strength and rigidity.

The significant variations in physical properties observed in the pith-bark direction evidence a wood instability closer to the pith due to the higher proportion of juvenile wood. It is recommended that the exploitation of wood would be carried out in the most peripheral regions and that it be free of any type of defect.

A wider planting spacing promoted better wood development, generating expressive results for the physical–mechanical properties.

The application of smaller planting spacings tends to reduce the technological properties of *A. peregrina* wood.

In general, the results highlighted the importance and need to carry out more studies with wood resulting from thinning, since they tend to contribute to alternatives for the timber sector, promoting more efficient processing of the still–young raw material.

However, research aimed at protecting young wood from practices that could lead to inappropriate disposal of the raw material is considered promising, as it contributes to inferences about future applications of the raw material, promoting greater competitiveness and an ecological bias in the sector.

Author Contributions: E.S.G.S.: investigation, methodology, writing—original draft, F.G.G.: writing—review and editing, conceptualization, investigation, supervision, resources; P.G.A.S.: visualization, formal analysis, C.M.P.F., I.L.S.C. and M.V.F.: investigation, methodology, D.G., B.M.M.L.E. and Y.M.L.: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The datasets used and/or analyzed during the current study are available upon reasonable request.

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Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Duarte, B.B.; Lahr, F.A.R.; Curvelo, A.A.S.; Christoforo, A.L. Influence of Physical and Chemical Components on the Physical-Mechanical Properties of Ten Brazilian Wood Species. *Mater. Res.* **2020**, *23*, e20190325. [CrossRef]
2. Schimleck, L.; Dahlen, J.; Apiolaza, L.A.; Downes, G.; Emms, G.; Evans, R.; Moore, J.; Pâques, L.; Van den Bulcke, J.; Wang, X. Non-Destructive Evaluation Techniques and What They Tell Us about Wood Property Variation. *Forests* **2019**, *10*, 728. [CrossRef]
3. Rendle, B.J. Juvenile and Adult Wood. *J. Inst. Wood Sci.* **1959**, *5*, 58–61.
4. Gryc, V.; Vavrčík, H.; Horn, K. Density of Juvenile and Mature Wood of Selected Coniferous Species. *J. For. Sci.* **2011**, *57*, 123–130. [CrossRef]
5. Latorraca, J.V.F. Efeito Do Rápido Crescimento Sobre as Propriedades Da Madeira. *Floresta e Ambiente* **2000**, *7*, 279–291.

