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WOOD COLORIMETRY OF LAURACEAE SPECIES NATIVE TO BRAZIL

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ABSTRACT

Considering the complexity and difficulty of identifying forest species, wooden disks were collected to verify the potential of colorimetry to distinguish native species from Araucaria Forest stands of the *Lauraceae* family. The following species were used: *Nectandra megapotamica*, *Ocotea indecora*, *Ocotea diospyrifolia* and *Ocotea puberula.* Nees, to provide data on these species that grow naturally in Santa Catarina state, southern Brazil, enriching a robust database that can be practically applied in the commercialization of native woods. Visible spectra and colorimetric parameters were obtained from each anatomical surface and the results were evaluated by comparing the mean of each species regarding radial trunk position and anatomical surface. The data were also submitted to principal component analysis and performance of discriminant models (k-NN, SVM and ANN) for species discrimination with raw and second-derivative data. In general,

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colorimetric data presented different behavior, and chromatic coordinates *a** and *b** had higher potential for distinguishing the species. According to the mean spectra, *Ocotea indecora* had reflectance values different from the other species. By principal component analysis, raw data indicated the separation only of *Ocotea indecora*, while second-derivative data allowed better distinction of species. In all discrimination models, second-derivative data produced the best results. Thus, the use of colorimetry has potential for wood distinction of the *Lauraceae* species evaluated, improving the oversight of illegally traded timber.

Keywords: Chromatic coordinates, native wood, *Nectandra, Ocotea,* species discrimination, visible reflectance spectra.

INTRODUCTION

Inspection and control of wood species in the market are difficult, principally because of the absence of tree vegetative and reproductive material, which are important and contribute to genus or species identification, as leaves that are available in most part of year, or reproductive material that are accessible at restrict months (Rzanny *et al.* 2017). When only wood can be accessed, evaluation of its anatomic characteristics can be used for species identification, but even though attaining reliable results, requires experienced specialists, and it can be a time-consuming process. Sometimes, wood identification at species level is difficult or impossible using traditional light microscopy (Gasson 2011).

Thus, complementary techniques are necessary to increase precision and to allow wood species identification or to contribute to wood characterization also for identification purposes. Among these new techniques, colorimetry is a fast and nondestructive method that can be applied for a great number of characterizations, as for example in wood color changes after photodegradation and monitoring surface modifications or conservation in wooden artifacts (Agresti *et al.* 2013, Calienno *et al.* 2014, Tolvaj *et al.* 2014). When analyzing the potential of colorimetry for wood analysis, Pastore *et al.* (2004) applied spectro-colorimetric data to evaluate the effect of ultraviolet irradiation on four tropical wood species. Also, some studies have applied colorimetry to distinguish wood species (Nishino *et al.* 1998, Silva *et al.* 2015, Silva *et al.* 2017).

However, wood color is influenced by a wide range of factors, such as trunk position (Moya *et al.* 2012), anatomical surface (Atayde *et al.* 2011), natural degradation and thermal treatment (Cademartori *et al.* 2013), roughness in the surface of the wood (Camargos and Gonçalez, 2001), among others. The use of colorimetry to describe wood species native to southern Brazil is still scarce, with highlight of *Myrtaceae* species growing in Araucaria Forest areas (Vieira *et al.* 2019a) and eight species from Rio Grande do Sul (Silva *et al.* 2015). However, there are few studies of *Lauraceae* species from Araucaria Forest stands.

According to Gasper *et al.* (2013), the *Lauraceae* family is the six richest in Araucaria Forest areas in the southern Brazilian state of Santa Catarina. *Lauraceae* species discrimination is complex and difficult, mainly in function of their high diversity but morphological uniformity of wood (Oliveira *et al.* 2001, Herdt and Melo Júnior 2016).

Considering wood anatomical characteristics, it is observed some similarity from *Nectandra megapotamica* (Spreng.) Mez, *Ocotea diospyrifolia* (Meisn.) Mez, *Ocotea indecora* (Schott) Mez and *Ocotea puberula* (Rich.) Nees, as diffuse porosity, septate fibers, axial parenchyma vasicentric, simple perforated plate, alternate intervessel pits and heterogeneous rays (Tortorelli 1956, Vieira *et al.* 2019b).

As a result of these anatomic similarities, species are confused in wood processing and commerce, which can be a problem, in native species, because this mistake can contribute to some illegalities and damages to forest conservation.

So, the objective of this work is to verify the potential of applying colorimetry to differentiate wood from four *Lauraceae* species native to Araucaria Forest areas: *Nectandra megapotamica* (Spreng.) Mez, *Ocotea diospyrifolia* (Meisn.) Mez, *Ocotea indecora* (Schott) Mez and *Ocotea puberula* (Rich.) Nees, to provide data on these species that grow naturally in Santa Catarina state, southern Brazil.

Material and methods

The wood samples of the four species were obtained from trees felled because they were in a region to be inundated by the São Roque hydroelectric project, in Santa Catarina state, southern Brazil. Three trees of each species were analyzed (Table 1). Access to the material is registered with the Brazilian Council for Management of Genetic Heritage (CGEN/SISGEN) under number AF3EDDC. Figure 1 shows a portion of the transversal surface of a disc of each species.

Table 1: Scientific and vernacular names in Portuguese, LUSC registration numbers, diameter at breast height (DBH) and geographic coordinates of evaluated species.

