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Colorimetry parameters and wood density for Amazonian species

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Abstract
Even though wood color is a subjective parameter, it can now be measured. Colorimetry is a technique that can be performed with specific tools, allowing a color to be identified and recorded by associating it with a numerical value. This study aims to relate the color of 11 Amazonian woods, on the tangential plane, to their basic density, using the CIEL a*b* system. The colorimetric parameters assessed were: lightness (L), red-green axis (a*), yellow-blue axis (b*), color saturation (C*), and color hue (h*), in addition to the physical parameter, bulk density. Shapiro-Wilk test, Spearman's correlation, and cluster analysis were performed to attest normality of data, correlations, and similarities between species, respectively. The grouped species showed correlations ranging from strong to weak. The strongest correlations were: (b*) positively correlating with (C*) and (a*) negatively correlating with (h*). The weakest correlations were: (L*) with (C*), and (a*) with (b*). *Peltogyne* sp. wood did not form a group due to its peculiar colorimetric characteristics, and *Hymenaea sp.* was classified with yellowish tones and grouped as a medium-density wood, showing that high-density wood does not necessarily exhibit a dark color.

Keywords
Wood color — Tropical species — Wood properties — Tropical timber

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1. Introduction

Wood is an extremely heterogeneous material. Its cells have different arrangements in each of its growth directions—transversal, tangential, or radial—and its anatomy influences its properties: physical, chemical, and mechanical, making it a highly complex material (Araújo, 2020). Besides, there are subjective wood characteristics, such as color, texture, taste, odor, grain, and basic density (Moreschi, 2014). Wood color is an organoleptic property; however, it could be measured. Colorimetry is a technique that can be performed using a specific instrument, which allows the color to be recorded by associating it with a numerical value (Bonfatti Júnior; Lengowsk, 2018; Mesquita et al. 2020). Various factors influence wood color, including concentration of chemical components present in each species, anatomical characteristics, genetic and phenotypic factors, as well as environmental conditions and how wood was felled and forwarded (Gonçalez, 1993).

Typically, wood color assessment is related to its visual aspect and beauty, which directly influences its intended use and value in the market (Mori et al. 2005). However, wood colorimetry is not limited to its aesthetic property; it is also be associated with characteristics that affect components involved in energy potential from biomass (Bekhta; Niemz, 2003; Esteves; Pereira, 2009; Garcia et al. 2014). Forest biomass is a renewable energy source, which may come in the form of charcoal, pellets, or from burning wood residues resulting from logging activities (Couto et al. 2000). Colorimetry can also used in pellets to assess its energy generation power, for example. Sgarbossa et al. (2014) found positive correlations between the variables of the CIEL*a*b* system and biomass ash content, moisture, and calorific value. However, aspects still need to be improved for colorimetry to be effectively applied as a procedure for biomass quality assessment.

Therefore, studies aiming to identify and classify wood using colorimetry to understand its physical and chemical properties are of great importance to establish a quality

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standard for raw material, both at the national and international levels. Such studies can contribute to developing more accessible technologies, assessing charcoal and energy production. This present study aims to relate the color of 11 Amazonian wood species in the tangential plane to their bulk density, using the CIEL a*b* system. Our hypothesis is that color is correlated with wood's basic density.

2. Material and Methods

2.1 Samples for analysis

Wood samples used in this study were provided by CKBV Florestal Ltda – Cikel, except for *Simarouba amara* species, commonly known as marupá, which was sourced from Parauapebas. Cikel, operating in the charcoal and forest management sectors, is in the city of Paragominas, in the southeastern mesoregion of the state of Pará, between the coordinates 3°30' and 3°45' south latitude and 48°30' and 48°45' west longitude (Pinto et al. 2009). According to Köppen and Geiger, Paragominas is classified as Am (tropical monsoon), with an average temperature of 26.6 °C and an average annual rainfall of 1,805 mm (Climate-Data ORG, 2019). Wood samples from eleven native forest species were selected to this study (Table 1) due to their representativeness in the region.

