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Original article

Colour and decay resistance and its relationships in *Eperua grandiflora*

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Abstract

• *Eperua grandiflora*, which is widely distributed in the French Guiana forest region, shows high variability in decay resistance. Further information concerning this wood quality parameter is necessary, but standard testing methods are complex and time-consuming. We assessed the use of colorimetry to determine durability in heartwood samples from a range of trees.
• *Eperua grandiflora* colour parameters were measured using a CIELAB system, revealing that the tree effect was greater than the radial position and height effects.
• The wood samples were exposed to *Coriolus versicolor* and *Antrodia* sp. according to two European standards (En 350-1 and XP CEN TS 15083-1). *Eperua grandiflora* is more susceptible to brown rot. These two standards did not give the same durability classes. The high variation in natural durability was due to the tree effect.
• These two properties were found to be correlated and the assessment also distinguished the extreme durability classes but they are not sufficient to classify the class of durability of this species.

Mots-clés :
durabilité naturelle / couleur / résistance à la pourriture / duramen / bois tropicaux

Résumé – Étude de la variabilité de la couleur, de la durabilité naturelle et recherche de corrélations chez *Eperua grandiflora*.

• *Eperua grandiflora,* essence largement répandue dans les forêts de Guyane soufre d'un défaut majeur : une grande variabilité de sa durabilité naturelle à l'égard des champignons lignivores. Dans un premier temps, nous avons étudié la variabilité de la mesure de la couleur selon le système CIElab afin de vérifier si la colorimétrie peut être utilisée comme un indicateur de la durabilité naturelle.
• Nous avons étudié la résistance de cette essence à l'échelle inter, et intra-arbres à l'égard de *Coriolus versicolor* et *Antrodia* sp., conformément aux normes européennes en vigueur : EN 350-1 et XP TS 15083-1. Les résultats ont révélé qu'*Eperua grandiflora* est plus sensible au champignon de pourriture brune.
• De même, l'utilisation des normes a montré que l'on n'obtenait pas les mêmes classes de durabilité. La variabilité de la durabilité et de la couleur est plus importante à l'échelle inter-arbres qu'à l'échelle intra-arbre.
• Enfin, ces deux propriétés sont corrélées mais nous ne pouvons envisager d'utiliser la colorimétrie comme indicateur de la durabilité naturelle, car elle ne permet de différencier que les classes extrêmes.

1. INTRODUCTION

Some tropical forest species have interesting characteristics like natural durability, which is an essential property for wooden constructions and in situations where there is a high risk of fungus and insect infestation. In some cases, however, different wood pieces in a structure may not have the same natural durability due to intraspecific variability in natural durability. This problem has been noted in *Eperua grandiflora* (Cesalpiniacae), which is found throughout the Guianian region and Amazon Basin. The study of the data base of CIRAD-Forêt (unpublished) shows that durability of this tree is highly variable, with the timber ranked in durability class 2 or 3 (durable to moderately durable). Several factors have been postulated to contribute to the variation in the natural durability of wood in different tree species. The same factors may also be partly responsible for variations between different stem sections and between individuals within durable species. The same is true for wood colour, which can

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vary greatly between different species and within the same species, between heartwood and sapwood and even in different parts of the tree (Amusant, 2003; Janin and Mazet 1987; Lavisci et al., 1989). Studies on wood colour variability have been focused on the anatomical elements, the woody framework of the species (fibres, vessels, extractives), the type of machining and the nature of light reflected from the wood surface (Burtin, 1994; Hiller et al., 1972; Wilkins et al., 1990). Physiological explanations for variations in heartwood colour have considered extractives like polyphenols or their precursors produced in the leaves, needles or cambium and transported by phloem and rays to the heartwood (Burtin et al., 1998; Da Costa et al., 1962; Mosedale et al., 1996b). These compounds supposedly then undergo chemical changes, thus leading to changes in heartwood colour. Differences in wood colour thus primarily reflect variations in the quantity and nature of wood extractives (Hillis, 1971). These compounds are also involved in wood durability to avoid fungal infestations, and differences in resistance correspond to variations in the quantity and quality of extractives. Some studies have shown that there is a relationship between colour measurements and decay resistance in some species (Boardman et al., 1992; Dumonceaud, 2001). The present study concerns study of colour measurements, decay resistance in *Eperua grandiflora*. The wood of this tree is brownish red and composed of polyphenolic and diterpenoic compounds (Blake and Jones, 1963; Villeneuve and Vergnet, 1988). The aim of this study was to assess variability in colour and decay resistance of a tree population from one site at intra-tree and inter-tree levels, and then to determine whether wood colour and durability are correlated. If these two properties are found to be correlated, colour measurements could be proposed as an indicator of decay resistance.