Species	Vernacular name in Portuguese	Registration number	DBH (cm)	Geographic coordinate	
				Lat (WGS84)	Long (WGS84)
N. megapotamica	Canela-imbuia	LUSC 6264	27,7	-27,49390	-50,80386
		LUSC 6265	23,1	-27,49387	-50,80384
		LUSC 6266	35,2	-27,49378	-50,80391
O. indecora	Canela	LUSC 6267	41,2	-27,49310	-50,80729
		LUSC 6268	34,1	-27,49306	-50,80729
		LUSC 6269	17,5	-27,49305	-50,80724
O. diospyrifolia	Canela	LUSC 6270	50,6	-27,49719	-50,81050
		LUSC 6271	38,8	-27,49707	-50,81049
		LUSC 6272	32,2	*	
O. puberula	Canela-sebo	LUSC 6273	33,7	-27,48253	-50,81121
		LUSC 6274	32,1	*	
		LUSC 6275	29,0	-27,48261	-50,81116

*Without information.

From each individual, samples with dimensions of 2 x 2 x 2 cm were obtained in regions close to the bark (2), intermediate (2) and close to the pith (2) to cover wood variations. To determine the location of the intermediate position, the distance between the pith and the bark of the disk was measured; subsequently, demarcation and removal of the specimens named "intermediate" were carried out. As some species had no visual distinction between heartwood and sapwood, there was no separation of the samples based on these positions. All samples were obtained from areas free of pathogens and/or disc anomalies. As recommended by Vanclay *et al.* (2008), the samples were manually smoothed with 100 sandpaper to obtain reliable color data and eliminate oxidation effects and saw marks on the surfaces. All samples were stored at a temperature of 25 ± 2 °C and relative humidity of 50 ± 2 %.

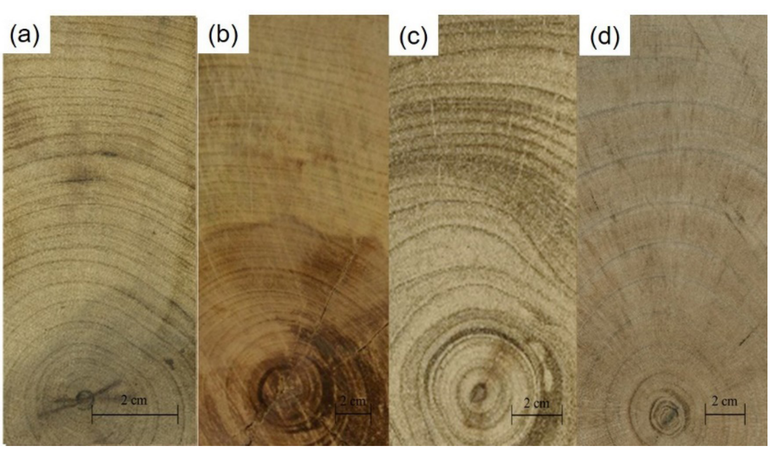

Figure 1: Wood samples. (a) *Nectandra megapotamica*, (b) *Ocotea diospyrifolia*, (c) *Ocotea indecora*, (d) *Ocotea puberula*.

Colorimetric parameters and visible spectroscopy

The CIEL*a*b* standard was used for the colorimetric evaluation of wood with daylight illuminant (D65) and an observation angle of 10 º. In each sample, 6 data were collected using a Konica Minolta CM-5 spectrophotometer and Spectra Magic NX software, with two readings in each anatomical section, totaling 108 readings. Data were obtained for lightness (*L**) which varies between 100 (representing a perfect diffuse reflector) and 0 (representing black), green-red axis (*a**) and blue-yellow axis (*b**), both (*a** and *b**) without numerical limits (Kamperidou *et al.* 2013). Additionally, reflectance spectra from 350 - 750 nm were also analyzed. The parameters *C** (chroma or saturation) and *h* (hue angle) were calculated based on the equations described by Camargos and Gonçalez (2001).

Test of means, principal component analysis and classification models

Initially, to compare the mean colorimetric parameter values, the normal distribution of the data was checked by the Kolmogorov-Smirnov test, and homogeneity of variance by the Bartlett test, both at 95 % probability. After confirmation, analysis of variance was performed to verify differences between evaluated mean data, and when there are significative variances, Scott-Knott test was applied, both at 95 % probability.

When considering different anatomical surfaces (transversal, longitudinal radial and longitudinal tangential) and trunk position (near bark, intermediate and near pith), again normality was verified by the Kolmogorov-Smirnov test and homogeneity of variance by the Bartlett test, both at 95 % probability. At this stage, results for *L** (*Nectandra megapotamica* (Spreng.) Mez), *a** (*Ocotea diospyrifolia* (Meisn.) Mez) and *h* (*Nectandra megapotamica* (Spreng.) Mez and *Ocotea diospyrifolia* (Meisn.) Mez) were transformed by the Box-Cox (Box and Cox 1964) method to satisfy the normal distribution requirement. Other data were normally distributed and needed no transformation.

After, variance analysis (95 % of probability) was performed to confirm the existence of differences between evaluated mean data for each species and colorimetric parameter in distinct anatomical sections and trunk position. When results indicated significative differences, Scott-Knott test was applied, also at 95 % probability. All data were analyzed with the R software (R Core Team 2018).

To evaluate the behavior of species according to visible spectra, principal component analysis (PCA) was performed. PCA was applied to the raw data and after Savitzky-Golay second derivative transformation, with 3 points of smoothing using the R software, applying the FactoMineR (Lê *et al*. 2008) and factoextra (Kassambara and Mundt 2017) packages.

