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RADIAL VARIATION OF TRACHEID FEATURES, SPECIFIC GRAVITY AND GROWTH RINGS IN *Araucaria angustifolia* (Bertol.) Kuntze PLANTED IN CUNHA-SP[1]

VARIAÇÃO RADIAL DAS CARACTERÍSTICAS DAS TRAQUEÍDES, DENSIDADE APARENTE E ANÉIS DE CRESCIMENTO EM *Araucaria angustifolia* (Bertol.) Kuntze PLANTADAS EM CUNHA-SP[1]

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ABSTRACT – We investigated wood features along growth rings of *Araucaria angustifolia* trees planted between November and December of 1980 in Parque Estadual da Serra do Mar in Cunha, State of São Paulo, Brazil. Our goal was to determine radial variation of the tracheid features and specific gravity. For these analyses, we employed the usual methodologies for determining the tracheid dimensions by maceration. Based on the relationship between weight/volume of samples and growth rings, specific gravity was determined after discs were polished. Following the Typical Radial Pattern – (TRP), we observed a significant increase in length, diameter and wall thickness of tracheids toward the bark. Positive relationships were observed between all tracheid features and specific gravity, showing that the increase in length and, especially, wall thickness contributed to the increase in specific gravity toward the bark.

Keywords: Araucária; gymnosperms; Brazilian native woods; wood properties.

RESUMO – Neste estudo, investigamos os anéis de crescimento e a variação radial das traqueídes na madeira de árvores de *Araucaria angustifolia* plantadas entre novembro e dezembro de 1980 no Parque Estadual da Serra do Mar em Cunha, Estado de São Paulo, Brasil. Nosso objetivo foi determinar a variação das características das traqueídes e densidade aparente. Nessas análises, empregamos metodologias usuais para estabelecer as dimensões das traqueídes pelo método de maceração. Com base na relação massa/volume das amostras e anéis de crescimento, a densidade aparente foi determinada após o polimento dos discos. De acordo com o Típico Padrão Radial – (TRP), observamos aumento significativo no comprimento, diâmetro e espessura da parede das traqueídes em direção à casca. Relações positivas foram observadas entre todas as características das traqueídes e a densidade aparente, mostrando que o aumento do comprimento e, especialmente, da espessura de suas paredes contribuem positivamente para o aumento da densidade aparente em direção à casca.

Palavras-chave: Araucária; gimnospermas; madeiras nativas do Brasil; propriedades da madeira.

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1 INTRODUCTION

A. angustifolia wood has good physical and mechanical qualities, which have helped it to become the major wood used in southern Brazil for many years, highlighting its economic importance in Brazil. *A. angustifolia* has been exported to the United States (Kukachka, 1969), but current conservation efforts have reduced its use, while, at the same time, the plantations and use of *Pinus* species has increased in Brazil. Nonetheless, due *A. angustifolia* has timber potential, it is interesting to study the structural and density variations from pith to bark to broaden our knowledge of variation in this species. There are reports that more than 100 million *A. angustifolia* trees have been cut between 1930 and 1990. Due to these practices, currently the exploiting of species is controlled by laws (Brasil, 2015).

Other studies evaluated the variations in *A. angustifolia* wood, (*e.g.*, Paula and Alves (1997); Wehr and Tomazello Filho (2000); Oliveira et al. (2010); Melo et al. (2010) and Mattos et al. (2011)), but we have no knowledge about wood characteristics or planting conditions in Cunha-SP.

Some studies have attested to the potential of *A. angustifolia* for dendrochronological studies (Seitz and Kanninen, 1989; Tomazello Filho, 1998; Roig, 2000). This species has growth rings based on the difference between earlywood, which has a light color caused by tracheids with thin cell walls, and latewood, which has a dark color caused by tracheids with thick cell walls (Santarosa et al., 2007). Oliveira et al. (2007), Zanon (2007) and Oliveira et al. (2009) reported that growth rings are formed each year.

Our goal was to evaluate the radial variation of the tracheid features and specific gravity in wood of *Araucaria angustifolia* trees planted in Cunha municipality, São Paulo State, Brazil. In this analysis, we propose to a) confirm the Typical Radial Pattern – TRP, as mentioned by Lachenbruch et al. (2011), that includes differences in juvenile wood when compared to mature wood and b) determine which period of the year growth rings are formed based on a climatic diagram from Cunha.