2. MATERIAL AND METHODS

Heartwood was obtained from nine trees in Paracou forest, French Guiana. The trees were 30–40 m high and growing in a natural stand. The average tree diameter was 42 cm (range 34–53 cm). From each tree, six replicate samples ($50 \times 25 \times 50$ mm R, L, T directions) were taken (in the same axis) in the outer, intermediate and inner heartwood located 3 and 15 m from the tree base. The samples were stabilised at 12% moisture content.

2.1. Colour measurements

The blocks were conditioned at 20 °C and 65% RH and stored in the dark to avoid colour modifications. Colour was measured on the radial (RL) side with a colorimeter (Datacolor Microflash 200 d) at ambient temperature and humidity. The sensor head diameter was 6 mm. Illuminant D65 and the 10° standard observer were used as the measurement conditions. The surface observed was 59 mm^2 and specular reflection setting was excluded. The reflectance readings were converted into L^*, a^*, b^*, C^*, h^* colour parameters, where L^* represents the lightness along the lightness axis (100 = white; 0 = black), a^* the redness ($a^* > 0$) or greenness ($a^* < 0$), B the yellowness ($b^* > 0$) and greenness ($b^* > 0$). The h^* angle can be calculated as $h^* = \text{arctg}\ (b^*/a^*)$, so the hue angle circle $h^* = 0°$ denotes redness and $h = 90°$ denotes yellowness. The C^* saturation measuring the colour intensity can be calculated as $C^* = [(a^*)^2 + (b^*)^2]^{1/2}$. Measurements on the radial side were conducted in triplicate and the data were averaged. The results were analysed via the L^*, C^*, h^* parameters because they are easy to interpret. The total number of samples was 324.

2.2. Decay resistance measurements

After the colour measurements, the wood samples obtained at 3 m height were used to determine the natural durability. Durability was assessed by exposing six replicates of outer, middle and inner heartwood from a tropical fungus (*Antrodia* sp. strain CTFT 57 A) and *Coriolus versicolor* (strain CTBA 863 A). The total number of samples was 162, while 20 additional samples (same dimensions) of beech and pine (*Fagus sylvatica*, *Pinus sylvestris*) were used to monitor fungal virulence. Samples were weighed (M1), sterilized (gamma ray) and then exposed to the fungi for 16 weeks under tropical conditions (75% RH and 27 °C). After the decay exposure, all wood blocks were placed in the oven (48 h, 103 °C) to determine the oven dry mass (M0f), and the percentage of mass loss (ML) based on the dry weight (M0i) was calculated.

For each tree, 10 wood blocks were used to establish the timber moisture content. After a conditioning period, the wood blocks were placed in the oven (24 h, 103 °C) and weighed. The mean moisture content (MC) was used to calculate the initial dry mass (M0i) in each wood block

$$M0_i = M_1 \times 100/(100 + MC)$$
$$ML = 100 \times (M0_i - -M0_f)/M0_i$$

where $M0_i$ is the initial dry mass of the sample, M_1 is the initial conditioned mass, MC is the moisture content, and $M0_f$ is the dry mass of the sample after exposure to the fungus. The durability rating against wood-destroying Basidiomycetes fungi is based on two standards:

– According to the guidance of the technical specifications of AFNOR (2006) to determine the "Durability of wood and wood-based products – Determination of the natural durability of solid wood against wood-destroying fungi, test methods – Part 1: Basidiomycetes".