The potential for classification of *Lauraceae* species was performed with visible spectra in raw form and after second derivative transformation. Artificial neural network (ANN), support vector machines with kernel radial basis function (SVM) and k-nearest neighbors (k-NN) techniques were used to point out the best classification models.

The models were tested by applying the “train” function in the “caret” package of R (Kuhn *et al.* 2020). The comparative accuracy and precision values of each dataset were assessed. Data were divided into learning (70 %) and testing (30 %) for the construction of models based on randomly stratified sampling of each species.

RESULTS AND DISCUSSION

Mean values obtained from the analysis of all specimens of the species for all colorimetric parameters (*L**, *a**, *b**, C* and *h*) of the four *Lauraceae* species (Table 2).

Table 2: Mean values obtained from the analysis of all specimens of the species and (standard deviation) of colorimetric parameters of *Lauraceae* species.

Species	*L**	*a**	*b**	*C**	*h*
N. megapotamica	61,14 b (7,88)	3,65 c (1,29)	20,88 b (3,39)	21,26 b (3,21)	79,62 a (4,95)
O. diospyrifolia	58,01 c (5,19)	5,58 b (2,05)	22,28 a (1,89)	23,06 a (1,86)	75,94 b (5,21)
O. indecora	69,60 a (2,01)	2,74 d (0,65)	11,38 d (1,05)	11,73 c (1)	76,33 b (3,61)
O. puberula	58,54 c (6,41)	7,65 a (1,76)	19,34 c (2,03)	20,82 b (2,68)	68,65 c (3,07)

*Means with the same letter in the column do not differ statistically by the Scott Knott test at 95 % probability.

Based on mean data (Table 2), for all evaluated species, chromatic coordinates *a** and *b** had positive values, in accordance with Lima *et al.* (2013), meaning the samples had red and yellow chromaticity. Also, it is possible to classify the species based on color described by Camargos and Gonçalez (2001). In function of intervals recommended by them, average wood colors are near pinkish gray (*Nectandra megapotamica* (Spreng.) Mez), grayish pink (*Ocotea diospyrifolia* (Meisn.) Mez*, Ocotea puberula*) and light olive green (*Ocotea indecora* (Schott) Mez). Also, considering parameters described in the literature, all species had high lightness because they had values of *L** higher than 54 (Nishino *et al.* 1998). Another classification available in the literature, according to Rowe (2012), indicates that wood typically exhibits lightness values ranging from 20 to 80, with values for *Lauraceae* species varying between 58 and 69, as expected. However, parameters in wood can have a great variation, and Rowe (2012) also comment that mean value for chromaticity (*a** and *b**) for wood is in the range 10 - 18, but for evaluated species only parameter *b** from *Ocotea indecora* (Schott) Mez is in this interval.

The results for *Ocotea* species, principally *Ocotea puberula*, were similar to those described by Silva *et al.* (2017), who evaluated the colorimetry of 30 forest species and characterized a sample from genus *Ocotea*, reporting mean values of *L**= 56,72; *a**= 8,84; *b**= 22,45; *C**= 24,17 and *h*= 68,60. There were some statistical differences between all species in all colorimetric parameters evaluated. This behavior was also described by Nisgoski *et al.* (2017a) when evaluating of *Myrtaceae* species of the genera *Eucalyptus* and *Corymbia.* However, for *Lauraceae* wood, only parameters *a** and *b** were able to discriminate all species. According to Pastore *et al.* (2004), variations in content and chemical composition of extractives in each species can explain the difference in colorimetry results.

The mean *L** value for *Ocotea indecora* was higher than for the other species, and *Ocotea diospyrifolia* (Meisn.) Mez and *Ocotea puberula* were classified as darker. The *L** values for *Lauraceae* wood found were high in comparison to data for *Tabebuia serratifolia* (39) and *Brosimum rubescens* (42,39) reported by Autran and Gonçalez (2006).

For chromatic coordinate *a**, *Ocotea puberula* had more reddish hue, followed by *Ocotea diospyrifolia* (Meisn.) Mez, *Nectandra megapotamica* (Spreng.) Mez and *Ocotea indecora* (Schott) Mez with lower results. Considering results for other wood species commonly used, these values are relatively low. For example, Teles and Costa (2014) found mean value of 13,5 for *a** in angelim (*Hymenolobium petraeum* Ducke) wood and Romagnoli *et al.* (2013) reported mean values of 9,14 for *a** in wood samples of yellow lapacho (*Tabebuia serratifolia* (Vahl)) Nichols with standard color.

For chromatic coordinate *b**, a low value was also found for *Ocotea indecora* (Schott) Mez. Considering only colorimetric values, this species could be the most valuable in the market, because wood with lower values of *a** and *b** generally have higher aggregate value (Zanuncio *et al.* 2014). Second lowest value was obtained for *Nectandra megapotamica* (Spreng.) Mez and third for *Ocotea puberula.* A higher result was found for *Ocotea diospyrifolia* (Meisn.) Mez*,* classified as yellowish, which can be confirmed (Figure 1).

