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Colorimetry and surface roughness of three amazon woods submitted to natural weathering

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ABSTRACT: This study aimed to evaluate the color and surface roughness of the wood of three Amazonian species submitted to natural weathering. For this purpose, samples of *Apuleia leiocarpa* (Vogel) J. F. Macbr., *Erisma uncinatum* Warm and *Parkia pendula* (Willd.) Benth. ex Walp., with dimensions of 1 x 2 x 30 cm (thickness, width and length, respectively), were exposed to natural weathering without contact with the soil for 240 days. The colorimetric characterization was performed by means of a colorimeter, and the parameters were L*, a*, b*, C*, h and ΔE. The roughness was determined with the aid of a profilometer of surface roughness, and the parameters Ra, Rz and Rt were evaluated. The wood exposed to natural weathering presented darkened (grayish color) surface, resulting from the reduction of colorimetric parameters L*, a* and b*. The *Parkia pendula* wood presented the greatest total variation of color in comparison to *Apuleia leiocarpa* and *Erisma uncinatum*. The parameters Ra, Rz and Rt showed an increase during the time of exposure of the woods to the natural weathering, in which *Erisma uncinatum* wood presented the roughest surface in comparison to the other species.

Keywords: field trial, deterioration of wood, tropical wood, wood quality.

Colorimetria e rugosidade superficial de três madeiras amazônicas submetidas ao intemperismo natural

RESUMO: Este estudo teve como objetivo avaliar a cor e a rugosidade superficial da madeira de três espécies amazônicas submetidas ao intemperismo natural. Para tanto, amostras de *Apuleia leiocarpa* (Vogel) J. F. Macbr. (garapeira), *Erisma uncinatum* Warm (cedrinho) e *Parkia pendula* (Willd.) Benth. ex Walp. (angelim-saia), com dimensões de 1 x 2 x 30 cm (espessura, largura e comprimento, respectivamente), foram expostas ao intemperismo natural, sem contato com o solo, durante 240 dias. A caracterização colorimétrica foi realizada por meio de um colorímetro, sendo determinados os parâmetros L*, a*, b*, C*, h e ΔE. Por sua vez, a rugosidade foi determinada com auxílio de um rugosímetro, sendo avaliados os parâmetros Ra, Rz e Rt. As madeiras expostas ao intemperismo natural apresentaram a superfície escurecida (coloração acinzentada) da superfície, sendo essa resultante da redução dos parâmetros colorimétricos L*, a* e b*. A madeira de angelim-saia apresentou a maior variação total da cor em comparação ao cedrinho e garapeira. Os parâmetros Ra, Rz e Rt apresentaram um acréscimo ao longo do tempo de exposição das madeiras ao intemperismo natural, em que a madeira de cedrinho apresentou a superfície mais rugosa em comparação às demais espécies.

Palavras-chave: ensaio de campo, deterioração da madeira, madeira tropical, qualidade da madeira.

1. INTRODUCTION

Variations in anatomical arrangement and chemical composition influence different technological properties of wood, among which the natural ability to resist to biotic and abiotic deterioration stand out.

When directly exposed to the action of the weather, wood is susceptible to physical, chemical and mechanical deterioration, these being caused by the joint action of oxygen, solar radiation, air humidity and the incidence of rains and winds (HON, 2001; SILVA; PASTORE, 2004).

Natural weathering is a process of surface deterioration, so that the wood is deteriorated to a limit of 2 mm below its surface (WILLIAMS, 2005). In addition, Feist; Hon (1984), Hon (2001) and Silva; Pastore (2004) highlighted that within the solar spectrum, the UV rays are responsible for the beginning of the reactions of chemical deterioration of wood.

Among the technological characteristics of the wood that are influenced by natural weathering we can highlight the alteration of color and surface roughness, which are perceptible in the first months of exposure to weathering. It should be noted that the alteration of these properties directly affects the aesthetic standard of the wood in service, as in the case of doors, windows, fences, decks, external furniture, among other uses. In advanced stages, the weathered wood presents greater dimensional instability and reduction of mechanical and biological resistance, due to the leaching of the extractives and oxidation of the lignin.

The color change of wood exposed to natural weathering is directly related to its chemical deterioration, especially the lignin, which among its macromolecular chemical components, has the greatest capacity of absorbing ultraviolet and visible rays, deriving from the sun (SILVA et al., 2007; PASTORE et al., 2008). The action of solar radiation, air humidity and air oxygen provide the oxidation of lignin, which results in the formation of chromophore groups that give a darkened coloration to the wood surface (WILLIAMS, 2005).