– According to the guidance of NF EN 350-1 (AFNOR, 1992) and NF EN 113 (AFNOR, 1986).

As five durability classes proposed by the guidances are defined in relation to the median mass loss and relative mass loss obtained with the most destructive fungus.

2.3. Statistical analysis

The XLSTAT software package was used for the statistical analysis. The effects of radial position and height on wood colour at the intra-tree and inter-tree level and the effect of the radial position on wood decay at the intra-tree and inter-tree level were studied by analysis of variance (ANOVA). Both intra-tree and inter-tree levels were studied by analysis of the calculated Pearson correlation coefficients to determine the relationship between colour parameters and decay resistance. Values were considered to be statistically significant at $P < 0.05$.

Table I. Mean, range, standard deviation (SD), coefficient of variation (CV%) of colour parameters for the nine trees (n = 324 samples from nine trees)

Colorimetric parameters	Mean	SD	Min	Max	CV
L^*	56.1	3.2	46.8	64.0	5.8
C^*	35.9	2.7	24.5	40.3	7.7
h^*	55.5	2.2	48.0	59.6	4.0

3. RESULTS

3.1. Colour measurements

As shown in Table I, all the colorimetric parameters studied revealed inter-tree variations, especially with respect to the L^* and C^* parameters. For example, the average L^* parameter ranged from 46.8 (tree 2) to 64.0 (tree 3). The high part of the total variation for the colour parameters is explained when taking into account tree, radial position, height and interaction between them. From the different monitored sources of variation, the between-tree effect was greater in comparison to the radial position and height effects (Tab. II). The explained variability values were 48% for L^*, 51% for C^*, and 58% for h^*. The low percentage of variance obtained for the radial position effect could be explained by the presence of resin pockets which masked a more marked effect. A local measurement of wood samples with and without resin showed that the presence of resin make the wood darker and less red (data not supply). The residual variation was relatively low, i.e. under 20% for the C^* and h^* parameters, which means that the variability between matched samples was low. The significant interaction noted between all effects indicated that the general colour variation pattern from the inner to the outer heartwood and from the base to the upper part of the trunk did not apply to all the trees. The Student's t-test analysis of L^*, C^*, h^* data revealed that the outer heartwood was not significantly different from the intermediary or inner heartwood, even at the 5% level. Figure 1 illustrates the absence of colour differences for the L^* parameter between the different heartwood areas. However, with tree No. 3, No. 5 and No. 9, the inner and intermediary heartwoods were significantly darker and redder ($P < 0.001$) than the outermost heartwood according to the Student's t-test. Because of the low variation in tree diameter and the absence of information on tree age, we cannot conclude that the colour variation gradient was due to the tree age. We also compared the wood samples located at 15 m (top) and 3 m (bottom) stem height and the Student's t-test showed no significant difference.

Like the different wood characteristics, the colorimetric parameters depended on the tree effect. With regard to the significance of the tree effect, our results are in accordance with those of Dumonceaud (2001) with *Castanea sativa*, Rink (1987) with *Juglans nigra* and Klumpers and Jarin (1992) in *Quercus robur*. All trees originated from the same place, with no differences due to soil characteristics or site quality. Our results suggest that the origin (genetics) has a strong effect, which would explain the differences between trees with respect to the colorimetric parameters, in accordance with the results of several previous studies (Gierlinger et al., 2004, Mosedale et al., 1996a). The inter-tree difference of colour was also due to the tree age. In our case, it was not possible to determine the age of *Eperua* spp. trees because of the absence of marked growth rings. The weak tree diameter distribution not allows to analyse trees with a large age distribution and valid an age effect. The presence of extractives, particularly polyphenolics, plays an important role in wood colour (Dellus et al., 1997; Mosedale et al., 1996b). *Eperua grandiflora* contains terpenoids and polyphenolic compounds (Blake and Jones, 1963; Villeneuve and Vergnet, 1988). When the heartwood colour is slightly red, polyphenolic compounds are mostly responsible for determining this trait. The quantity and quality of extractives varies at inter- and intra-tree levels (Klumpers and Janin, 1992; Klumpers et al., 1993). The relations observed in some trees between colorimetric parameters and the radial position was due to the wood age. Duraminisation and the ageing process play an important role in the variability in the extractive content and explain 80% of the variation in some properties at the intra-tree level (Masson et al., 1995). However, in our study, the presence of resin pockets hampered measurement of the impact of polyphenol compounds.