For parameter *C**, the behavior was similar to that of coordinate *b**. Again, *Ocotea indecora* had lower values and *Ocotea diospyrifolia* (Meisn.) Mez higher values, but for this parameter, other intermediate species (*Nectandra megapotamica* (Spreng.) Mez and *Ocotea puberula)* had statistically similar results. For hue angle

(h), samples of *Nectandra megapotamica* (Spreng.) Mez had higher values, while intermediate data were observed for *Ocotea diospyrifolia* (Meisn.) Mez and *Ocotea indecora* (Schott) Mez, and lower values for *Ocotea puberula*. Lower values of h, in accordance with Sousa *et al.* (2019), influenced the classification of whitish wood, which also can be confirmed (Figure 1).

The evaluation of the influence of trunk radial position and anatomical surface (Table 3 and Table 4) on the colorimetric parameters revealed some differences.

For the L^* parameter regarding trunk position, the species presented distinct behavior, with a tendency for lower means in the region near pith for *Ocotea diospyrifolia* (Meisn.) Mez and *Ocotea indecora* (Schott) Mez, while for *Nectandra megapotamica* (Spreng.) Mez, the near bark region had statistically higher values than the other species. For *Ocotea puberula*, there was no influence of radial position on L^*. For anatomical section, values of L^* had the same tendency, with mean data similar and higher for radial and tangential surfaces, and lower values for the transversal surface. Nishino *et al.* (2000) also described this behavior in evaluating the relationship between colorimetric parameters and sapwood density of 25 species, and concluded that probably transversal sections of fibers were responsible for diminishing the lightness in transversal wood surfaces.

Table 3: Mean values of parameters L^*, a^* and b^* in two separated analyses: evaluating only different trunk position (near bark, intermediate, near pith) and considering only anatomical section (transversal, radia and tangential) in wood from *Lauraceae* species.

		Near bark		Intermediate		Near pith	
L^*	*N. megapotamica*	64,88 (4,11)	a	60,17 (10,07)	b	58,38 (6,94)	b
	O. diospyrifolia	62,61 (2,63)	a	56,90 (4,69)	b	54,52 (4,23)	c
	O. indecora	69,56 (1,39)	b	70,84 (1,48)	a	68,41 (2,27)	c
	*O. puberula***	58,79 (7,34)		58,82 (6,29)		58,00 (5,64)	
		Transversal		Radial		Tangential	
	N. megapotamica	57 (7,26)	b	63,87 (8,36)	a	62,55 (6,31)	a
	O. diospyrifolia	55,95 (4,99)	b	58,61 (5,46)	a	59,48 (4,54)	a
	O. indecora	68,92 (1,93)	b	70,10 (2)	a	69,79 (1,95)	a
	O. puberula	55,55 (6,57)	b	60,94 (5,58)	a	59,12 (5,99)	a
a^*		Near bark		Intermediate		Near pith	
	N. megapotamica	3,05 (1)	b	3,75 (1,44)	a	4,15 (1,18)	a
	O. diospyrifolia	3,54 (0,69)	c	5,90 (1,97)	b	7,30 (1)	a
	O. indecora	2,64 (0,35)	b	2,29 (0,52)	c	3,30 (0,60)	a
	O. puberula	6,20 (1,45)	c	8,01 (1,65)	b	8,72 (1,07)	a
		Transversal		Radial		Tangential	
	*N. megapotamica***	3,47 (1,12)		3,46 (1,43)		4,02 (1,26)	
	*O. diospyrifolia***	5,19 (2,01)		5,98 (2,13)		5,57 (1,98)	
	O. indecora	2,46 (0,59)	b	2,86 (0,63)	a	2,91 (0,65)	a
	*O. puberula***	7,40 (1,91)		7,73 (1,90)		7,80 (1,45)	
b^*		Near bark		Intermediate		Near pith	
	N. megapotamica	22,45 (3,20)	a	20,52 (3,93)	b	19,66 (2,27)	b
	*O. diospyrifolia***	22,17 (1,58)		22,84 (2,09)		21,83 (1,86)	
	O. indecora	11,36 (1,02)	b	11,73 (0,95)	a	11,05 (1,10)	b
	O. puberula	17,67 (2,27)	b	19,82 (1,98)	a	20,52 (1,58)	a
		Transversal		Radial		Tangential	
	N. megapotamica	18,66 (2,86)	b	22,18 (3,24)	a	21,79 (2,96)	a
	O. diospyrifolia	20,83 (1,63)	b	23,01 (1,59)	a	23,01 (1,57)	a
	O. indecora	10,64 (0,80)	b	11,89 (1,11)	a	11,62 (0,79)	a
	O. puberula	17,70 (2,19)	b	20,09 (1,90)	a	20,22 (1,89)	a

*Means with the same letter in the row do not differ statistically by the Scott Knott test at 95% probability.

** Represents data with no significative difference in variance analysis.

Regarding chromatic coordinate *a**, for trunk position all species from the genus *Ocotea* had a tendency of higher values in the near pith region. On the other hand, *Nectandra megapotamica* (Spreng.) Mez had lower values for the near bark region and the other positions were similar. With respect to anatomical surface, there were no significant differences for *Nectandra megapotamica* (Spreng.) Mez, *Ocotea diospyrifolia* (Meisn.) Mez and *Ocotea puberula*. In wood of *Ocotea indecora* (Schott) Mez, the transversal surface had lower values, and radial and tangential surfaces were statistically equal and superior, respectively. The same behavior was reported by Atayde *et al.* (2011) for *Brosimum* sp.

Table 4: Mean values of parameters *C** and *h* in two separated analyses: evaluating only different trunk position (near bark, intermediate, near pith) and considering only anatomical sections (transversal, radial and tangential) in wood from *Lauraceae* species.

