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Does a silicon-based nanoproduct improve the surface characteristics of amazonian woods?

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TECHNOLOGY OF FOREST PRODUCTS

ABSTRACT

Background: Natural weathering reduces the durability of wood products. In this situation, preservative surface treatments are recommended for wood products to increase life and resistance and decrease the wood's hygroscopic capacity. This study aimed to evaluate the surface characteristics of three Amazonian wood species – *Schizollobium parahyba* var. *amazonicum*, *Cordia goeldiana*, and *Manilkara elata* – treated with a silicon-based nanoproduct.

Results: The species were classified according to the following classes of basic density: low (<0.550 g cm^{-3}), medium (between 0.550 and 0.720 g cm^{-3}), and high density (> 0.730 g cm^{-3}). The nanoproduct was sprayed along the grain of the wood samples. Wettability, roughness, and colorimetric properties were determined before and after treatment application. The application of the nanoproduct significantly reduced the wettability of the wood, particularly in *S. parahyba* var. *amazonicum*, which showed a 117% increase in contact angle, indicating lower hydrophilicity. Although the application of the nanoproduct affected the colorimetric parameters (L*, a*, and b*), the colorimetric grouping table showed that the colors of the wood did not change. Additionally, the surface roughness of *S. parahyba* var. *amazonicum* increased significantly post-treatment compared to untreated samples.

Conclusion: Therefore, the nanoproduct can be indicated for low, medium, and high-density wood species and for purposes that need to maintain their natural color and reduce their hydrophilicity.

Keywords: wettability; roughness; colorimetry; native woods.

HIGHLIGHTS

Nanoproduct reduces wood's wettability, reducing its natural affinity for water.
The nanoproduct changed the roughness of Paricá wood.
Wood's colors did not change after applying the silicon nanoproduct.
Low, medium, and high-density woody species can benefit from the nanoproduct.

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INTRODUCTION

The growing demand for wood-based products has led to significant technological and environmental advancements (Costa et al., 2020). Wood is one of the natural resources most used due to its versatility, which allows for a wide range of applications and uses for various purposes. Wood is a truly renewable material, commonly used indoors and outdoors (Tomak, 2022). Nevertheless, wood is extremely susceptible to the action of deteriorating and degrading agents, which limits its usefulness and requires treatment to extend its useful life (Castro et al., 2018).

The hygroscopicity of wood and the different climatic conditions expose the wood to weathering, which causes it to wear and significantly interferes with its quality (Carvalho et al., 2016). Obtaining high-quality wood products is mainly related to the surface quality of wood (Stanojevic et al., 2017). In this perspective, the development of treatments and processes to minimize the negative effects caused by wood deteriorating agents is necessary.

The main action of the biological agents begins on the surface structure of wood and is facilitated by moisture. Woods with high moisture are more susceptible to the action of biotic and abiotic agents. In this condition, the deterioration of the wood is enhanced, which consequently causes changes in its physical and mechanical properties (Wang et al. 2021). The use of chemical preservatives increases the durability of wood and hinder the action of biotic agents (Ukoima and Uko, 2013). However, wood preservation with chemical products is still questionable due to the harmful effects on humans (Souza and Lima, 2017). Moreover, the irregular disposal of treated wood waste can generate environmental contamination (Silva and Evaldt, 2014). Therefore, new products need to be studied to minimize such problems involving wood preservation.

The manipulation of products at the nanometric scale can modify the properties of materials for new applications in several areas of materials science (Resch; Farina, 2015). In general, nanotechnologies have the potential to affect all fields of wood preservation and the development of new preservatives, presenting low toxicity and high efficacy characteristics (Borges et al., 2018).

The use of nanotechnology in surface treatment and finishing has grown significantly. This new technology brings several possibilities and advantages, making the wood more resistant and durable, with reduced risk to the environment and human health (Borges et al., 2018). According to the same authors, nanotechnology products present the possibility of use in low concentration, which allows for maintaining the natural color of the wood and releasing the active ingredient in a controlled way. Most nanoproducts used for wood preservation modify the wood surface and reduce its hygroscopicity (Poubel, 2017).

