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Original Paper

Colorimetry of *Acacia mangium* wood from plantations in northeast Brazil

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Abstract

The aim of this study was to evaluate color characteristics in wood samples from *Acacia mangium* from a homogeneous plantation in Bahia state, northeast Brazil, and also analyze the influence of anatomical section and radial position in the trunk on color response to contribute to information for the best use of the wood, such as, for example, the optimization of the performance of the pieces in sawmill through the most acceptable aesthetic form by the final consumer. Six trees with age of 14 years were cut. The species was identified by anatomical analysis at the Laboratory of Wood Anatomy of the Federal University of Paraná, comparing the sample collected with the authenticated material. A disc from the base of each tree was divided into six samples oriented in anatomical sections (transversal, radial and tangential), with dimensions of 20 × 20 × 30mm, named near pith, intermediate and near bark. A total of 36 samples were evaluated, 12 from each position. The colorimetric evaluation was performed with a CM-5 spectrophotometer. Data on lightness, green-red and blue-yellow chromatic coordinates were obtained, and values of saturation and hue angle were calculated. *Acacia* wood from planted forest is classified as olive color. Color parameters were influenced by anatomical section and radial position in the trunk, being found 44 for the transversal section, 55 for the tangential section and 57 in the radial for luminosity. Transversal sections had lower values in comparison to longitudinal surfaces and radial sections had higher luminosity than tangential sections. The near bark region presented lower values in most colorimetric parameters, except hue angle, in comparison with the intermediate and near pith regions, which was around 70 in the different positions of the wood.
Key words: anatomical surface, chromatic coordinate, ciel*a*b*, radial position, wood color.

Resumo

O objetivo deste estudo foi avaliar as características de cor em amostras de madeira de *Acacia mangium* de uma plantação homogênea no estado da Bahia, nordeste do Brasil, e também analisar a influência da secção anatômica e posição radial do tronco na resposta de cor para contribuir com informações para o melhor aproveitamento da madeira, como por exemplo, a otimização do rendimento das peças em serraria através da forma estética mais aceitável pelo consumidor final. Foram cortadas seis árvores com idade de 14 anos. A espécie foi identificada por análise anatômica no Laboratório de Anatomia da madeira da Universidade Federal do Paraná, comparando a amostra coletada com o material autenticado. Um disco da base de cada árvore foi dividido em seis amostras orientadas em cortes anatômicos (transversal, radial e tangencial), com dimensões de 20 × 20 × 30 mm, próximo a medula, região intermediária e região próxima a casca. Foram avaliadas um total de 36 amostras, 12 de cada posição. A avaliação colorimétrica foi realizada com um espectrofotômetro CM-5. Foram obtidos dados sobre a luminosidade, coordenadas cromáticas verde-vermelho e azul-amarelo e foram calculados valores de saturação e ângulo de tonalidade. A madeira de *Acacia* de floresta plantada é classificada como cor de azeitona. Os parâmetros de

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cor foram influenciados pela secção anatômica e posição radial no tronco, sendo observado valores de luminosidade de 44 para a seção transversal, 55 para a tangencial e 57 para a radial. As secções transversais tinham valores mais baixos em comparação com as superfícies longitudinais e as secções radiais tinham maior luminosidade do que as secções tangenciais. A região próxima da casca apresentava valores mais baixos na maioria dos parâmetros colorimétricos, exceto o ângulo de tonalidade, em comparação com as regiões intermédias e próximas da medula, o qual está em torno de 70 para todas as posições na madeira.
Palavras-chave: superfície anatômica, coordenada cromática, ciel*a*b*, posição radial, cor da madeira.

Introduction

The genus *Acacia* Miller has more than 1,300 species in tropical and subtropical regions of the world. The species *Acacia mangium* Willd. is native of Australia, Indonesia and Papua New Guinea. The tree typically grows to a height of 25–30 m and diameter at breast height of 90 cm (Rossi *et al.* 2003). The trees can be planted for landscaping and recuperation of degraded soils or for producing pulp and paper, firewood, charcoal, wood for civil construction, medium density fiberboard and plywood, among other uses (Attias *et al.* 2013). The leaves can serve as forage for livestock and used for fuel. Non-timber uses include adhesives and honey production (Krisnawati *et al.* 2011).