Table 1. Forest species assessed in the study

n	Common name	Scientific name	Family
1	Amesclim	*Tetragastris altissima*	Burseraceae
2	Cupiúba	*Goupia glabra*	Goupiaceae
3	Guajará bolacha	*Pouteria sp.*	Sapotáceas
4	Imbira quiabo	*Sterculia pruriens*	Malvaceae
5	Jatobá	*Hymenaea sp.*	Leguminosae
6	Jiboião	*Eschweilera amazonica*	Lecythidaceae
7	Maçaranduba	*Manilkara sp.*	Sapotaceae
8	Marupá	*Simarouba amara*	Simaroubaceae
9	Rouxinho	*Peltogyne sp.*	Leguminosae
10	Tachi branco	*Tachigali vulgaris*	Leguminosae
11	Timborana	*Pseudopiptadenia psilostachya*	Leguminosae

2.2 Wood properties

Three wood samples were prepared for each species, totaling 33 samples. Wood density (1) was carried out according to the procedures described in standard NBR 11941 (ABNT, 2003).

$$db = \frac{m_3}{m_2 - m_1} \quad (1)$$

Where:
d_b = bulk wood density (g.cm^{-3});
m_3 = oven-dried mass (g) (105 ± 2) °C;
m_2 = container plus water and immersed wood weight (g);
m_1 = container plus water weight (g).

2.3 Colorimetry

The samples were obtained from heartwood tree branches and stems. Three samples were prepared for each species, totaling 33 2.5 cm × 2.5 cm × 10 cm samples. The surfaces of each sample was sanded using 120- and 220-grit sandpaper. The samples were stored in a climate-controlled room at 12% moisture content.

The methodology adopted for colorimetric parameter determination was the CIEL*a*b* system, according to the standards of the Commission Internationale de L'Éclairage – CIE (1976). This system is composed of three coordinates: (L), lightness, ranging from 0 (black) to 100 (white), and (a*), representing green-to-red axis, with negative values indicating greenness and positive values indicating redness, and (b*) blue-to-yellow axis, with negative values indicating blueness and positive values indicating yellowness.

A portable colorimeter CR400 (Konica Minolta) with an 8 mm sensor aperture was used. The measurements were performed by placing each sample in direct contact with the device's viewing area. The device was calibrated and configured to use a D65 light source (illuminant), made of a xenon lamp, simulating daylight radiation, with a 0° observation angle, at room temperature, and an illumination area of 11 mm in diameter.

The colorimetric characterization of the wood samples was carried by taking three measurements from each sample from the tangential plane. The colorimetric parameters evaluated were: lightness (L), red-green chromatic coordinate (a), yellow-blue chromatic coordinate (b*), color saturation (C*), and hue angle (h*). The values for color saturation (C*) and hue angle (h*) were calculated afterward, according to formulas 2 and 3.

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

Where:
C* – Color saturation;
a* – color coordinate along the *X* axis red (+) to green (-);
b* – Yellow-blue chromatic coordinate.

$$h^* = \tan^{-1}\left(\frac{b*}{a*}\right) \quad (3)$$

Where:
h* – Hue angle;

a* – Red-green chromatic coordinate;
b* – Yellow-blue chromatic coordinate.

2.4 Statistic assessment

Shapiro-Wilk normality test was applied to the data to test if the data distribution followed a Gaussian (normal) distribution (Campos; Leite, 2009). Shapiro-Wilk test is one of the most important statistical tests, as its results serve as a prerequisite for conducting further analyses.

The Spearman correlation test is a non-parametric analysis indicating the relationship between two continuous or ordinal variables when the order (monotonicity) is preserved (Bunchaft; Kellner, 1999). This correlation analysis was applied to the colorimetric parameters and wood density values examined in this study.

Cluster analysis is a multivariate method that groups similar data based on a predefined characteristic (Hair et al. 1998). The formation of similar groups depends directly on the measure of distance between them, which is given by the Euclidean distance, in which closer elements are more similar and belong to the same cluster, while more distant elements are different and fall into separate clusters (Bem; Waismann, 2015). Cluster analysis and boxplot were based on colorimetric and density. All analyses were conducted using the Statistical Package for Social Sciences (SPSS) version 18.0 and Minitab 14 software.