Therefore, studies that evaluate the effect of nanotechnology products applied on wood surfaces are necessary, because they aim to improve and increase the durability and resistance of the material by reducing its hygroscopic capacity. The scientific question that guided the study was: What are the effects of applying a silicon-based nanoproduct on the surfaces of native woods from the Brazilian Amazonia? We believe that the treatment will promote a reduction in the water absorption capacity of the woods; however, it will be more intense in low-density woods. Thus, the objectives of this study were: i) to evaluate the surface characteristics of three Amazonian wood species – *Schizollobium parahyba* var. *amazonicum*, *Cordia goeldiana*, and *Manilkara elata* – treated with a silicon-based nanoproduct; ii) to analyze the possible modifications of wettability, roughness, and colorimetry of the woods with the surface treatment; and iii) to indicate the treated species with lower water absorption capacity.

MATERIAL AND METHODS

Wood sampling

The woods treated with nanoproduct were provided by the Árboris Group, a forestry company that manages and processes products from natural and planted forests, located in the municipality of Dom Eliseu, Pará State.

The tree species used were *Schizolobium parahyba* var. *amazonicum* (Huber x Ducke) Barneby (Paricá), *Cordia goeldiana* Huber (Freijó-cinza), and *Manilkara elata* (Allemão ex Miq.) Monach (Maçaranduba). The species were selected according to the company's availability and classified based on the following basic density classification proposed by Silveira et al. (2013): low density (< 0.550 g cm^{-3}), medium density (between 0.550 and 0.730 g cm^{-3}), and high density (≥ 0.730 g cm^{-3}).

Discs of approximately 8 cm thickness were obtained in the 0, 50, and 100% longitudinal positions of the logs of five trees of *S. parahyba* var. *amazonicum*; discs in the 0% and 50% longitudinal positions of the logs of five trees of *M. elata* and discs in indeterminate positions of the logs of four trees of *C. goeldiana* (Table 1).

Wood samples were made with a circular saw, measuring 5.0 x 3.0 x 1.0 cm (length x width x thickness). The samples were identified and separated by species.

Table 1: Sampling of native wood for the study.

Species	Basic density (g cm^{-3})	Number of logs	Longitudinal Position (%)	Number of discs	Diameter of discs (cm)
S. parahyba var. *amazonicum*	Low (~0,30)	5	0, 50, and 100	30	15 – 25
C. goeldiana	Medium (~0,50)	4	-	8	25 – 50
M. elata	High (~0,83)	5	0 and 100	10	25 – 60

Wood surface treatment

The wood surface treatment was carried out with a silicon-based nanoproduct (Nanoclean Wood 30) that is water-repellent, biodegradable, and non-hazardous to the environment and human health, according to standard NBR 14725-2 (ABNT, 2009). It is a German product from the Nanoclean brand, which supplies the Brazilian market with nanotechnological solutions through the State of Santa Catarina. This product has the capacity for innovation and development of new technologies, with quality and efficiency for protecting wooden surfaces.

The nanoproduct was applied along the grain of the wood samples, according to the manufacturer's recommendations. The application was performed in the laboratory using a sprayer without volume control.

After the nanoproduct application, the samples were kept in the laboratory at a controlled temperature (23ºC ± 2ºC), free of solar radiation incidence, until the treated surface dried. Subsequently, the samples were taken to an oven at a temperature of 103ºC ± 2ºC for complete drying. This process was performed before and after the application of the nanoproduct to ensure that all samples had the same moisture conditions. Finally, the surface properties were evaluated at the Wood Technology Laboratory of the Federal University of Lavras (UFLA), located in Minas Gerais State.

Determination of surface properties

The surface properties of the wood were determined on samples treated (WT) and untreated (NT) with nanoproduct. The parameters related to surface quality were determined following adaptations of the methodology described by Pereira et al. (2017).

The surface wettability was evaluated before and after the surface treatments, by measuring the contact angle in 5 points distributed on the wood surface. The definition of the wettability was performed using the sessile drop method, in which the goniometer equipment (Krüss model DSA30) measured the contact angle values of a drop on the tangential surface. These values were obtained by image analysis at 1, 5, and 60 seconds, allowing the wettability of the wood samples to be estimated. The contact angle was determined by the arithmetic average of the values captured at the five points shown in Figure 1.