In relation to roughness, the wood exposed to weathering becomes rougher (FEIST, 1982; TOLVAJ et al., 2014), and this characteristic a result of the joint action of solar radiation, oxygen and rainfall incidence. Rains cause the leaching of the layer of photo-oxidized material by sunlight on the wood, forming superficial cracks (WILLIAMS et al., 2001; WILLIAMS, 2005).

Despite the vast employability of Amazonian tropical woods, few studies have addressed the resistance to weathering of these species (SILVA; PASTORE, 2004; SILVA et al., 2007; PASTORE et al., 2008; BARRETO; PASTORE, 2009; COSTA et al., 2011; TELES; COSTA, 2014), and the existing ones were made in laboratory (artificial weathering). In this sense, the development of studies of natural weathering is of paramount importance, since field trials are more reliable than those performed in laboratory.

It should be noted that Mato Grosso is one of the main states, together with Para and Rondonia, responsible for local and external commercialization of tropical timber in Brazil. Among the tropical species with the highest volumes and values of commercialization in the northern region of Mato Grosso state, *Apuleia leiocarpa* (Vogel) J. F. Macbr., *Erisma uncinatum* Warm and *Parkia pendula* (Willd.) Benth. ex Walp. stand out, both largely employed in construction.

In view of the above, the present work had as objective to evaluate the color and roughness of three Amazonian woods (*Apuleia leiocarpa*; *Erisma uncinatum*; *Parkia pendula*) subjected to natural weathering for 240 days.

2. MATERIAL AND METHODS

2.1. Collection and preparation of test specimens

For this study, wood boards of *Apuleia leiocarpa* (Vogel) J. F. Macbr., *Erisma uncinatum* Warm and *Parkia pendula* (Willd.) Benth. ex Walp. were obtained from logging companies in the municipality of Uniao do Sul, Mato Grosso.

Three boards, one of each species, were planed with the aid of surface and panel planers. Later, test specimens were made with the aid of circular table saw.

Twenty-five test specimens of each species were made with nominal dimensions of 1 x 2 x 30 cm (thickness, width and length, respectively).

In order to standardize the initial colorimetric and roughness evaluations, the test specimens were sanded (200 grit sandpaper) and subjected to oven drying with forced air circulation and 50 ° C temperature until anhydrous condition.

2.2. Colorimetry

The colorimetry of woods was determined on the tangential face by using a spectrophotometer with a resolution of 3 nm, angle of observation of 10º, equipped with an integrating sphere of diffuse and illuminating reflectance D65.

Before conducting the analyzes, the instrument was calibrated by using a reference sample supplied with the equipment, with the following colorimetric characteristics: Y = 86.8; x = 0.3193; y = 0.365.

The colorimetric parameters L* (luminosity), a* (green-red coordinate), b* (yellow-blue coordinate), C* (chromaticity) and h (ink angle) were obtained by employing the CIEL*a*b* method, and the average of three readings was carried out for each test specimen.

In addition, the total color variation (ΔE) was determined according to ASTM D 2244 standard (2009).

2.3. Roughness

The surface roughness of the woods was determined on the tangential face by using a profilometer of surface roughness with a cut-off of 0.8 mm and an evaluation path of 8 mm, in accordance with procedures B 0601 of the Japanese Industrial Standard – JIS (2001).

The evaluated parameters were Ra (arithmetic mean of the deviations of the midline profile), Rz (sum of the mean height of the five highest peaks and of the depth of the five deepest valleys, measured from a line parallel to the midline) and Rt (sum of maximum peak height and maximum valley depth), and the average of three readings, perpendicularly to the fibers, were carried out for each test specimen.

2.4. Natural weathering trial

The natural weathering trial was carried out in an experimental area of the Federal University of Mato Grosso, Sinop University Campus (coordinates 11º 51' South latitude and 55º 29' West longitude), from December 2013 to August 2014, totaling 240 days.

The test specimens of the three species were randomly arranged horizontally, on two support beams, placed 20 cm apart from each other and 30 cm high in relation to the ground. This methodology was adopted for the purpose of a more reliable evaluation of the colorimetric and roughness pattern of the three Amazonian woods when in use in similar conditions, such as for example, for decks and external floors.

At the end of the exposure period, the specimens were removed from the field test and submitted to drying in an air circulating oven at 50 ºC until obtaining the anhydrous condition, for later colorimetric and roughness characterization of the surfaces exposed to natural weathering.

2.5. Statistical analysis

For analysis of wood color and roughness, before and after exposure to natural weathering, researchers performed analysis of variance and Fischer's Mean test of MSD (Minimum Significant Difference - 5% of error probability).