6. Vidaurre, G.; Lombardi, L.R.; Oliveira, J.T.S.; Arantes, M.D.C. Lenho Juvenil e Adulto e as Propriedades Da Madeira. *Floresta e Ambiente* **2011**, *18*, 469–480. [CrossRef]
7. Nugroho, W.D.; Marsoem, S.N.; Yasue, K.; Fujiwara, T.; Nakajima, T.; Hayakawa, M.; Nakaba, S.; Yamagishi, Y.; Jin, H.-O.; Kubo, T.; et al. Radial Variations in the Anatomical Characteristics and Density of the Wood of *Acacia Mangium* of Five Different Provenances in Indonesia. *J. Wood Sci.* **2012**, *58*, 185–194. [CrossRef]
8. Darmawan, W.; Nandika, D.; Rahayu, I.; Fournier, M.; Marchal, R. Determination of Juvenile and Mature Transition Ring for Fast Growing Sengon and Jabon Wood. *J. Indian Acad. Wood Sci.* **2013**, *10*, 39–47. [CrossRef]
9. Lu, C.; Wu, J.; Jiang, Q.; Liu, Y.; Zhou, L.; You, Y.; Cheng, Y.; Liu, S. Influence of Juvenile and Mature Wood on Anatomical and Chemical Properties of Early and Late Wood from Chinese Fir Plantation. *J. Wood Sci.* **2021**, *67*, 72. [CrossRef]
10. Rahayu, I.; Laksono, G.; Darmawan, W.; Maddu, A.; Prihatini, E. Demarcation Area between Juvenile and Mature Wood in *Elaeocarpus angustifolius*. *Biodiversitas J. Biol. Divers.* **2021**, *22*, 2583–2590. [CrossRef]
11. Kartkawati, E.; Bienitta; Prastiwi, F.W.; Nugroho, W.D. Determination of the Boundary between Juvenile–Mature Wood of Diospyros Kaki and Their Wood Anatomical Variations. *J. Korean Wood Sci. Technol.* **2024**, *52*, 191–203. [CrossRef]
12. Del Río, M.; Bravo-Oviedo, A.; Pretzsch, H.; Löf, M.; Ruiz-Peinado, R. A Review of Thinning Effects on Scots Pine Stands: From Growth and Yield to New Challenges under Global Change. *For. Syst.* **2017**, *26*, eR03S. [CrossRef]
13. Smith, D.M.; Larson, B.C.; Kelty, M.J.; Ashton, P.M.S. *The Practice of Silviculture: Applied Forest Ecology*, 9th ed.; John Wiley & Sons: New York, NY, USA, 1997.
14. David, H.C.; Péllico Netto, S.; Arce, J.E.; Corte, A.P.D.; Marinheski Filho, A.; Araújo, E.J.G. Efeito Da Qualidade Do Sítio e Do Desbaste Na Produção de Pinus. *Floresta e Ambiente* **2017**, *24*, e00096414. [CrossRef]
15. Lorenzi, H. *Árvores Brasileiras: Manual de Identificação e Cultivo de Plantas Arbóreas Nativas Do Brasil*, 2nd ed.; Editora Plantarum: Nova Odessa, Brazil, 1998.
16. Teixeira, B.M.R.; Evangelista, W.V.; Silva, J.C.; Della Lucia, R.M. Radial and Longitudinal Evaluation of the Mechanical Properties and Basic Specific Gravity of Angico-Vermelho Wood (*Anadenanthera Peregrina* (L.) Speg.). *Sci. For.* **2011**, *39*, 463–468.
17. Rocco Lahr, F.A.; Chahud, E.; Arroyo, F.N.; Christoforo, A.L.; Rodrigues, E.F.C.; Almeida, J.P.B.; Aquino, V.B.M.; Santos, H.F. Ratio Analysis between Compression and Shearing of 72 Brazilian Wood Species. *Wood Res.* **2021**, *66*, 711–720. [CrossRef]
18. Souza, C.O.; Silva, J.G.M.; Arantes, M.D.C.; Vidaurre, G.B.; Dias Júnior, A.F.; Oliveira, M.P. Pyrolysis of *Anadenanthera peregrina* Wood Grown in Different Spacings from a Forest Plantation in Brazil Aiming at the Energy Production. *Environ. Dev. Sustain.* **2020**, *22*, 5153–5168. [CrossRef]
19. de Souza, P.H.; Caldeira, M.V.W.; Delarmelina, W.M.; Trazzi, P.A.; Paula, R.R.; Momolli, D.R.; Moreau, J.S.; Gomes, G.S.L.; Gomes, R.; Sanquetta, C.R. Comparing Spacings of *Anadenanthera peregrina* (L.) Speg Stand: Response in Biomass and Carbon Stock above and below Ground. *Rev. Ambient. Água* **2023**, *18*, e2919. [CrossRef]
20. Souza, C.O. *Potencial Energético Da Madeira e Carvão Vegetal de Angico-Vermelho (Anadenanthera peregrina) Jovem*; Universidade Federal do Espírito Santo: Jerônimo Monteiro, Brazil, 2018.
21. Valente, B.M.d.R.T.; Evangelista, W.V.; Silva, J.C.; Della Lucia, R.M. Della Variabilidade Radial e Longitudinal Das Propriedades Físicas e Anatômicas Da Madeira de Angico-Vermelho. *Sci. For.* **2013**, *40*, 485–496.
22. Alvares, C.A.; Stape, J.L.; Sentelhas, P.C.; Gonçalves, J.L.M.; Sparovek, G. Köppen's Climate Classification Map for Brazil. *Meteorol. Z.* **2013**, *22*, 711–728. [CrossRef]
23. Martins, G.S.; Yuliarto, M.; Antes, R.; Sabki; Prasetyo, A.; Unda, F.; Mansfield, S.D.; Hodge, G.R.; Acosta, J.J. Wood and Pulping Properties Variation of *Acacia Crassicarpa* A.Cunn. Ex Benth. and Sampling Strategies for Accurate Phenotyping. *Forests* **2020**, *11*, 1043. [CrossRef]
24. EDG. *Recommendation, Assessment of Drying Quality of Timber*; Welling, J., Ed.; Pilot Edit.; European Drying Group: Hamburg, Germany, 1994.
25. *D-143-22*; Standard Test Methods for Small Clear Specimens of Timber. ASTM American Society for Testing and Materials: West Conshohocken, PA, USA, 2023.
26. *NBR 7190-3*; Métodos de Ensaio Para Classificação Visual e Mecânica de Peças Estruturais de Madeira. ABNT Associação Brasileira de Novas Técnicas: Rio de Janeiro, Brazil, 2022.
27. Ferreira, D.F. Sisvar: A Guide for Its Bootstrap Procedures in Multiple Comparisons. *Ciência e Agrotecnologia* **2014**, *38*, 109–112. [CrossRef]
28. Coradin, V.T.R.; Muñiz, G.I.B. *Normas de Procedimentos Em Estudos de Anatomia de Madeira: I. Angiospermae II. Gimnospermae*; IBAMA; DIRPED: Brasília, Brazil, 1991.
29. Klitzke, R.J. Secagem Da Madeira. In *Tecnologias Aplicadas ao Setor Moveleiro*; Oliveira, J.T.S., Fiedler, N.C., Nogueira, M., Eds.; Suprema: Jerônimo Monteiro, Brazil, 2007.
30. Dias, F.M. A Densidade Aparente Como Estimador de Propriedades de Resistência e Rigidez Da Madeira. Master's Thesis, Universidade de São Paulo, São Carlos, Brazil, 2000.
31. Christoforo, A.L.; Aftimus, B.H.C.; Panzera, T.H.; Machado, G.O.; Lahr, F.A.R. Physico-Mechanical Characterization of the *Anadenanthera Colubrina* Wood Specie. *Eng. Agrícola* **2017**, *37*, 376–384. [CrossRef]
32. Kollmann, F.F.P.; Cotê, W.A. *Principles of Wood Science and Technology*; Springer: New York, NY, USA, 1968.
33. Elaieb, M.T.; Shel, F.; Jalleli, M.; Langbour, P.; Candelier, K. Physical Properties of Four Ring-Porous Hardwood Species: Influence of Wood Rays on Tangential and Radial Wood Shrinkage. *Madera y Bosques* **2019**, e2521695. [CrossRef]