Contact angles with values less than 90º tend to present high wettability, while angles that have values greater than 90º present low wettability (YUAN; LEE, 2013). Thus, the value of the wettability of the woods was calculated by the average of the contact angles between 5 and 60 seconds, according to Equation 1. The wettability calculation is described in the standard ASTM D724-99 (ASTM, 2010).

$$R = \frac{(A - a)}{55} \quad (1)$$

Where, R is the rate of change of wettability (º/s), "A" is the average contact angle after 5 seconds (°), and "a" is the average contact angle after 60 seconds (°).

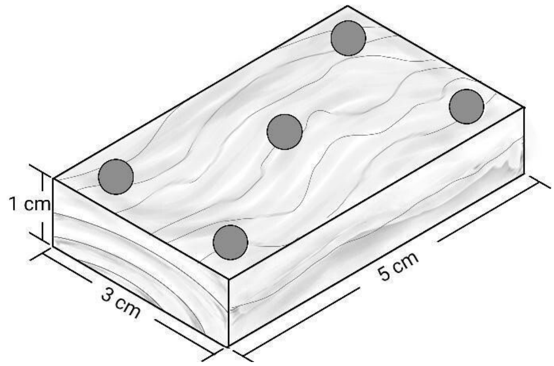

Figure 1: Scheme for determining the wettability in the wood samples.

The surface roughness was determined with a rugosimeter (Mitotoya, model SJ - 210). The roughness measurements were performed on the tangential surface, in 3 different positions of each wood sample in the perpendicular direction to the fiber arrangement, as shown in Figure 2. The measuring needle covered a surface area of approximately 8 mm at each data collection point on the sample.

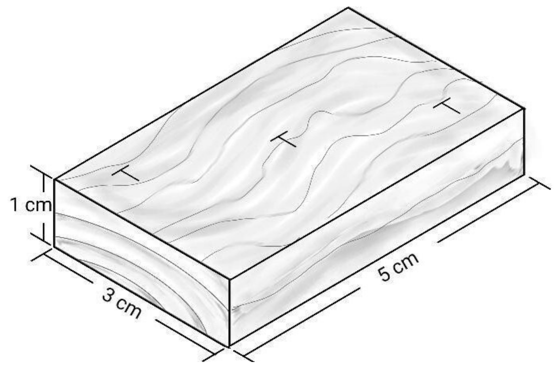

Figure 2: Scheme for determining the roughness in the wood samples.

The equipment that measures the surface roughness obtains the peak-valley profile of the surface by moving the needle of the scanning tip up and down on the wood surface. The roughness of each sample will correspond to the arithmetic average of the measurement of the three measured positions.

Colorimetry of the Amazonian woods

Colorimetry of the samples was done with a Konica Minolta CM-5 spectrophotometer. The wood color was determined before and after the nanoproduct application. The integrating sphere of the equipment has 150 mm in diameter and the wavelength range between 360 and 740 nm with a reading interval of 10 nm was used.

The color was determined at points distributed over the wood surface. Color values provide data to evaluate the colorimetric parameters (L* - lightness, a* - green/red axis, b* - blue/yellow axis). These parameters, defined by *Commision Internationale L'Eclairage* (CIE) in (1976), were used to determine the color of the woods. Equations 2 and 3 were used to obtain the color saturation values (C*) and the hue angle (h*), respectively:

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

$$Hh^* = \mathrm{Tan}^{-1}\left(\frac{b^*}{a^*}\right) \quad (3)$$

Where: C* - Color saturation; h* - hue angle; a* - green/red axis; b* - blue/yellow axis.

The mathematical relationship between the measured colorimetric parameters was calculated using Equation 4 to verify changes in the color of the wood after application of the nanoproduct. ASMT D 2244 (2011) standardizes the methods for measuring the colorimetric parameters.

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (4)$$

Where: ΔE - the color variation between treatment and control; ΔL - lightness variation; Δa - variation of the parameter a*; and Δb - variation of the parameter b*.