3.2. Decay resistance measurements

The mean mass losses in the beech and pine control samples were 55% for *Antrodia* sp. and 44% for *Coriolus versicolor*. These values were higher than the minimal value indicated in the standards, which indicates that the fungi were very virulent under tropical conditions and validates the durability test results. Table III presents means, ranges, standard deviations and coefficients of variation in mass loss with *Coriolus versicolor* and *Antrodia* sp. *Eperua grandiflora* is very durable against the white rot fungus *Coriolus versicolor.* With *Antrodia* sp., the mean mass loss was close to 15.6%. The mass losses caused by *Antrodia* sp. ranged from 1.35% (tree 5) to 32.21% (tree 4), suggesting a tree effect. According to the classification of both standards, under the climatic conditions of this study, *Eperua grandiflora* was ranked in class 2 (durable) with EN 350-1: most of the samples were durable (47%) and moderately durable (45%), while 34% of the wood samples were moderately durable and 53% were slightly durable according to XP CEN TS 15083-1 (Tab. IV). These results showed the high variability in natural durability of *Eperua grandiflora* as compared to *Antrodia* sp. Both standards did not generate the same durability class. This difference is due to the fact that with EN 350-1, the calculations take into account the value of the virulence to calculate a relative mass loss while XP CEN TS 15083-1 used a median mass loss without any correction to determine the durability class. Under tropical conditions, XP CEN TS 15083-1 was more suitable for determining the natural durability against fungal attack. When taking the high fungal virulence values into account, the durability classification was less severe. Further field tests will be necessary to confirm the durability class.

The variance analysis was carried out and the ANOVA results and total variation decomposition are shown in Table V. When taking the tree, radial position and interaction between

Table II. L*, C*, h* analysis of variance of the "tree-radial position-height" and interaction ("tree × radial position" ; "tree × height", "radial position × height" ; "tree × radial position × height").

		L*			C*			h*		
Source of variation	Degree of freedom	Mean square	$P > F$	% variance	Mean square	$P > F$	% variance	Mean square	$P > F$	% variance
Tree	8	206.9	< 0.01%	48	160.47	< 0.01%	51.0	117.52	< 0.01%	58.3
Radial position	2	34.7	< 0.01%	0.5	15.43	< 0.01%	1.2	9.56	< 0.01%	1.2
Height	1	17.2	< 0.01%	2.0	32.70	< 0.01%	1.3	0.99	< 0.01%	0.06
Tree × height	8	13.45	< 0.01%	3.1	3.15	< 0.01%	1.0	5.19	< 0.01%	2.6
Tree × RP*	16	15.05	< 0.01%	7.0	27.33	< 0.01%	17.4	11.07	< 0.01%	11.0
Height × RP	2	31.54	< 0.01%	1.8	0.48	< 0.01%	0.0	5.07	< 0.01%	0.6
Tree × Height × RP	16	12.91	< 0.01%	6.0	19.40	< 0.01%	12.3	7.50	< 0.01%	7.5
Error	270	3.95		31.11	1.47		15.8	1.12		18.7
Total	323			100			100			100

*RP = Radial position.