3. RESULTS AND DISCUSSION

Table 1 shows that the values of the colorimetric parameters of the woods exposed to natural weathering reduced statistically

Table 1. Colorimetric characterization of *Apuleia leiocarpa*; *Erisma uncinatum* and *Parkia pendula* woods before and after exposure to natural weathering.
Tabela 1. Caracterização colorimétrica das madeiras de angelim-saia, cedrinho e garapeira antes e depois da exposição ao intemperismo natural.

Period (days)	L*	a*	b*	C*	h
	Parkia pendula				
0	71.96 a (1.97)	8.31 a (0.79)	25.99 a (0.92)	27.29 a (1.02)	72.29 a (1.39)
240	45.10 b (2.70)	1.06 b (0.26)	7.26 b (0.97)	7.33 b (0.98)	81.72 b (1.43)
	Erisma uncinatum				
0	54.26 a (1.05)	13.82 a (0.81)	22.33 a (0.99)	26.22 a (1.15)	58.25 a (0.99)
240	42.66 b (1.75)	0.61 b (0.21)	5.73 b (0.68)	5.77 b (0.70)	84.02 b (1.47)
	Apuleia leiocarpa				
0	67.94 a (1.88)	9.82 a (0.98)	29.40 a (1.48)	31.01 a (1.36)	71.50 a (2.09)
240	49.29 b (1.63)	0.62 b (0.21)	6.86 b (0.86)	6.89 b (0.88)	84.90 b (1.34)

Where: within each colorimetric parameter, means followed by distinct letters differ statistically from each other at 5% of error probability. Values in parentheses refer to the standard deviation.

in comparison to their initial condition, before the field trial, except for the parameter h, which presented significant increase.

Reduction in values of parameter L*, which defines the luminosity or clarity of the wood, can be attributed to the formation of quinine compounds resulting from the deterioration of lignin (HON, 2001; TEMIZ et., 2005). The results obtained corroborate with those verified by Silva; Pastore (2004) and Teles; Costa (2014) when evaluating the luminosity of tropical woods exposed to artificial weathering.

In relation to the chromatic coordinates a* e b*, the decreases in values can be attributed to the deterioration and/or leaching of chromophore compounds present in the superficial layers of the woods (SILVA; PASTORE, 2004), so as to make them less reddish (a*) and yellowish (b*). Similar results were observed by Turkoglu et al. (2015) when assessing the colorimetry of *Pinus sylvestris* L. and *Fagus orientalis* L. woods after 6 months (180 days) of exposure to natural weathering.

Chromaticity (C*) is a parameter dependent on the chromatic coordinatess a* and b*, which justifies the decrease of their values, providing a reduction in the color saturation of the wood and a consequent greyish appearance on the wood surface. According to Cademartori et al. (2015), the grayish appearance of the wood surface exposed to natural weathering is related to the combination of two factors, the lightening (resulting from the degradation of lignin) and the darkening of wood (resulting from fungus colonization).

Tolvaj; Mitsui (2010) mentioned that the ink angle parameter (h) shows a positive correlation with luminosity (L*). However, in the present study it was observed an inverse relationship. Martins et al. (2011) and Cademartori et al. (2015) also verified an increase in the values of parameter h when evaluating genus *Eucalyptus* woods exposed to artificial and natural weathering trials, respectively.

Among the three woods evaluated in the present study, *Parkia pendula* presented the highest total color variation (ΔE), as observed in Figure 1.

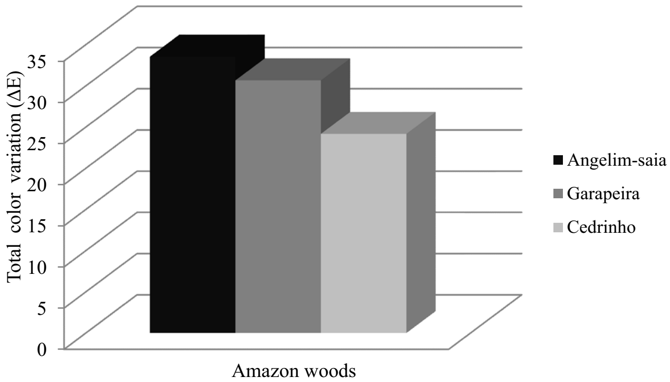

Figure 1. Total color variation (ΔE) of the *Apuleia leiocarpa*; *Erisma uncinatum* and *Parkia pendula* woods after exposure to natural weathering.
Figura 1. Variação total da cor (ΔE) das madeiras de angelim-saia, cedrinho e garapeira após a exposição ao intemperismo natural.