The smaller value of ΔE implies a smaller variation in color, so that the changes in color become perceptible to the human eye from 1.5, values between 3 and 6 are considered appreciable, and values greater than 6 are classified as very appreciable (NZOKOU; KAMDEM, 2006). Table 2, proposed by Hikita et al. (2001), presents the classification of wood color variation.

Table 2: Classification of the total color variation of woods.

Color variation (ΔE*)	Classification
0.0 – 0.5	Negligible
0.5 – 1.5	Slightly perceptible
1.5 – 3.0	Notable
3.0 – 6.0	Appreciable
6.0 – 12.0	Highly appreciable

Data analysis

The experiment was conducted in a completely randomized design (CRD). The data were submitted to Shapiro-Wilk and Levene tests, at a 5% significance level, to test the normality of residuals and homogeneity of variance, respectively. The effects of silicon-based nanoproduct and species on the surface properties of wood were verified by analysis of variance. The data were subjected to the F test, at a 5% significance level ($p < 0.05$), to verify the effect of the application of nanoproduct within each species. On the other hand, the Scott-Knott test evaluated the effect of species within the data of wood treated or not with nanoproduct ($p < 0.05$). For characteristics that did not meet the variance analysis requirements, the Mann-Whitney non-parametric test was used at 5% significance level. The number of repetitions for each characteristic is described in Table 3. Statistical analyses were performed using R software, version 4.3.2.

Table 3: Number of repetitions for each characteristic evaluated.

Species	Characteristic		
	Contact Angle	Surface Roughness	Colorimetry
Paricá	9	25	10
Freijó	6	15	10
Maçaranduba	6	22	10

RESULTS AND DISCUSSION

Wettability

Figure 3 shows the averages obtained by analyzing the contact angle before and after surface treatment with nanoproduct. Species effect was observed within the woods treated and not treated with nanoproduct for the CA variable. Wettability was higher in untreated wood, differing statistically from treated wood for all species. The highest wettability was reported for paricá, while maçaranduba proved to be more resistant. Freijó showed a higher contact angle compared to the other treated woods, but paricá showed a greater difference between treated and untreated wood.

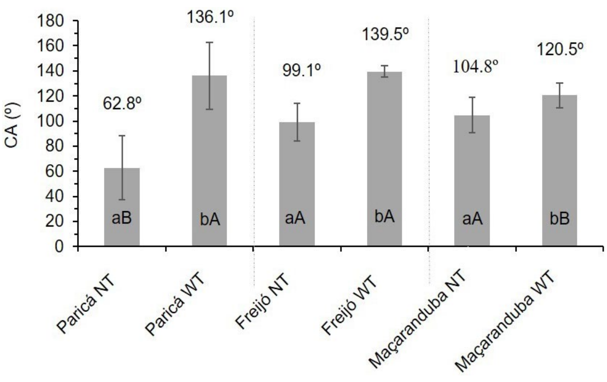

Figure 3: Averages of the contact angle (CA) in the woods before (NT) and after (WT) the application of the nanoproduct. Equal lowercase letters within each species do not differ statistically ($p < 0.05$) by the F test. Equal uppercase letters indicate that comparisons of species within each nanoproduct treatment level (treated and untreated) do not show statistical differences, according to the Scott-Knott test ($p < 0.05$). Error bars represent the standard deviation.

The contact angle (CA) of the samples with water, without treatment, indicates that the wood of the species *S. parahyba* var. *amazonicum* (paricá) has more affinity with water when compared to *C. goeldiana* (freijó-cinza) and *M. elata* (maçaranduba) which are less hydrophilic.

The application of the product on the surfaces of paricá, freijó, and maçaranduba wood caused a significant increase in the average CA of the sessile drop in relation to the wood surface of the three species. Before the application of the nanoproduct, paricá, a low-density species, highly had a hydrophilic behavior, so that the angle value was below 90º (62.8º). After the application of the nanoproduct, the species presented an angle higher than 90º (136.1º), with an increase of 117% in the contact angle.