3. Result and Discussion

Table 2 presents the mean values of bulk density (bd) and the colorimetry parameters (Lightness; color saturation; red-green chromatic coordinate, yellow-blue chromatic coordinate, hue angle) for each species. Table 3 shows the corresponding wood colors according to Camargos, Gonçalez (2001) classification.

3.1 Normality test

Shapiro-Wilk test indicated that the variables (a) and (C) followed normal distribution, with p-values greater than α, the significance level, with 95% of confidence (Table 4). The other variables, (L), (b), (h), (db), did not show a normal distribution.

If data had followed a normal distribution, the analysis could have been done with more room to accommodate other tests, allowing for parametric statistics. However, when the number of observations is not large, as is the case here, it is common to have non-normal data (Moraes et al., 2005). An incorrect assumption of normality could lead to big errors in statistical analysis and interpretation. It is more common for observations to be only approximately normally distributed (Johnson; Leone, 1964). Based on this, and following the principle of parsimony, the Spearman correlation was applied. Although it is less commonly used than Pearson's correlation, it does not

Table 2. Average bulk density (db) and colometry parameters according to CIEL a*b* system for each species

Scientific name	db	L*	a*	b*	C*	h*
Eschweilera amazonica	0.72	50.58	10.06	18.74	21.27	61.79
Goupia glabra	0.71	53.21	5.40	16.18	17.06	71.48
Hymenaea sp.	0.81	65.02	9.35	26.02	27.65	70.25
Manilkara sp.	0.80	52.78	10.29	17.99	20.73	60.29
Peltogyne sp.	0.64	43.27	17.08	6.66	18.33	21.31
Pouteria sp.	0.57	49.45	13.62	23.47	27.14	59.89
Pseudopiptadenia psilostachya	0.86	54.68	6.79	17.75	19.00	69.10
Simarouba amara	0.33	79.13	1.58	19.40	19.47	85.37
Sterculia pruriens	0.22	72.16	4.40	22.17	22.60	78.80
Tachigali vulgaris	0.64	57.05	8.44	20.05	21.75	67.20
Tetragastris altissima	0.54	65.90	4.99	14.32	15.16	70.79

db ($g.cm^{-3}$) density; L* Lightness; C* Color saturation; a* Red-green chromatic coordinate; b* Yellow-blue chromatic coordinate, h* Hue angle.

Table 3. Color classification of the wood species according to Camargos; Gonçalez (2001) classification

Scientific name	Color
Eschweilera amazonica	Yellowish orange
Goupia glabra	Yellowish orange
Hymenaea sp.	Olive brown
Manilkara sp.	Red
Peltogyne sp.	Purple
Pouteria sp.	Light brown
Pseudopiptadenia psilostachya	Olive yellow
Simarouba amara	White
Sterculia pruriens	Light olive
Tachigali vulgaris	Yellowish olive
Tetragastris altissima	Light yellow

Table 4. Shapiro-Wilk normality test

Parameter	W. Calc	D.F.	p-value	Result
L*	0.929	33	0.033	Not normal
a*	0.954	33	0.170	Normal
b*	0.917	33	0.015	Not normal
C*	0.941	33	0.073	Normal
h*	0.768	33	0.001	Not normal
db cm-3	0.888	33	0.003	Not normal

db ($g.cm^{-3}$) density; L* Lightness; C* Color saturation; a* Red-green chromatic coordinate; b* Yellow-blue chromatic coordinate, h* Hue angle require normal data to compromise the reliability of the results (Figueiredo; Silva, 2009).

3.2 Spearman correlation

Table 5 shows Spearman correlation between colorimetry parameters and bulk density. Correlations between (b*/ C*) and (L*/h*) were positive and strong, close to +1. Regarding (b*/C*), an increase in (b*) means a yellowish tone, and higher chromaticity (C*) indicates greater pigment or color concentration, characterizing the wood.