*C**		Near bark		Intermediate		Near pith	
	N. megapotamica	82,29 (3,24)	a	78,72 (3,60)	b	77,86 (2,16)	b
	O. diospyrifolia	80,93 (1,60)	a	75,49 (2,07)	b	71,39 (1,74)	c
	O. indecora	76,83 (0,98)	b	78,89 (0,94)	a	73,28 (1,07)	c
	O. puberula	70,81 (2,52)	a	68,15 (2,33)	b	67,00 (1,76)	b
		Transversal		Radial		Tangential	
	*N. megapotamica***	78,91 (2,63)		80,66 (2,98)		79,30 (2,84)	
	*O. diospyrifolia***	75,95 (1,52)		75,38 (1,42)		76,48 (1,68)	
	*O. indecora***	76,91 (0,78)		76,24 (0,98)		75,85 (0,69)	
	O. puberula	67,63 (2,65)	b	69,26 (2,42)	a	69,07 (2,25)	a
h		Near bark		Intermediate		Near pith	
	N. megapotamica	22,67 (2,19)	a	20,96 (6,61)	b	20,14 (3,88)	b
	O. diospyrifolia	22,46 (1,70)	b	23,67 (4,88)	a	23,05 (3,01)	b
	*O. indecora***	11,67 (2,15)		11,97 (2,65)		11,55 (3,42)	
	O. puberula	18,75 (2,90)	b	21,40 (2,97)	a	22,31 (1,94)	a
		Transversal		Radial		Tangential	
	N. megapotamica	19,05 (5,22)	b	22,52 (5,43)	a	22,21 (4,05)	a
	O. diospyrifolia	21,56 (5,64)	b	23,88 (5,44)	a	23,74 (4,56)	a
	O. indecora	10,94 (3,27)	b	12,25 (3,89)	a	12,00 (3,67)	a
	O. puberula	19,22 (3,64)	b	21,56 (3,08)	a	21,69 (2,11)	a

*Means with the same letter in the row do not differ statistically by the Scott Knott test at 95 % probability.

**Represents data with no significative difference in variance analysis.

For chromatic coordinate *b**, each species showed distinct behavior regarding trunk radial position. For *Ocotea diospyrifolia* (Meisn.) Mez, the results were similar for all average values. In the near bark region, the values of *Nectandra megapotamica* (Spreng.) Mez were higher than for the other positions, and for *Ocotea puberula* the results were lower. In *Ocotea indecora* (Schott) Mez, the intermediate region had higher value than other positions. Regarding anatomical section, again all species had lower values for transversal surface and the mean values of the radial and tangential surfaces were similar. Garcia *et al.* (2014), the relationship between colorimetric parameter sand wood density of *Eucalyptus* and *Corymbia,* also found statically equal values of *b** in most analyzed samples.

For the saturation parameter (*C**), the *Ocotea indecora* (Schott) Mez wood from the trunk intermediate position had the highest values. For other species, higher values occurred in wood near the bark. In the comparison of different anatomical sections, only *Ocotea puberula* had lower values for transversal surface. The parameters in the other species (*Nectandra megapotamica* (Spreng.) Mez, *Ocotea diospyrifolia* (Meisn.) Mez and *Ocotea indecora* (Schott) Mez) did not present statistical differences between sections. Similarity of the saturation parameter among sections was also described by Barros *et al.* (2014) for abarco (*Cariniana micrantha* Ducke) and *Protium puncticulatum* J.F.Macbr.

No tendency was observed for parameter *h* when evaluating radial trunk position in the four *Lauraceae* species. For *Ocotea indecora* (Schott) Mez*,* similar mean values were verified in all regions, while for *Nectandra megapotamica* (Spreng.) Mez, the near bark region had higher values. This tendency was also reported for eucalyptus clones by Mori *et al.* (2005) and Martins *et al.* (2015). On the other hand, the near bark region had the lowest value for *Ocotea puberula*, and for *Ocotea diospyrifolia* (Meisn.) Mez the intermediate region had the highest result. In relation to anatomical surfaces, the same tendency was observed for all species, with lower values for transversal sections. Ribeiro *et al.* (2018) also described similar results for radial and tangential surfaces of commercial wood from the Amazonian region.

Besides comparison of mean colorimetric parameters, analysis of the reflectance curve in visible spectra was also performed (Figure 2).

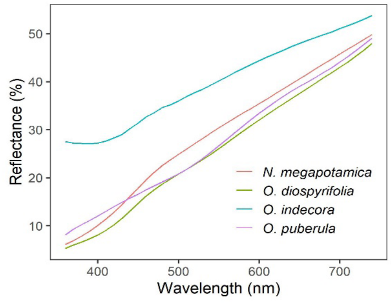

Figure 2: Mean visible spectra of *Lauraceae* species.

The mean visible spectra of *Lauraceae* species (Figure 2) indicate the difference from 360 to 740 nm for *Ocotea indecora* (Schott) Mez*.* We expected species from the same genus to have similar behavior in the wavelength evaluated, but the mean spectra by species (Figure 2) showed distance of *Ocotea indecora.* Also, *Nectandra megapotamica* (Spreng.) Mez and *Ocotea diospyrifolia* (Meisn.) Mez had the most similar spectral behavior, and *Ocotea puberula* was different from *Nectandra megapotamica* (Spreng.) Mez and *Ocotea diospyrifolia* (Meisn.) Mez, principally in the region from 450-570 nm, where the predominant colors were blue, cyan and green. The similarity and/or influence of trunk position and anatomical surface in the spectrum range (Figure 3).