The medium (Freijó) and high density (Maçaranduba) species, even though they are less hydrophilic compared to Paricá, also obtained a considerable increase in the CA values after the application of the nanoproduct, presenting significant differences in the CA values and lower standard deviation after the treatment. The Freijó before treatment had an angle of 99.1 ± 15.1º and after the nanoproduct application, the angle value increased to 139.5 ± 4.5º, with an increase of 41%. The same occurred for the Maçaranduba species, which increased CA by 15% after applying surface treatment.

The intensity of surface alteration in relation to the contact angle was inversely proportional to the increase in wood density. The higher the wood density, the lower the impact of the nanoproduct application in relation to the increase in contact angle. In this way, the treatment with nanoproduct promoted significant surface changes in the woods of the three species with differences in the intensity of the results between them.

Studies indicate that, the variation of the contact angle of liquids with wood depends on the characteristics of the species and surface, considering that measures of contact angle of liquids on solid surfaces are important and an easy diagnostic tool for the study of wettability (Petric and Oven, 2015; Tomak; 2022). Figure 4 shows the wettability test in laboratory conditions.

The Paricá species, due to the hydrophilicity of its surface before treatment, did not allow the capture of the images of 5 and 60 seconds, because of the rapid absorption of the material. After surface treatment, it was possible to capture the angle after 5 and 60 seconds, which showed the non-absorption of the material, indicating lower hydrophilicity acquired after treatment. Freijó and maçaranduba before treatment after 60 seconds showed a decrease in the angle indicating water absorption, after treatment the angle remained on the surface without decrease for both species.

Contact angles greater than 90 degrees typically indicate that a material is hydrophobic, as they suggest a low affinity between the liquid and the solid surface. This phenomenon is supported by various studies that explore the relationship between wettability, contact angles, and hydrophobicity (Wennman et al. 2023; Zhang et al. 2024; Yan et al. 2024; Yao et al, 2024). While contact angles above 90 degrees generally indicate hydrophobicity, the context of surface texture and material composition can influence this relationship.

Table 4 shows the average wettability values of the species before (NT) and after (WT) the nanoproduct treatment. The effect of species on wettability was observed only in the wood treated with the nanoproduct, with maçaranduba showing the highest mean value.

The three species showed significant differences for the surface treatment. The average angle at 5 and 60 seconds obtained for the wettability of the three species after treatment was close to 0 °/s, that is, every second 0 ° was modified in the angle of contact with water, indicating no absorption of the material. In this way, the application of nanoproducts showed a positive influence on wood protection, increasing the contact angle and reducing wettability. Such impact reported in this study can add even more value to wood and provide the use of little explored woods.

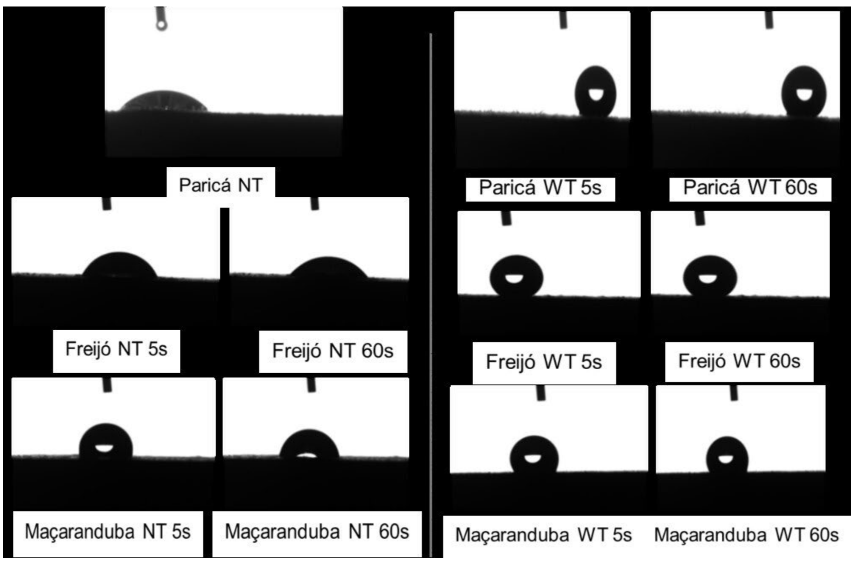

Figure 4: Wettability tests in the laboratory, showing the water droplets interacting with the surface of untreated wood (NT) and treated (WT) with the nanoproduct.