L and h showed similar proportions, in which lighter colors are present due to high lightness (L*), and hue angle (h*), characterizing a softer tone influenced by the level of lightness. Camargos, Gonçalez (2001) found a strong correlation between (L*/h*), although in cases where the wood exhibits low lightness (L*), hue angle (h*) may have little expressive effect on wood's appearance. Median correlation values were calculated for (a*/bd) and (L*/b*). Although these correlations were lower, away from 1 and -1, some level of interaction between the variables was still evident.

Negative Spearman correlation coefficients indicate that an increase in one variable decreases the other. Values closer to -1 indicate a strong negative correlation, as observed for (a*/h*) and (L*/a*). The other interactions between the colorimetric parameters and density showed moderate correlations, with coefficients away from -1, indicating a weaker negative association.

Correlation between hue angle (h*) and density (db) shows that higher h* enhances lighter tones, reflecting greater lightness and, consequently, lower density. Conversely, the correlation between lightness (L*) and basic density (db) is inversely proportional, indicating that woods with higher lightness tend to have medium to low basic density values. The other correlations were close to zero and not statistically significant. Other researchers have explored the uses of color to correlate to other wood characteristic behaviors. For example, Forsthuber et al. (2014) high correlation between color parameters and discoloration of late and earlywood.

3.3 Cluster analysis to colorimetry parameters and density

Cluster analysis can be conducted using hierarchical or non-hierarchical methods. In this study, to group the 11 Amazonian species based on the set of analyzed variables, the hierarchical clustering method was chosen (Figure 1). A similar study was conducted by Silva et al. (2017), who also clustered third tropical species based on color and observed their relationship to basic density. The species are clustered into 5 groups from very dark and very dense wood to less dark and lighter wood.

Table 5. Spearman correlation of colometry parameters and density

Variable	a*	b*	C*	h*	db cm -3
L*	-0.861	0.321	-0.040	0.883	-0.325
a*		-0.044	0.285	-0.943	0.415
b*			0.924	0.227	-0.053
C*				-0.108	0.110
h*					-0.352

db (g.cm^{-3}) density; L* Lightness; C* Color saturation; a* Red-green chromatic coordinate; b* Yellow-blue chromatic coordinate, h* Hue angle

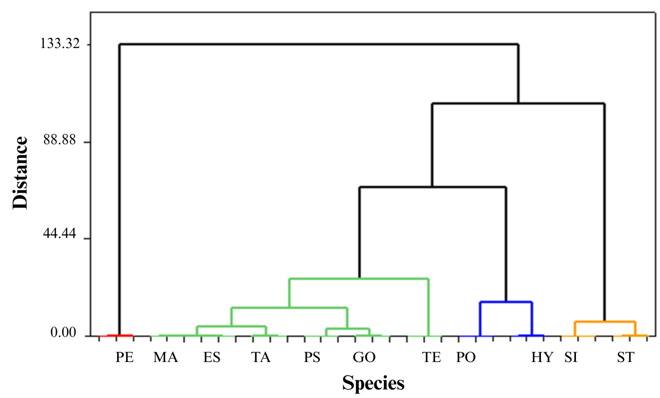

Figure 1. Cluster analysis groups species based on colorimetry parameters and bulk density. PE = *Peltogyne sp.*, MA = *Manilkara sp.*, ES = *Eschweilera amazonica*, TA = *Tachigali vulgaris*, PS = *Pseudopiptadenia psilostachya*, GO = *Goupia glabra*, TE = *Tetragastris altíssima*, PO = *Pouteria sp.*, HY = *Hymenaea sp.*, SI = *Simarouba amara* e ST = *Sterculia pruriens*.

The first cluster is composed of a single species: *Peltogyne sp.*, which has a medium density and is represented by the color red. This separation can be explained by its colorimetric characteristics, which differ significantly from those of the other species. The most pronounced distinction is observed in the red-green axis (a*), which is the main contributor to this wood's color (Ribeiro et al. 2019). On the other hand, the hue angle (h*) showed the lowest value among all species, further emphasizing its unique profile. The variables (b*) and (L*) also presented low values, indicating a lesser presence of yellow pigments and a stronger tendency toward reddish tones.