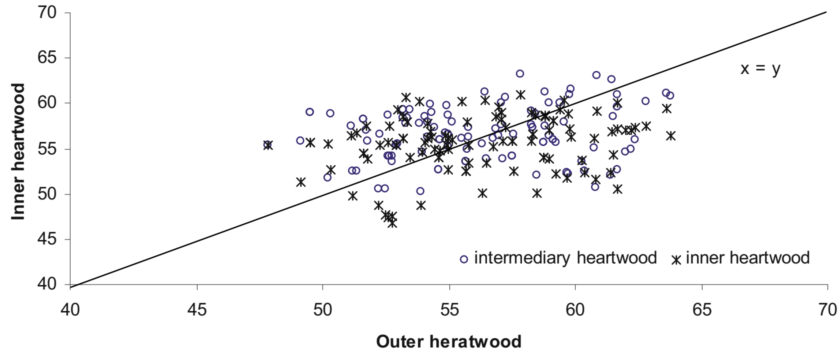

Figure 1. Relationships between outer, intermediary and inner heartwood for L* (n = 324).

Table III. Means (%), ranges, median standard deviation (SD) coefficient of variation (CV%) of mass losses with *Coriolus versicolor* and *Antrodia* sp. (n = 162 samples from nine trees).

Fungi	n	Mean	Median	SD	Min	Max	CV
Antrodia sp.	162	15.6	15.2	5.3	1.3	32.2	34.0
Coriolus versicolor	162	1.95	1.6	1.33	0.10	7.5	0.67

Table IV. Natural durability classification of wood samples from *Eperua grandiflora* according to EN 350-1 and XP CEN TS 15083-11.

	Classification according to En XP CEN TS 15083-11	Classification according to NF EN 350 -1
Very durable	5%	8%
Durable	8%	47%
Moderately durable	34%	45%
Slightly durable	53%	0%
Not durable	1%	0%

them into account, the variability between trees was the most important effect, i.e. it explained 45% of the total variability and there was a relatively low residual variation level. The "tree × radial position" interaction explained 32% of the variation. Analysis of the decay resistance by the Student's t-test showed that the outer heartwood was not significantly different from the intermediary and inner heartwood, even at the 0.5% level, because of the high variability in the results. With regard to the significance of the tree effect, our results are in agreement with those obtained previously by, Freitag and Morell (2000) with *Thuja plicata* and Dumonceaud (2001) with *Castanea sativa*. Like the colour parameters, the decay resistance variability could be explained by several factors like a genetic effect, the genotype influences several characters like the amount of heartwood and decay resistance of wood. This phenomenon was demonstrated by Viitanen et al. (1998) and Venäläinen et al., (2001) in *Larix sibirica*. Tree age also has a marked effect. Generally young trees have a high proportion of juvenile wood and an early formed heartwood, which is less durable than the heartwood in mature trees (Bhat, 1998; Guglielmo, 1981). In this study, it was difficult to determine the age of trees because in tropical conditions trees grow continuously, hence we could not evaluate the effect of age in the durability variability at the inter-tree level. The natural decay resistance of wood is dependant on the amount and quality of primary metabolites and on the storage of extractives deposited in the heartwood (Delaveau and Vidal-Tessier, 1988; Zabel and Morell, 1992). These substances inhibit the primary metabolism of fungi or the degradation process that they trigger, and their content increases with the tree age (Hillis, 1987; Nault, 1988; Posey and Robinson, 1969). These results agree with those obtained with other temperate species

Table V. Decay resistance analysis of variance of "tree and radial position" and interaction "tree × radial position" – *Antrodia* sp. (%).

Effects	Degree of freedom	Mean square	F	$P > F$	% variance
Trees	8	257.08	48.75	< 0.01	45
Radial position	2	180.50	34.23	< 0.01	8
Trees × radial position	16	90.84	17.22	< 0.01	32
Error	135	5.27			15
Total	161				100

(Gartner et al., 1999, Guilley et al., 2004). Decay variations were due to the presence of extractives formed between the sapwood and the outermost, to the duraminisation and ageing process. Extractives in the outermost heartwood are present in greater quantity and more toxic and they decrease and lose their toxicity near the crown of the stem (Reis, 1973).