2 MATERIALS AND METHODS

2.1 Description of Experimental Area

Samples were collected at Serra do Mar State Park-Cunha – PESM-Cunha, located in Cunha municipality, São Paulo State, Brazil, at the coordinates 23º13' and 23º16' South latitude and the meridians 45º 02' and 45º05' West longitude, at an altitude above 1,000 meters. The region is mountainous, and the original vegetation is dense rain forest (Atlantic Forest) (Cicco et al., 2007). This area (Figure 1) is distinguished by a wet, rainy season from October to March and a somewhat wet, but mostly dry, season from April to September. The average annual air temperature is 16.5 ºC, the average winter air temperature is 10 ºC, while the average summer air temperature is 22º (Arcova, 1996).

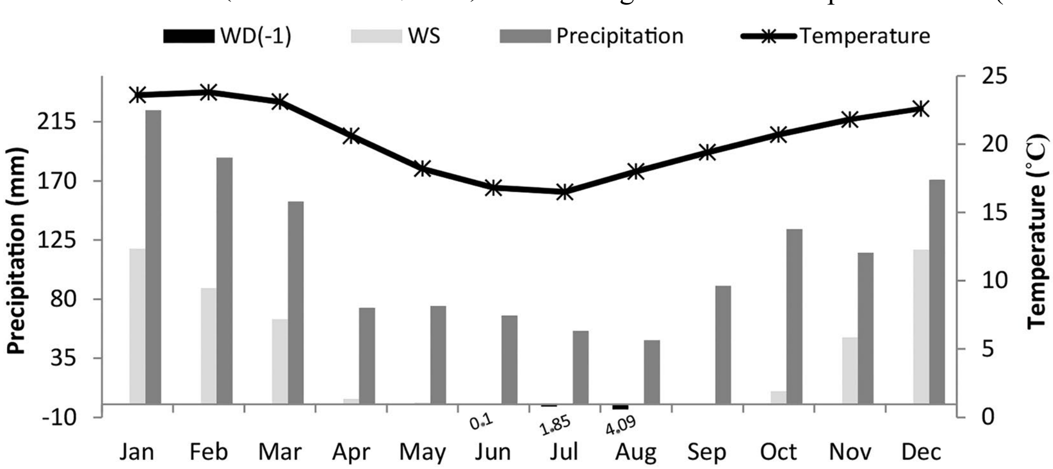

Figure 1. Climatic data for the City of Cunha, compiled from the Centro de Pesquisas Meteorológicas e Climáticas Aplicadas à Agricultura – CEPAGRI (Center of Meteorological and Climate Research Applied to Agriculture – CEPAGRI), database (CEPAGRI, 2012) of 1961-1990. WD = water deficit, WS = water surplus.

Figura 1. Dados climáticos para a cidade de Cunha, perto do PESM-Cunha. Compilados a partir dos dados do Centro de Pesquisas Meteorológicas e Climáticas Aplicadas a Agricultura – CEPAGRI (CEPAGRI, 2012) de 1961-1990.

2.2 Sampling, Wood Anatomy and Specific Gravity Analysis

A. angustifolia planting was performed in November and December of 1980 to restore the vegetation, using seeds that originated from Campos do Jordão-SP. Samples were collected from three female trees that fell between 2008 (two trees) and 2010 (one tree). From each tree, we took a disc at breast height, DBH (1.3 m from the ground). The discs (≈ 25 cm in diameter and ≈ 10 cm deep) were polished with an electric planer and sandpaper (600-1000 grits) to show the growth rings, which were analyzed with a 10x hand lens and then marked with pencil with a Carl Zeiss Jena Citoval 2 stereomicroscope. Next, the samples were scanned in a Hewlett Packard Officejet Pro 8500 scanner at 1200 ppi and high bit depth. Measurements of growth ring width were made from pith to bark using the Image Pro Plus software, version 6.3.

We cut a strip (each disc) from pith to bark to provide samples for wood anatomy and specific gravity. For wood anatomy we remove fragments from each growth ring and prepared according to the methods developed by Johansen (1940). Dissociated tracheids were placed on a slide, and the length, diameter and wall thickness of tracheids were measured (n = 25 for each growth ring) according to IAWA Committee (1989). Digital photos were taken in the stereo microscope and the measurements were made with the Image Pro Plus software, version 6.3.