The next cluster, in green in Figure 1 consists of the following species: *Manilkara sp.*, *Eschweilera amazonica*, *Tachigali vulgaris*, *Pseudopiptadenia psilostachya*, *Goupia glabra*, and *Tetragastris altissima*. This group is mostly composed of medium-density woods, except *Manilkara sp.* and *Pseudopiptadenia psilostachya*, which

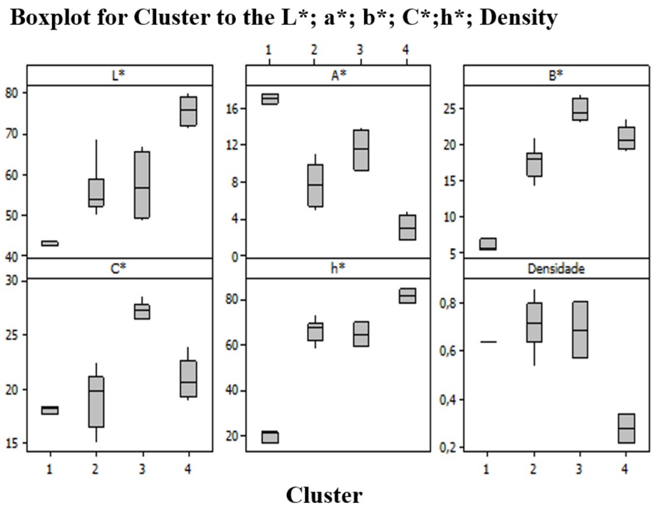

Figure 2. Box plot representing each cluster for L, a, b, C, h, and density. Density in cm^3 (0.2 to 0.8); (L*): lightness (40 to 80); (a*): Red-green chromatic coordinate (0 to 16); (b*) Blue-yellow chromatic coordinate (5 to 25); (C*) color saturation (15 to 30) and (h*) hue angle (20 to 80).

are classified as high-density. The grouping of these species can be mainly explained by two variables: basic density (db) and color saturation (C*). Basic density contributed to the clustering due to the similarity in values across species, even among those with higher density, for example *Manilkara sp* and *Pseudopiptadenia psilostachya*. As for color saturation (C*), the low values, ranging from 15.16 to 21.75 indicate limited chromatic intensity, resulting in minimal influence on the (a*) and (b*) coordinates. This pattern characterizes the species in this group as having medium pigmentation.

Th next group, composed by the *Pouteria sp.* and *Hymenaea sp.* species are part of the blue cluster. They are medium and high-density woods, respectively. The grouping of these species is primarily due to the similarity in their values for color saturation (C*) and hue angle (h*), which directly affect the intensity of the chromatic coordinates (a*) and (b*). These characteristics result in both species displaying color tones that tend toward yellow. According to the color chart by Camargos, Gonçalez (2001), *Pouteria sp.* can be described as light brown or yellowish-brown, while *Hymenaea sp.* may present shades of olive brown to yellowish olive.

Cluster *4*, represented by the color orange, is composed by the species *Sterculia pruriens* and *Simarouba amara*, both low density and high luminosity, which set them apart from the other wood species analyzed. There was a strong negative correlation between lightness (L*) and basic density (db), where an increase in L corresponds to a decrease in density. This inverse relationship is clearly illustrated in Figure 2, where the clusters are represented by numbers 1 through 4.

4. Conclusion

Our hypothesis was proven true, since density had an average to strong correlation to color parameters. The strongest correlations observed were between the chromatic coordinate on the blue-yellow axis (b*) with color saturation (C*). Green-red chromatic coordinate (a*) had a significant negative correlation with hue angle (h*). The weakest correlations were between lightness (L*) and color saturation (C*), as well as between the chromatic coordinates (a*) and (b*). The *Peltogyne sp.* species was the only one to form a distinct cluster by itself, due to its unique colorimetric characteristics, particularly along the (a*) axis. In contrast, *Hymenaea sp.,* dark coloured, was grouped with medium-density species, demonstrating that high density does not always correspond to dark tones. This highlights the importance of multivariate analysis in understanding the complex relationship between physical properties and visual attributes in wood species.

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