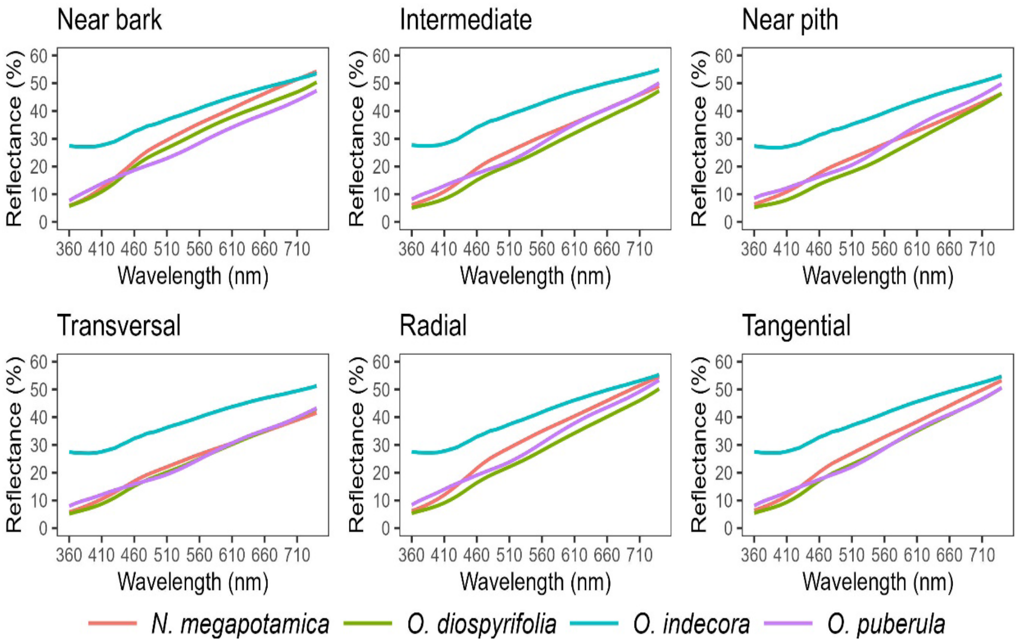

Figure 3: Mean visible spectra for wood from different trunk positions and anatomical surfaces of *Lauraceae* species.

In the analysis according to trunk radial position or anatomical section (Figure 3), in general samples from the intermediate and near pith regions had similar behavior to the general mean of each species. However, the average values from the near bark region had diverse behavior, with highlight on *Ocotea indecora* (Schott) Mez, which had some approximation with the other species, mainly at wavelengths 680 and 740 nm, corresponding to red color. When considering anatomical sections, some interesting observations can be made. Distinction between transversal and longitudinal (radial and tangential) sections was evident. Also, the surface with best species distinction was radial, since the transversal values formed a group with three species (*Nectandra megapotamica* (Spreng.) Mez, *Ocotea diospyrifolia* (Meisn.) Mez and *Ocotea puberula*). For tangential surface, at wavelengths higher than 460 nm, *Ocotea diospyrifolia* (Meisn.) Mez and *Ocotea puberula* had the highest spectral similarity.

After visual evaluation of visible spectra, and based on the generally similar results, we applied principal component analysis with raw data (without mathematical transformations) (Figure 4). In this analysis results, only samples of *Ocotea indecora* (Schott) Mez were identified as separate from the other samples and species, probably in function of high reflectance values at all wavelengths, resulting from color differences that can be verified in Figure 1, Figure 2 and Figure 3. Based on information of PC1 and PC2 biplot, samples from *Nectandra megapotamica* (Spreng.) Mez, *Ocotea diospyrifolia* (Meisn.) Mez and *Ocotea puberula* were not visually distinct from each other, confirming the similarity in color parameters (Table 1).