In Brazil, the first plantations were established in 1979 by Embrapa Forests (Attias *et al.* 2013), and in 2018 the planted area of the genus covered 161,907 ha (IBÁ 2019). The species is recommended for use in deforested or abandoned regions in Amazonia, due to rapid growth and wood production, and can be a substitute for native species for firewood production (Souza *et al.* 2004). Also, its integration with crops and livestock has shown economic potential for agroforestry systems in the state of Piaui (Araújo *et al.* 2015).

Acacia mangium sapwood is classified as light colored and its heartwood is medium brown, with specific gravity that can vary from 0.40 to 0.60 g/cm^3 in timber plantations and natural strands, respectively (Krisnawati *et al.* 2011). Based on the machining properties, its wood is indicated for making furniture and indoor components (Redzuan *et al.* 2019), but some properties are variable in function of origin (Nugroho *et al.* 2012). Climate conditions where trees grow, tree height, intrinsic characteristics of wood (presence of sapwood and heartwood, grain pattern, distance from pith) and drying affect wood quality (Tenorio & Moya 2011). The presence of knots, moderate permeability and wettability are important for high value products, influencing principally the finishing process (Redzuan *et al.* 2019)

Tenorio & Moya (2011) observed that lumber from trees growing in humid tropical climates subjected to low relative humidity drying schedule can develop wet pockets, and Redzuan *et al.* (2019) recommended surface pretreatment before finishing. Nugroho *et al.* (2012) commented that trees with higher fiber lengths near the pith and narrower juvenile wood might be appropriate for breeding programs that focus on improving wood quality in Indonesia.

In wood commerce, color can be a parameter for aesthetic classification (Mori *et al.* 2005), and differences in color in the same board can diminish its market value (Luis *et al.* 2018). A study with 30 native tropical species from Brazil indicated that darker wood was denser (Silva *et al.* 2017), and some heat treatments can change natural wood color and increase some properties, suggesting alternative applications (Luis *et al.* 2018). Quantification of this parameter can be done based on CIEL*a*b* parameters and applied to appraise wood value in comparison with other species (Camargos & Gonçalez 2001).

The literature contains descriptions of color parameters in some Brazilian species (Silva *et al.* 2017; Vieira *et al.* 2019), comparison of color parameters between sites in native and planted forest (Sotelo-Montes *et al.* 2013; Cisneros *et al.* 2019), for example. In wood industries, grades for heartwood color and color variations can be assigned using colorimetry to identify market preferences. This is important to increase the quality of plantation species, where heartwood color should be included as a trait in selection and breeding programs. Changes in color preferences with time due to fashion will be reflected in changing demand for different color grades, making this one of the risk factors in domestication and breeding (Bradbury *et al.* 2010).

There are variations in color parameters inside a tree in function of anatomical section and radial trunk position related to intrinsic characteristic of species (Atayde *et al.* 2011; Vieira *et al.* 2019) and in the same species comparing natural and planted forests (Cisneros *et al.* 2019). The knowledge of variation in color parameters from each species is important to standard applications, for example, the cut of boards in radial or tangential direction can produce lots of wood more homogenous in color, in accordance with market preferences (Atayde *et al.* 2011). Also, the reflectance curve in visible length can be applied is species discrimination (Nisgoski *et al.* 2017; Vieira *et al.* 2019) in forest control, and a database from this information is necessary.

Some descriptions of color of *Acacia mangium* wood exists, but in Brazil there are no details of color parameters for this species plantation. So, this study evaluated colorimetric characteristics in trees of *Acacia mangium* planted in northeast Brazil, by analyzing the influence of anatomical section and radial position in the trunk on color response to contribute to information to an adequate final use of this material and with high aggregate value. Also, to add color and reflectance visible spectra to a database for species discrimination.

Material and Methods

Wood samples from *Acacia mangium* Willd. were obtained from a homogeneous plantation in Valença, Bahia state, northeast Brazil (13º22'26"S and 39º4'3"W). The climate in the region based on the Köppen classification is Af, tropical with mean temperature of 23–27 °C (Alvares *et al.* 2013). To confirm the nomenclature of the species, the scientific identification was performed at the Laboratory of Wood Anatomy of the Federal University of Paraná based on the anatomical characteristics described and compared to the collection of the xylotheque and the data available in Inside Wood (2004), confirming that the collected material was *Acacia mangium*.