We took three samples (2 x 23 cm) every five growth rings (1, 5, 9, 13, 17, 21 and 25), totaling 21 samples per tree to determine the specific gravity (G12). Samples were dried at standard temperature to reach about 12% moisture content to obtain the volume of wood. Then, the oven-dry mass samples were determined with semi-analytical balance. Specific gravity was determined from the relationship between the sample mass and volume of water displaced when it was immersed in a graduated cylinder containing water. The following equation was used: $\rho_{ap} = P_u/V_u$, where ρ_{ap} = specific gravity, kg m^{-3}, P_u = oven-dry weight of wood, kg) and V_u = dry volume of wood m^3 (Glass and Zelinka, 2010).

2.3 Statistical Analysis

We employed a logarithmic regression function, which was the best model from the data distribution, to assess the radial variation in the growth ring diameter, tracheid dimensions and specific gravity and linear regression to relate the tracheid features to specific gravity. Statistical analysis was performed employing the SigmaStat 3.5 software for Windows (SPSS Incorporation).

3 RESULTS AND DISCUSSION

3.1 Radial Variation of Tracheid Features and Specific Gravity

A significant increase in length, diameter and wall thickness of tracheids was observed toward the bark (Figure 2a-c). This result confirms the Typical Radial Pattern – TRP, as noted by Lachenbruch et al. (2011). The same pattern was described by Paula and Alves (1997) for *A. angustifolia*.

Lachenbruch et al. (2011) describe the complexity and interactions in the development of woody plants that may cause the typical radial pattern and the authors mention that gradual radial variations are the rule in many properties of wood. However, it is interesting to determine whether these changes are ontogenetically fixed or plastic, and triggered by factors that vary as the plant grows. Day et al. (2002) and Day and Greenwood (2011) present three potential models to describe age-related changes in plant development, including: intrinsic control, which is programmed by gene expression; extrinsic control, which is related to changes induced by the environment; and extrinsic-intrinsic control, involving the change in gene expression by external signals.