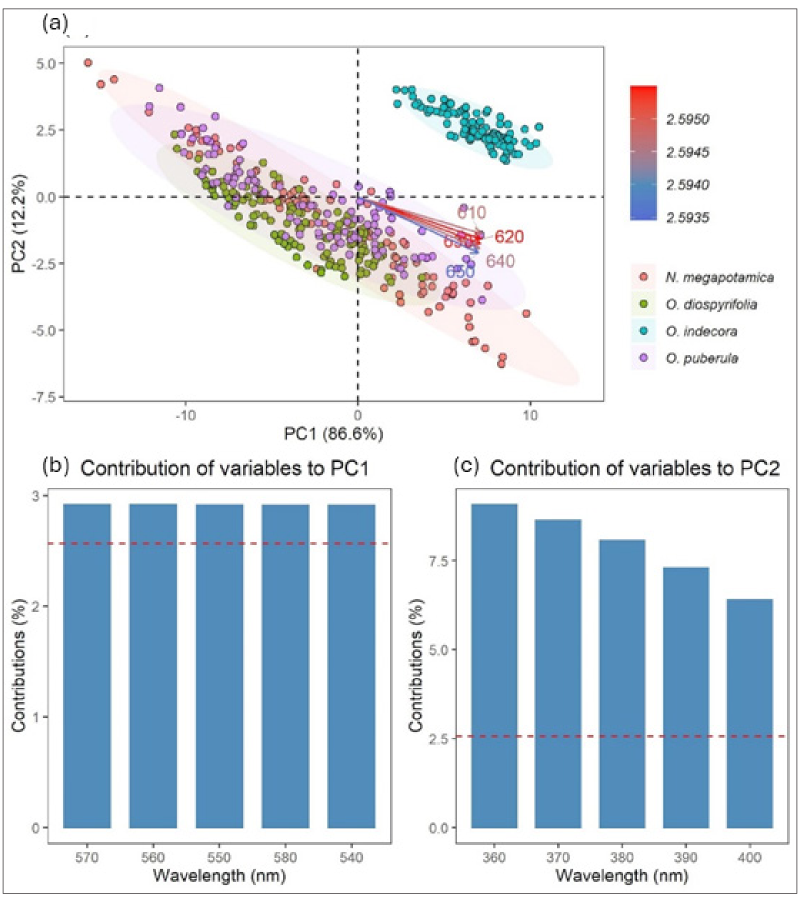

Figure 4: (a) PCA score plot from raw visible spectra of *Lauraceae* species. Arrows indicate most informative wavelength considering both PC1 and PC2. Color scale red-blue indicate the intensity of contribution of each wavelength in species discrimination, being, in gradual scale, higher contribution in red color and lower contribution in blue. (b), (c) Histograms indicate the five most informative wavelengths in each PC, and red dotted line represents mean value of contribution from all wavelength in species discrimination.

Also, Figure 4, samples from *Ocotea indecora* (Schott) Mez are more grouped than the other species samples and is possible to verify the most important wavelength and its contribution in species differentiation. When the analysis is in function of both PC1 and PC2 (Figure 4a), region from 610-650 nm contribute in all species distribution, and evaluating each PC individually, in PC1 (Figure 4b), region from 540 to 580 nm is most informative, and in PC2 (Figure 4c), region from 360 to 400 nm. In general, it is expected that wavelengths with higher importance in species discrimination based on the block PC1 and PC2 have similar values compared to those observed individually, but it not occurred probably in function of the low difference in each influence related to mean value for the contribution of all wavelengths (Figure 4b, Figure 4c).

In accordance with Hongyu *et al.* (2016), sample grouping in PCA is the result of similar variation in its characteristics. In the present study, this behavior was observed in the visual approximation of samples from *Nectandra megapotamica* (Spreng.) Mez, *Ocotea diospyrifolia* (Meisn.) Mez and *Ocotea puberula*. Other factor that must be considered, for raw data, is that for PC1 higher wavelengths contributors had similar results and were obtained in yellow color region. On the other hand, for PC2, higher differences in the wavelength's contributors were observed, and the highest were obtained in violet color region.

To maximize the species distinction, spectra were submitted to second-derivative transformation and a new PCA was performed (Figure 5). The isolation of *Ocotea indecora* (Schott) Mez samples remained, but different species discrimination also occurred. Wavelengths with more influence in species discrimination is different from results with raw data. For PC1 (Figure 5b), higher influence, in decrescent order, was from 480 nm, 460 nm, 430 nm, 510 nm and 400 nm. On the other hand, for PC2 (Figure 5c), wavelength from 500 nm, 530 nm, 380 nm, 550 nm and 600 nm were the five with higher influence in species distinction. In this analysis, when the analysis of importance is with both PC (Figure 5a), wavelengths from 460-500 nm are most informative, with higher contribution from region 480 nm, values similar to individual PC1. The results are diverse from raw data as influence of each most important PC is higher than mean value of all wavelengths.

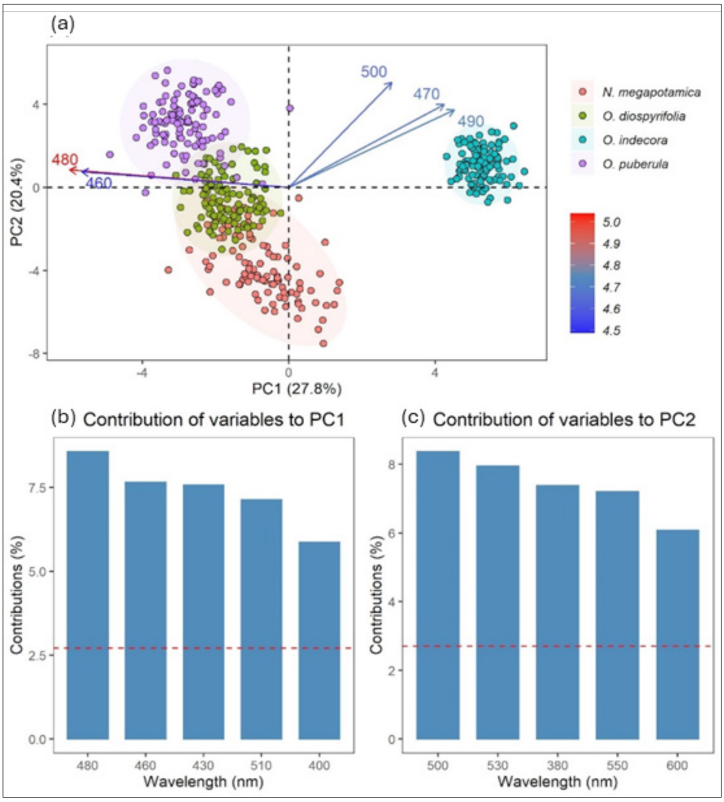

Figure 5: (a) PCA score plot from second-derivative visible spectra of *Lauraceae* species. Arrows indicate most informative wavelength considering both PC1 and PC2. Color scale red-blue indicate the intensity of contribution of each wavelength in species discrimination, being, in gradual scale, higher contribution in red color and lower contribution in blue. (b), (c) Histograms indicate the five most informative wavelengths in each PC, and red dotted line represents mean value of contribution from all wavelength in species discrimination.