The parameter L* had the greatest influence on ΔE, since *Parkia pendula* and *Apuleia leiocarpa* woods presented higher initial L * values (lighter woods), 71.96 and 67.94, respectively, and also had the highest values of ΔE, 33.55 and 30.66, respectively. On the other hand, the *Erisma uncinatum* wood, because of its darker coloration (initial L * value of 54.26), presented the lowest ΔE, which was 24.17.

The ΔE values verified in the present study are superior to those found for other Amazonian woods (SILVA; PASTORE, 2004; SILVA et al., 2007; COSTA et al., 2011; TELES; COSTA, 2014). However, it should be emphasized that these differences of ΔE values are related to the type of trial. In the present study, the wood was exposed to natural weathering, while in other studies the wood was submitted to artificial weathering.

For natural weathering trials, Cademartori et al. (2015) and Turkoglu et al. (2015) verified ΔE values of the wood between 24.39 and 25.70 (after 360 days of weathering) and 24.50 to 33.15 (after 180 days of weathering), respectively.

In relation to surface roughness, the values of Ra, Rz and Rt of *Erisma uncinatum* and *Apuleia leiocarpa* woods had a significant increase compared to the initial condition, before exposure to natural weathering (Table 2). For *Parkia pendula* wood, there was also increase in the roughness parameters; however, these did not differ statistically between the periods of exposure to natural weathering.

In general, the surface roughness of the wood, when protected from weathering, is related to its intrinsic characteristics, such as grain type, arrangement of anatomical elements, presence of incrustations and width of growth rings, as well as unfolding and further processing procedures, in the case of drying and surface preparation with planers and sandpaper (THOMA et al. 2015). This explains the similarity of values of Ra, Rz and Rt between the three Amazonian woods before exposure to weathering tests.

Tolvaj et al. (2014) mentioned that the increase in the surface roughness of wood exposed to natural weathering can be attributed to the degradation of the lignin present in the middle lamella, a layer that is characterized by a high concentration of lignin, which is important for binding between cell walls.

Saei et al. (2015) verified that the average roughness (Ra) of *Fagus orientalis* (Initial Ra of 5 μm) and *Abies* sp. (Initial Ra of 6 μm) woods presented a significant increase in the first 30 days of exposure to natural weathering, remaining constant

Table 2. Surface roughness of *Apuleia leiocarpa*; *Erisma uncinatum* and *Parkia pendula* woods before and after exposure to natural weathering.
Tabela 2. Rugosidade superficial das madeiras de angelim-saia, cedrinho e garapeira antes e depois da exposição ao intemperismo natural.

Period (days)	Ra	Rz	Rt
		(μm)	
Parkia pendula			
0	6.88 a (1.10)	21.49 a (2.28)	59.16 a (14.18)
240	8.15 a (0.86)	22.19 a (2.65)	68.68 a (5.97)
Erisma uncinatum			
0	6.87 a (1.86)	18.15 a (1.87)	54.53 a (16.40)
240	12.11 b (1.92)	28.67 b (2.75)	107.20 b (16.86)
Apuleia leiocarpa			
0	6.81 a (0.71)	19.11 a (0.66)	57.68 a (5.95)
240	9.13 b (0.57)	25.13 b (2.41)	71.19 b (9.70)

Where: within each roughness parameter, means followed by distinct letters differ statistically from each other at 5% of error probability. Values in parentheses refer to the standard deviation.

until the final period of 90 days (final Ra of 9 and 7.5 for *Fagus orientalis* and *Abies* sp., respectively). The difference between the initial and final values of Ra, obtained by Saei et al. (2015), is similar to what was verified in the present study for *Parkia pendula* and *Apuleia leiocarpa*.

The greatest variations of roughness were verified for *Erisma uncinatum* wood, before and after exposure to natural weathering. This result can be related to its higher lignin content, so as to provide the greater degradation of the surface, due to the oxidation of the said constituent. Santana; Okino (2007) verified lignin contents of 33.6 and 28.2% for *Erisma uncinatum* and *Apuleia leiocarpa* woods, respectively. On the other hand, *Parkia pendula* presented a lignin content of 29.01% (AMORIM, 2013).

It is important to highlight that in addition to the leaching of lignin degraded by natural weathering reactions, the increase in the roughness of the wood is also related to the sudden changes of humidity (absorption and desorption of the humidity of the environment), providing the development of superficial cracks.

4. CONCLUSIONS

The wood exposed to natural weathering presented a darkening of surface, resulting from the reduction of the colorimetric parameters L*, a* and b*, among which the *Parkia pendula* wood had the highest total color variation.

The parameters Ra, Rz and Rt had an increase with the exposure of the woods to natural weathering, in which *Erisma uncinatum* wood presented the roughest surface in comparison to the other species.

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