From an experimental standpoint, the choice of standard and the bioassay conditions are very important in wood durability classification. Heterogeneous results have a negative impact on wood uses. The results obtained in tropical conditions with tropical fungi were clearly worse than those obtained with European standards. When the wood is to be used in tropical conditions, decay resistance should be monitored under the same conditions in order to be close to the actual situation. In tropical conditions, the decay resistance of *Eperua grandiflora* was found to be variable and the median mass loss obtained from XP CEN TS 15083-1 should be considered in order to avoid disappointing end users. It is thus important to find indicators that could accurately predict durability.

3.3. Relation between colour and durability

Because of the high variability in natural durability, it would be interesting to propose an indicator that could be used to classify the natural durability of wood pieces for end users. Some correlation coefficients between colour coordinates and decay resistance are listed in Table VI. Correlation coefficients calculated with all values ($n = 162$) were low but significant (Pearson's correlation coefficients: 0.22 for L^*, 0.18 for C^* and 0.46 for h^*). The correlation coefficients calculated for each tree shows that significant Pearson correlations were obtained for some of the trees (No. 1 – 2 – 7 – 8 – 9), but the correlations differed according to the trees. We noted that redder wood was more resistant. A stepwise multilinear regression (stepwise criteria: probability of F to enter $\leq 0.05\%$ of to remove ≥ 0.1) analysis was carried out to predict mass loss with two colour coordinates (L^* and h^*). R^2 was 0.26 and the standard error of the estimate was 4.58. The Fisher test results validated the model and the Student's t test results indicated that the constant was also significant. The contingency table (Tab. VII) obtained between the measured and predicted mass losses according to the different durability classes showed that the measured colorimetric parameters were effective for classifying 22% of the wood samples. Kokutse et al., 2006 find also a positive correlation between decay resistance and colour with

Table VI. Pearson correlation coefficients for colour values (L^*, C^*, h^*) and decay resistance against *Antrodia* sp. ($P < 5\%$).

Decay tests	L^*	C^*	h^*
All the trees (9)	0.22	0.18	0.46
Tree 1	ns	–0,50	0,23
Tree 2	ns	–0,55	0.45
Tree 3	ns	ns	ns
Tree 4	ns	ns	ns
Tree 5	ns	ns	ns
Tree 6	ns	ns	ns
Tree 7	+ 0.81	+ 0.56	+ 0.88
Tree 8	ns	–0,58	ns
Tree 9	–0.60	–0,60	+ 0.63

Table VII. Contingency table (M = moderately; S = slightly). Number of samples = 162.

Calculated mass loss	Predicted mass loss: Very durable	Durable	M durable	S durable	Not durable
Very durable		5			
Durable		4	4		
M durable		13	20		
S durable		12	40		
Not durable			1		

Teak, particularly with L* parameter which explained 30% of the variation. In conclusion, the method was not suitable and had the drawback of outclassing a high number of the wood samples. The first results on the prediction of decay resistance based on colour parameters are encouraging, but colour measurement cannot be the only element considered for predicting decay resistance. It would be interesting to combine methods like infrared or near-infrared spectroscopy to improve the predictions like with Larch species (Gierlinger et al., 2003). Wood colour and decay resistance were found to be related with the extractive content. In a future study, it would be interesting to investigate the phenol compound content in relation with the colour and decay resistance and to evaluate the impact of the resin pockets.

4. CONCLUSIONS

This study confirmed that the tree effect had a very marked impact on decay resistance and colour measurements in *Eperua grandiflora* as compared to the radial position and height effects. Many of the individual wood species were found to be durable to moderately durable according to EN 350-1 and moderately durable to slightly durable according to XP CEN TS 15083-1 This difference in classification is very important when considering future use of this species in tropical conditions. Further field tests are necessary to determine the long-term performance. The best correlation between colour parameters and decay resistance was obtained with the h* parameter (hue angle): redder wood was found to be more resistant. The correlation between the colour parameters and decay resistance is encouraging but not sufficient to classify wood by durability class. Combining colour measurements with spectral analysis results would enhance the identification of different durability classes and thus broaden the scope for use of this important resource in French Guiana. It will be also interesting to have more information about the quantitative proportion of resin pockets in the wood in order to better take into account the impact on colour measurements.

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