When the spectra were submitted to second-derivative transformation (Figure 5), all samples of each species were grouped and a better separation of *Lauraceae* species was verified. All species discrimination was possible in comparison to raw data. Based on Biplot graphic of PC1 and PC2, it is possible to identify visually all species, even though some samples of *Ocotea puberula* and *Nectandra megapotamica* (Spreng.) Mez are mixed with samples from *Ocotea diospyrifolia,* corroborating with the similarity of the wood. The use of second-derivative data for wood discrimination is frequent and has already been reported for eucalyptus wood (Nisgoski *et al.* 2017a) and *Myrtaceae* species from Araucaria Forests (Vieira *et al.* 2019a), among others. When observed the contribution of wavelengths, it was not verified the same tendency that with raw data. With second derivative data, results are different from raw data, PC1 had the higher results in regions of spectra related to blue (480 nm, 460 nm), violet (430 nm, 400 nm), and green (510 nm) color. In PC2, higher contributions were present in wavelengths related to violet (380 nm), orange (600 nm) and green (500 nm, 530 nm, 550 nm) color.

To verify if *Lauraceae* species discrimination based on visible spectra would be really effective, discriminant models were tested and their accuracy evaluated (Table 5).

Table 5: Accuracy of discrimination models tested from visible spectra of four *Lauraceae* species.

Visible Spectra	Model	Accuracy (%)
Raw	ANN	99
Second derivative	ANN	100
Raw	k-NN	80
Second derivative	k-NN	99
Raw	SVM	99
Second derivative	SVM	100

All tested models were efficient with accuracy superior to 80 % using both raw and second-derivative data. Artificial Neural Network (ANN) and support vector machines with kernel radial basis function (SVM), presented better results than k-NN for visible spectra of the four *Lauraceae* species.

The possibility of species distinction based on visible spectra was confirmed based on discriminant models (Table 5). In all evaluated models, some increase in accuracy occurred when data were submitted to second-derivative transformation. The worst accuracy was found for the k-NN method with raw spectra (80 %) and second-derivative spectra (99 %), indicating the adequate discrimination of species.

High accuracy was also obtained for species discrimination by Nisgoski *et al.* (2017b), with mean values of 100 ± 2 %, in the differentiation of *Ocotea odorifera*, *Ocotea porosa, Nectandra* sp. and *Eucalyptus* sp. based on ANN and near-infrared spectra. Wang *et al.* (2019) described accuracy values of 97,5 % for identification of commercial species applying terahertz (THz) time-domain spectroscopy (TDS) and discriminant analysis based on support vector machines with radial basis kernel function.

It is important to highlight that is not a general result, i.e., is a behavior found specifically to identify the discriminant model with better results for visible spectra of studied *Lauraceae* species (*Nectandra megapotamica* (Spreng.) Mez, *Ocotea diospyrifolia* (Meisn.) Mez, *Ocotea indecora* (Schott) Mez and *Ocotea puberula*) with standardized sampling. It is not possible to confirm that for other species from the same family, the results will be similar.

CONCLUSIONS

Chromatic coordinates a^* and b^* showed the best potential to distinguish the *Lauraceae* species evaluated. When analyzing the influence of trunk position and anatomical sections, we verified that lower results of L^* and C^* were present in the samples from the near pith region and lower mean values for L^*, b^* and h were found in the transversal samples.

The mean visible spectra of *Ocotea indecora* were different than the spectra of other species. Considering trunk position, the near bark region was slightly different. Regarding anatomical surfaces, radial and tangential spectra were similar. Principal component analysis with raw visible spectra data indicated the separation of *Ocotea indecora*, and after second-derivative treatment, all species were identified. It was observed different behavior in wavelengths contributions for principal component analysis with raw and second derivative data.

All tested models (ANN, k-NN, SVM) were efficient for species discrimination based on visible spectra, but second-derivative spectra produced better results.

Therefore, colorimetric parameters could contribute to distinguish wood from studied tree of species *Nectandra megapotamica*, *Ocotea diospyrifolia*, *Ocotea indecora* and *Ocotea puberula* growing in Araucaria Forest stands. It should also be emphasized that these results contribute to the expansion of available databases on the color of native woods, adding knowledge to the subject and enabling this information to be used in the future for the oversight of timber trade, thus preventing the illegal commerce of this product.

Authorship contributions

H. C. V.: Data curation, investigation, methodology, software, validation, visualization, writing - original draft, writing - review & editing. J. X. S.: Data curation, investigation, methodology, software, validation, visualization, writing - original draft, writing - review & editing. D. V. S.: Data curation, investigation, methodology, software, validation, visualization, writing - original draft, writing - review & editing. T. L. N.: Data curation, investigation, methodology, software, validation, visualization, writing - original draft, writing - review & editing. P. D. R.: Formal analysis, project administration, resources, supervision, writing - review & editing. G. I. B. M.: Formal analysis, project administration, resources, supervision, writing - review & editing. S. R. M.: Formal analysis, project administration, resources, supervision, writing - review & editing. S. N.: Funding acquisition, formal analysis, project administration, resources, supervision, writing -T review & editing.

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