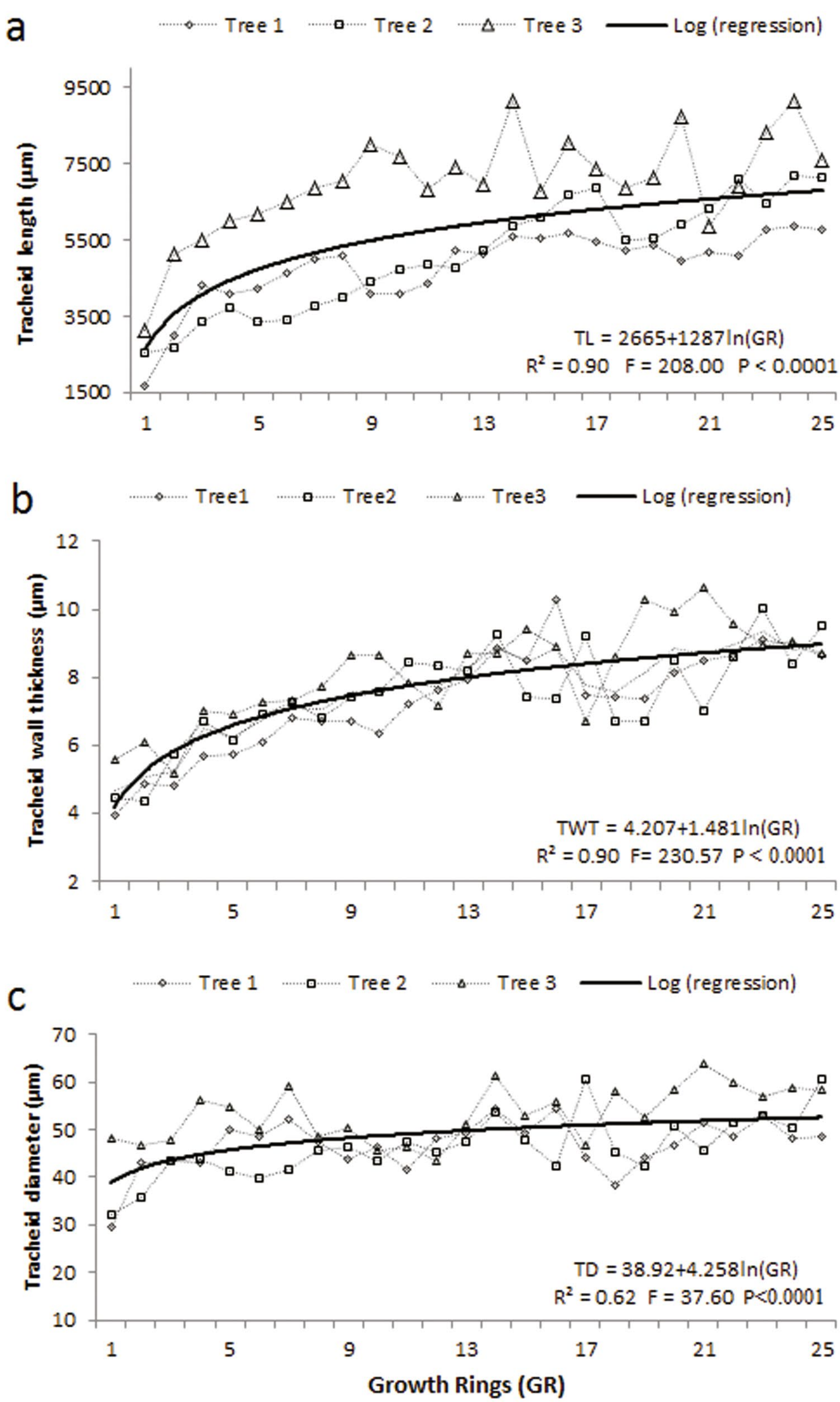

Figure 2. Radial variation in tracheid length (a), wall thickness (b) and diameter (c) of *Araucaria angustifolia* wood.
Figura 2. Variação radial no comprimento (a), espessura da parede (b) e diâmetro (c) das traqueídes de *Araucaria angustifolia*.

Radial variation in *A. angustifolia* seems to result from intrinsic control in that it is genetically programmed. In support of this notion, Oliveira et al. (2010) reported that the trees of *A. angustifolia* share a common pattern of growth associated with variations in temperature during the current and previous growth season, even when growing in different disturbance regimes. However, a study of heritability in tracheids for *A. angustifolia* would be needed to confirm this hypothesis.

In *Podocarpus lambertii*, another gymnosperm species native to Brazil, tracheid length increased toward the bark, while the diameter showed little change, and no change was noticed in wall thickness (Maranho et al. 2006). These results do not support TRP, suggesting another radial variation pattern in this species.

Anatomical variations observed in this study appear to influence the wood properties of *A. angustifolia*, as supported by Melo et al. (2010) who found a higher dimensional instability near the pith and increased mechanical strength of wood taken from the most external positions close to the bark, possibly linked to larger cells and thicker walls.

On the other hand, no stabilization in the tracheid features were found, although the results of the present study found the average cell size near to the bark to be 6.5 mm in length, 51.5 µm in diameter and 8.7 µm in wall thickness on wood formed between the 25th and 27th year. These results are similar to those described by Mattos et al. (2006), who characterized the wood of 38-year-old *A. angustifolia* trees, noting tracheids 5.84 mm in length, 54.95 µm in diameter, and 7.3 µm in wall thickness. These similarities suggest that 25-year-old wood of *A. angustifolia* trees can be considered adults.

We observed a significant increase in specific gravity toward the bark (Figure 3). This agrees with the result of Melo et al. (2010) who found specific gravity of 0.39 g.cm^{-3} in the juvenile wood and 0.48 g.cm^{-3} in adult wood. By studying the axial variation in three gymnosperm species, including *A. angustifolia*, Mattos et al. (2011) found a decrease in wood density from base to top of trunk. This result is related to radial variation, since cambial age changes, and wood closest to the bark was formed by younger cambium. According to Moreschi (2005), increase in specific gravity toward the bark is common for many conifers. However, when Wehr and Tomazello Filho (2000) applied X-ray microdensitometry to study *A. angustifolia* growth rings, they reported that wood density showed only small variations with uniformity from pith to bark. Rolim and Ferreira (1974) studied radial variation in basic density in *A. angustifolia* from stands in Capão Bonito, São Paulo State (two male and two female trees), and the authors concluded that basic density increases up to 15 years old, with growth more pronounced up to 9 years and less pronounced after this age. We could not establish an age range with more pronounced growth.