Six trees with age of 14 years were cut. A disc from the base of each tree was used for color evaluation. The material was divided into six samples, oriented in anatomical sections (transversal, radial and tangential), with dimensions of 2 × 2 × 3 cm, named near pith, intermediate and near bark (Fig. 1). Samples were from heartwood, transition and sapwood, varying in function of tree diameter, and were smoothed with #1200 sandpaper. A total of 36 samples were evaluated, 12 from the near pith region, 12 from the intermediate position and 12 from the near bark region.

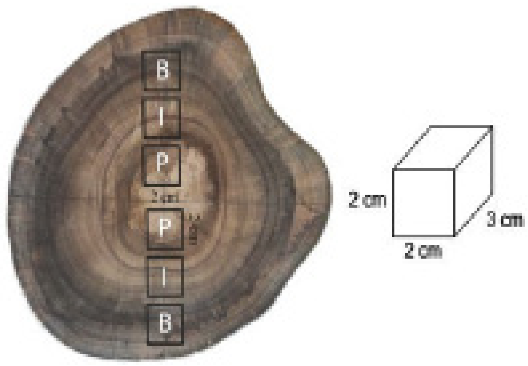

Figure 1 – Illustration of sampling diagram in disc from *Acacia mangium*. B = near bark; I = intermediate; P = near pith.

The colorimetric evaluation was performed with a CM-5 spectrophotometer, in a spectral range from 350–750 nm, with D65 light source and 10º observation angle (CIE-L*a*b* standard). Data on lightness (L*), green-red chromatic coordinate (a*) and blue-yellow chromatic coordinate (b*) were obtained. Values of saturation (C*) and hue angle (h) were calculated with equations 1 and 2, respectively.

$$C^* = (a^{*2} + b^{*2})^{1/2} \quad (1)$$

$$h = arctg\ (b^*/a^*) \quad (2)$$

Data were obtained at 16 points in each anatomical section (transversal, radial, tangential), for a total of 48 per sample, and 288 to evaluate color variation in the radial position. Mean data of colorimetric parameters in function of surface and radial position were applied in subsequent analysis.

Linear discriminant analysis (LDA), based on the linear method assuming equal prior probabilities, was performed with raw reflectance spectra of all samples, evaluating the distinction of anatomical sections and radial trunk position. A confusion matrix was evaluated.

Normality and homogeneity of data were checked by the Lilliefors and Cochran tests, respectively. When normal distribution occurred, the Tukey test was applied, while otherwise the data were analyzed by the nonparametric Kruskal-Wallis test, both at 95 % significance.

Results

Mean values of color parameters in each anatomical section (Fig. 2) indicated that the transversal sections were different than the

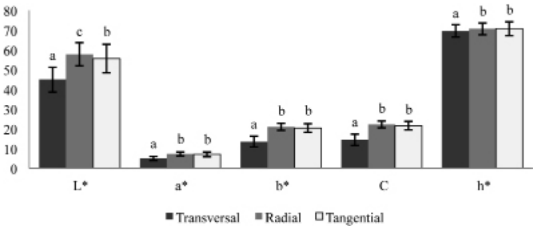

Figure 2 – Mean color parameters of *Acacia mangium* wood in function of anatomical section. Same letter for each parameter indicate no statistical difference according to the Kruskal-Wallis test at 95% probability. L* = lightness; a* = green-red chromatic coordinate; b* = blue-yellow chromatic coordinate; C = saturation; h* = hue angle.

longitudinal surfaces, with lower values of all characteristics. The radial sections had higher luminosity than tangential sections but for other parameters no distinctions were observed.

Wood from the radial trunk position (Fig. 3) near the bark had lower values of most colorimetric parameters, except hue angle, in comparison to intermediate and near pith regions.

Mean values of color parameters in function of anatomical section in each radial position, and in function of radial position in each anatomical surface (Fig. 4) indicated some trends for each parameter.