34. Ribeiro, A.d.O.; Mendes, R.F.; Mendes, L.M.; Mori, F.A.; Ziech, R.Q.d.S. Retratibilidade Da Madeira de *Toona Ciliata* M. Roem Proveniente de Três Municípios Do Sul de Minas Gerais. *CERNE* **2014**, *20*, 351–361. [CrossRef]
35. Juizo, C.G.F.; Loiola, P.L.; Zen, L.R.; Marchesan, R.; Carvalho, D.E.; Bila, N.F.; Egas, A.F.; Rocha, M.P.d.; Klitzke, R.J. Variação Radial Das Propriedades Físicas Da Madeira de *Pinus patula* Plantados Em Moçambique. *Pesqui. Florest. Bras.* **2015**, *35*, 285–292. [CrossRef]
36. Chafe, S.C. Radial Variation of Collapse, Volumetric Shrinkage, Moisture Conent and Density in *Eucalyptus regnans* F. Muell. *Wood Sci. Technol.* **1986**, *20*, 253–262. [CrossRef]
37. Antwi-Boasiako, C.; Ofosu, E.S.; Glalah, M. Physico-Mechanical and Anatomical Properties of Normal and Tension Woods of *Terminalia superba* (Engl. & Diels). *Wood Mater. Sci. Eng.* **2024**, *18*, 1–7. [CrossRef]
38. Arriaga, F.; Wang, X.; Íñiguez-González, G.; Llana, D.F.; Esteban, M.; Niemz, P. Mechanical Properties of Wood: A Review. *Forests* **2023**, *14*, 1202. [CrossRef]
39. Pfeil, W.; Pfeil, M. *Estruturas de Madeira*; LTC: Rio de Janeiro, Brazil, 2003.
40. Pereira, J.M.S.; Satler, G.M.; Lima, J.S.S.; Segundinho, P.G.A. Avaliação Das Propriedades Mecânicas Em Madeira Seca de *Eucalyptus urograndis*. *Rev. Univap* **2017**, *22*, 717. [CrossRef]
41. Gonçalves, F.G.; Oliveira, J.T.S.; Della Lucia, R.M.; Sartório, R.C. Estudo de Algumas Propriedades Mecânicas Da Madeira de Um Híbrido Clonal de *Eucalyptus urophylla* × *Eucalyptus grandis*. *Rev. Arvore* **2009**, *33*, 501–509. [CrossRef]