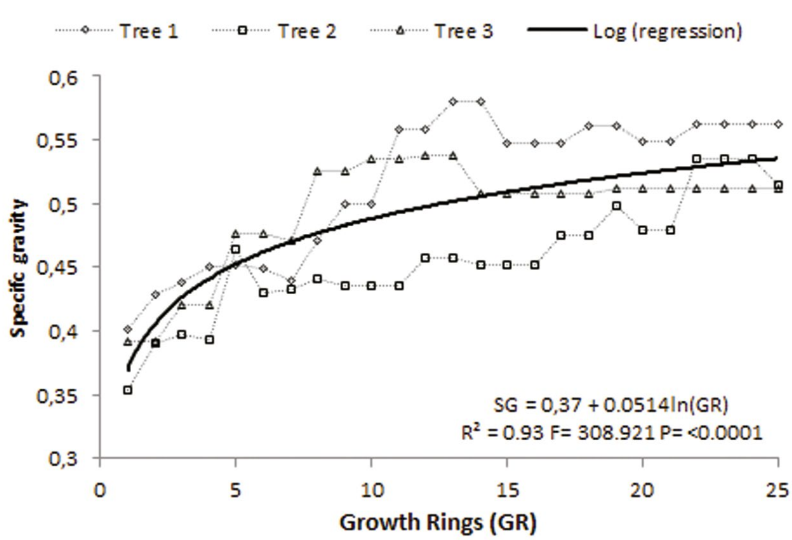

Figure 3. Radial variation in the specific gravity of *Araucaria angustifolia* wood.

Figura 3. Variação radial da densidade aparente da madeira de *Araucaria angustifolia*.

3.2 Relationship between Tracheid Features and Specific Gravity

We observed a positive relationship between all tracheid features and specific gravity (Figure 4), showing that the increase in length and, especially, wall thickness contributed to the increase in specific gravity toward the bark. We observed the same pattern in these features in many studies from our group in angiosperm species (Longui et al., 2009; Longui et al., 2012).

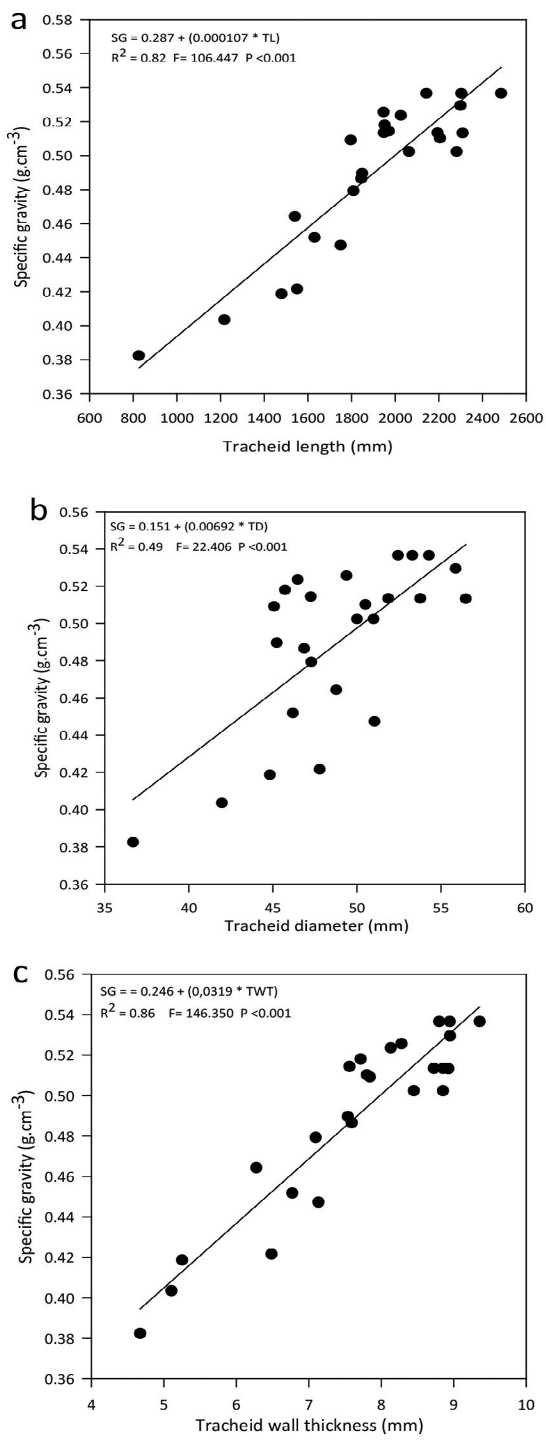

Figure 4. Linear regressions between tracheid features and specific gravity of *Araucaria angustifolia* wood.