The reflectance curves of visible light from different sampling positions and anatomical sections (Fig. 5) show the similarity of all material, as expected. There was a decrease in light reflection from pith to bark, as a result of the decrease in the material's luminosity. Also, among anatomical sections, the transversal surface had lower reflectance curve, in function of smaller values of all colorimetric parameters.

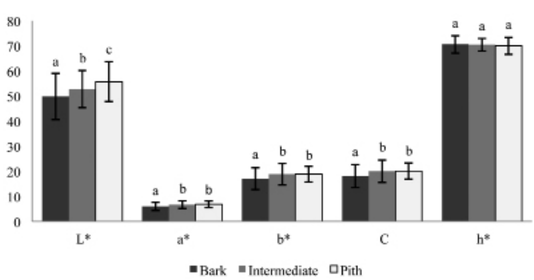

Figure 3 – Mean color parameters of *Acacia mangium* wood in function of radial position in trunk. Same letter in each parameter indicates no statistical differences according to the Kruskal-Wallis test at 95% probability. L* = lightness; a* = green-red chromatic coordinate; b* = blue-yellow chromatic coordinate; C = saturation; h* = hue angle.

The confusion matrix from reflectance data based on anatomical section (Tab. 1) indicates similarity between longitudinal sections (radial and tangential), with good distinction of transversal surfaces, with 100 % correct classifications. For radial surface, 66.7 % of the measurements resulted in correct distinction, and for tangential surface, 58.3 % of the results were adequate. In turn, the confusion matrix from reflectance data based on trunk position (Tab. 2) indicates the homogeneity of all positions, with correct classification of 69.4 % (bark), 61.1 % (intermediate) and 75.0 % in pith samples.

Discussion

All color parameters were positive, luminosity varied from approximately 40 to 60, value related to light wood, chromatic coordinate a* from 4.4 to 7.5 indicating the presence of red pigmentation, and chromatic coordinate b* from 11.6 to 21.7, related to yellow color. So, the color of *Acacia mangium* wood is classified as olive, based on the timber color chart of Camargos & Gonçalez (2001). The results are different from medium brown described by Krisnawati *et al.* (2011) in plantations in Indonesia.

Based on anatomical section (Fig. 2), mean color parameters of *Acacia mangium* were different, principally in transversal section, with lower values of all colorimetric parameters. The confusion matrix presented in Table 1, achieved a similar result, in which the radial and tangential planes presented greater confusion in the classification and the tranvesal plane presented a correct classification around 97.3%. These results corroborate literature that describe variation in colorimetric parameters from transversal to radial or tangential sections

Table 1 – Confusion matrix from LDA with raw reflectance spectra of *Acacia mangium* wood based on anatomical section.

	Transversal	Radial	Tangential
Transversal	36	0	1
Radial	0	24	14
Tangential	0	12	21

in native forest, as Vieira *et al*. (2019) which reported a tendency of parameter b* to be smaller in transversal sections in some Myrtaceae species and verified the influence of each species. Evaluating wood from different sites, native and planted forest, of *Prosopis alba* Griseb*,* Cisneros *et al.* (2019) reported that transversal sections were darker in heartwood while in sapwood there were no differences among sections.

The analysis of the confusion matrix of the reflectance data presented in Table 2 did not present a good classification among the analyzed radial positions. Indicating a weak classification, consequently a homogenization of the colorimetric