Figura 4. Regressões lineares entre as características das traqueídes e densidade aparente da madeira de *Araucaria angustifolia*.

3.3 Growth Rings

We observed 25 rings in two trees and 27 rings in one tree and a significant decrease in growth ring width diameter toward the bark (Figure 5). This pattern is very common in many species as a result of reduction in growth rate. According to Paludo et al. (2011), the initial growth of *A. angustifolia* is slow, and according to Carvalho (2003), it is only from the fifth year that the rate of growth increment reaches 1.5 to 2 cm. Moreover, our samples were derived from DBH, therefore with less rings than the base of the tree, justifying the lowest number of rings when compared with trees planted in 1980 because *A. angustifolia* has annual growth rings (Oliveira et al., 2007).

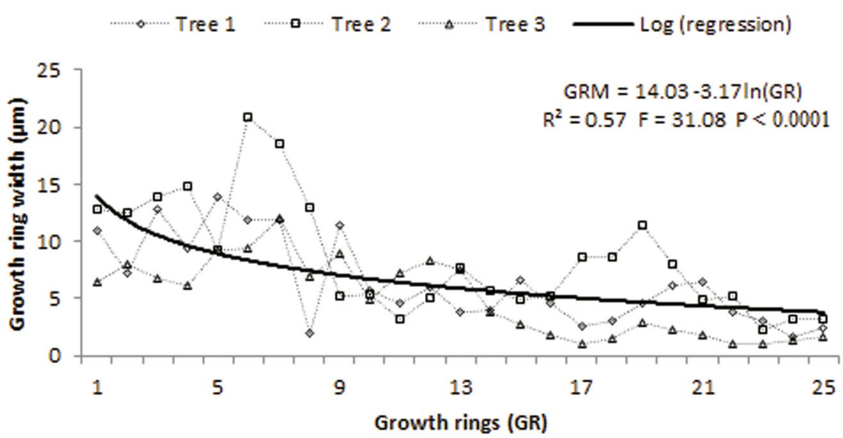

Figure 5. Radial variation in growth ring width of *Araucaria angustifolia* wood.

Figura 5. Variação radial na largura dos anéis de crescimento da madeira de *Araucaria angustifolia*.

Concerning earlywood and latewood, Santarosa et al. (2007) explained that increased temperature during the spring and summer provides for the development of earlywood, while the gradual decrease in temperature during the fall and winter months affects the formation of latewood in *A. angustifolia*. Using dendrometer bands, Zanon (2007) studied the annual increment of the species in the Florestal Nacional de São Francisco de Paula, Rio Grande do Sul State, and have detected the beginning of growth in September and a decrease or cessation of cambial activity from March to April, representing a period of 5-6 months. Similar results were reported by Oliveira et al. (2009), who observed a growing season between October and April for *A. angustifolia* in Floresta Nacional de São Francisco de Paula (municipality of São Francisco de Paula, Rio Grande do Sul, Brazil).

The climatic diagram of Cunha municipality (Figure 1) shows a dry period from April to August/September and water deficit between June and August. Based on this evidence, we suggest that cambial activity ceases during these periods and that earlywood and latewood (Figure 6) are most likely formed between September and October, as well as February and March.

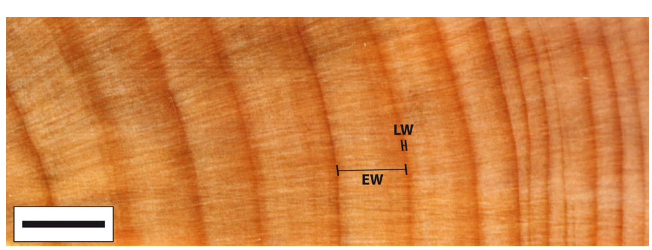

Figure 6. Transversal surface of *A. angustifolia* wood showing some growth rings composed of earlywood (EW, light portion) and latewood (LW, dark portion). Scale bar = 1 cm.

Figura 6. Superfície transversal da madeira de *A. angustifolia* mostrando os anéis de crescimento compostos por lenho inicial (EW, parte clara) e lenho tardio (LW, parte escura). Escala = 1 cm.

4 CONCLUSION

Following the Typical Radial Pattern – TRP, we observed a significant increase in length, diameter and wall thickness of tracheids toward the bark. A positive relationship was found between all tracheid features and specific gravity, showing that the increase in length and, especially, wall thickness contributed to the increase in specific gravity toward the bark.

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