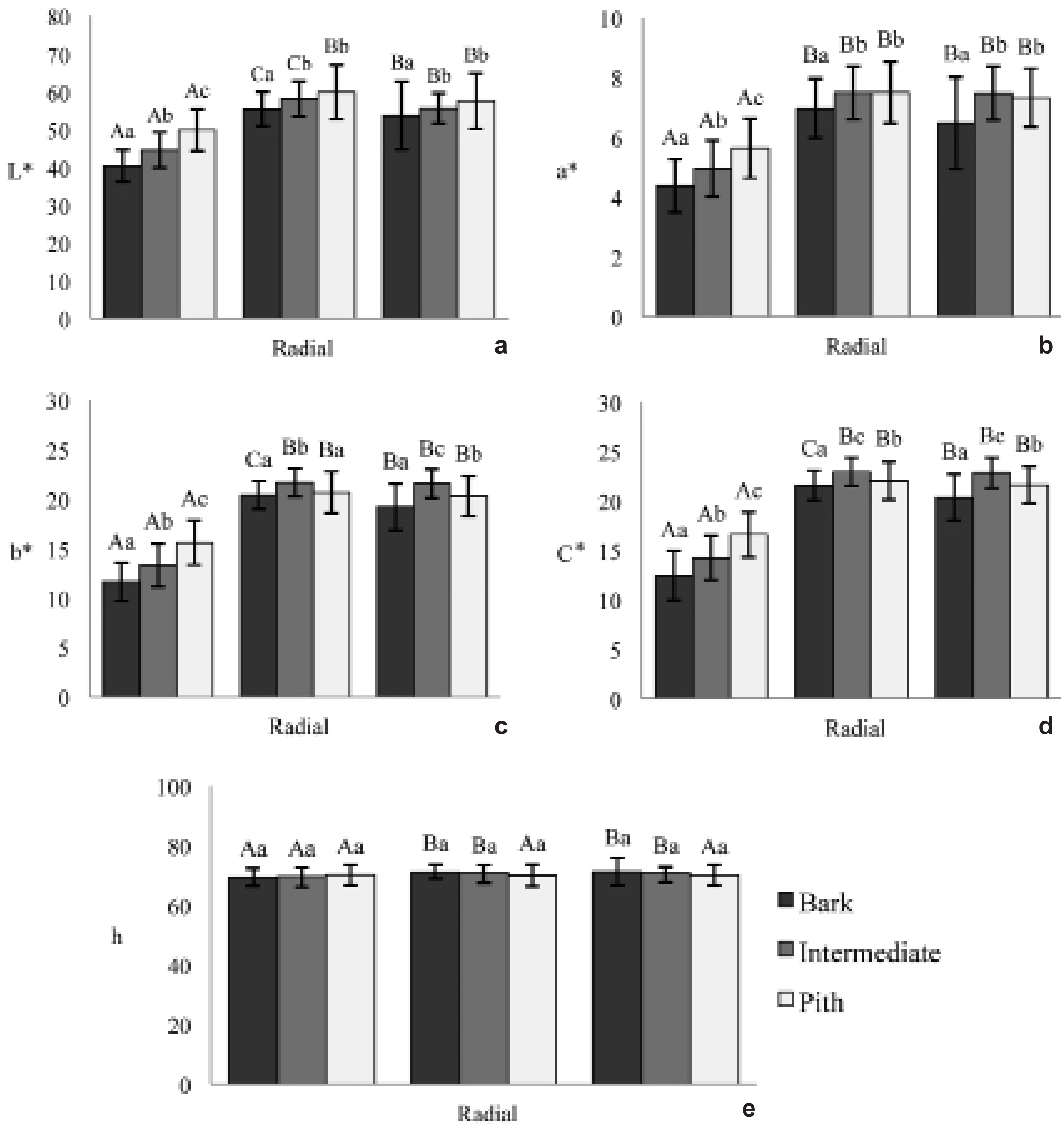

Figure 4 – a-e. Colorimetric parameters of *Acacia mangium* wood in different anatomical sections and radial positions (same capital letter in the same trunk position between different sections and same small letter in the same section between trunk positions do not differ significantly based on the Tukey or Kruskal-Wallis test at 95% probability) – a. lightness (L*); b. green-red chromatic coordinate (a*); c. blue-yellow chromatic coordinate (b*); d. saturation (C*); e. hue angle (h).

Table2 – Confusion matrix from LDA with raw reflectance spectra of *Acacia mangium* wood based on trunk position.

	Bark	Intermediate	Pith
Bark	25	13	2
Intermediate	11	22	6
Pith	0	1	28

data of the *Acacia mangium* wood in the radial direction. In the mean analysis, colorimetric parameters L*, a* and b*, are higher near pith and lower near bark. The influence of radial position in trunk (Fig. 3) in color parameters was expected since wood in the near bark region is mainly sapwood, and the literature indicates that it is often white or yellowish-white while the heartwood is classified as yellowish brown to golden brown when recently cut, or dull brown after long exposure (Tenorio *et al.* 2012).

Moya *et al.* (2012) described higher L* and lower a* when comparing sapwood and heartwood of *Acacia mangium* from 7–10-year-old trees from 30 different plantations in two regions of Costa Rica, and verified the influence of amount and type of extractives. Also, some differences in wood color of *Acacia melanoxylon* R.Br. between sapwood and heartwood were verified by Monteoliva *et al.* (2009), as well as differences among growing sites. Tenorio *et al.* (2012), studying *Acacia mangium* wood, reported a negative correlation between L* and the distance from pith, and a positive correlation of a* and b* with board radial percentage.

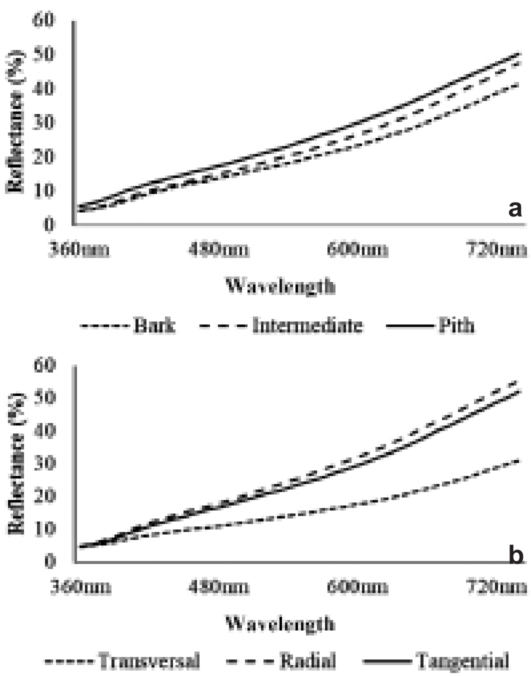

Figure 5 – Reflectance curves of visible light in *Acacia mangium* wood in function of radial position in trunk (a) and anatomical sections (b).

Differences between heartwood and sapwood have been described in other species related to growing conditions. In *Prosopis alba*, Cisneros *et al.* (2019) found a distinction between and inside trees and observed darker heartwood at sites with more precipitation. Sotelo Montes *et al.* (2013) also described the influence of environment on wood color.

Some trends for each colorimetric parameter was observed in function of anatomical section in each radial position (Fig. 4). In all sampling positions, *i.e.*, near bark, intermediate and near pith, transversal sections had lower values of luminosity, chromatic coordinates a*, b* and parameter C*. For the near pith region, parameter h was not influenced by anatomical section. In the near bark region, data for L*, b* and C* were higher in the radial position, and a* and h were statistically equal. In samples from the intermediate region, only luminosity was higher on the radial surface and no differences were found in other parameters. In the near pith region, parameters L*, a*, b* and C* were statistically similar in radial and tangential sections.

Also, some tendency for each colorimetric parameter was verified in function of radial position in each anatomical surface (Fig. 4). Luminosity and parameter a* were different in transversal sections in all trunk positions and in radial and tangential surfaces, samples near the bark had lower values. Chromatic coordinate b* was equal in radial sections in near bark and near pith samples, with no pattern in the other sections. Chroma, calculated based on a* and b*, was different in all anatomical sections in all sample positions. Hue angle results were not distinct in all samples.

So, in *Acacia mangium* wood from Brazilian plantations, anatomical surface evaluation has more influence in colorimetric parameters and reflectance of light than trunk position, which is a parameter that can be applied in wood industry planning, to guide the choice of models and final applications of wood in function of its esthetic characteristics. In general, wood radial sections show more brightness and lightness, in function of light reflection and ray dimension, and the color results can be an information for pre-classification of material, considering market preferences.

Acacia mangium wood from planted forest in Valença, northeast Brazil, is classified as olive color.

Color parameters from *Acacia mangium* wood are more strongly influenced by anatomical section than radial position in the trunk. Transversal sections have lower values of colorimetric parameters in comparison to longitudinal surfaces. Radial sections have higher luminosity than tangential sections and no distinction of other parameters. The near bark region presented lower values in most colorimetric parameters, except for hue angle, in comparison with intermediate and near pith regions.

Reflectance spectra can distinguish transversal surface, indicate the similarity between longitudinal sections (radial and tangential) and the homogeneity of trunk position, with some confusion between all data.

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