Table 4: Wettability of species before (NT) and after (WT) surface treatment with nanoproduct.

Species	Wettability (º/s)	
	No treatment (NT)	Treated (WT)
Paricá	0.35 ± 0.38 aA	0.00 ± 0.01 bB
Freijó	0.43 ± 0.31 aA	0.00 ± 0.01 bB
Maçaranduba	0.53 ± 0.43 aA	0.10 ± 0.08 bA

The values followed by different lowercase letters in the same line differed statistically ($p < 0.05$) by the F test. Different uppercase letters in the column show statistical differences, according to the Scott-Knott test ($p < 0.05$).

Other innovative wood surface treatment methods, including plasma treatments (Duan et al., 2024), lignin-based modifications (Herrera et al., 2023), lignin combination with plasma (Herrera et al., 2023), combination oil and boron (Tomak, 2022), polyvinyl alcohol and methyltrimethoxysilane (Zheng et al., 2024), thermal modification (Candan et al., 2021), cellulose nanofibers combined with silica nanoparticles (Bang et al., 2024), silicone nanofilaments (Yin et al., 2022), have been shown to effectively alter the wood's surface characteristics, regarding its wettability.

These methods have promoted numerous benefits, increasing the durability, stability, and functionality of wood. However, even given these benefits, it is important to consider potential challenges, such as the long-term stability of these treatments and their environmental impact.

Wood roughness

The average roughness (Ra) of paricá, freijó, and maçaranduba species before and after surface treatment are presented in Figure 5. Paricá showed the highest wood roughness, with a significant increase of 21% after the application of the surface treatment. It is important to note that the Scott-Knott test detected a species effect on the behavior of the roughness (Ra) variable, regardless of whether the wood was treated or untreated.

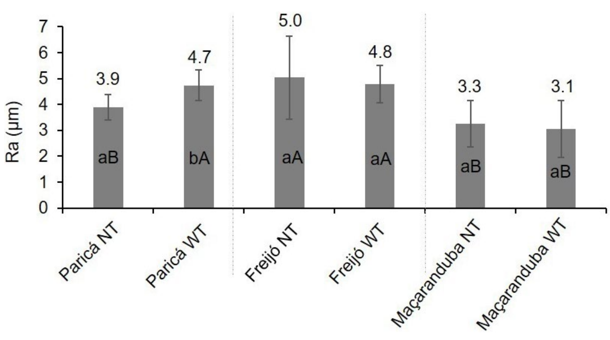

Figure 5: Average roughness of untreated (NT) and treated (WT) species. Equal lowercase letters within each species do not differ statistically ($p < 0.05$) by the F test. Equal uppercase letters indicate that comparisons of species within each nanoparticle treatment level (treated and untreated) do not show statistical differences, according to the Scott-Knott test ($p < 0.05$). Error bars represent the standard deviation.

The wood's roughness is a result of its anatomy and processing. Thus, several factors influence the roughness. The lower the roughness value the better the surface quality that this wood will have (Leão, 2016; Bajic et al., 2008). According to the authors, wood roughness can be influenced by controlled or uncontrolled processes, such as cutting, cutting speed, and depth. Therefore, the nanoproduct treatment was expected to reduce the surface roughness of the wood. However, a significant increase in this parameter was observed for Paricá species, a result conflicting with what was expected. This behavior may be associated with possible reactions and interactions between the chemical components present in the wood and the nanoproduct. However, further studies should clarify the possible variables that influenced the Paricá wood to present increased roughness after the application of the nanoproduct.

According to Floch et al. (2015), wood is considered a heterogeneous material and presents in its composition cellulose, lignin, hemicelluloses, extractives, and minerals. Mesquita (2016) studied the behavior of wood species subjected to artificial weathering with different finishing products. The author shows that wood can present different behaviors in relation to finishing products, and that roughness is a variable characteristic between species, so not only the machining and application of finishing products have an influence, but also the anatomical composition and basic density.

The roughness values tended to decrease for the other species, by 4 and 6% respectively, after the application of the nanoproduct. However, the statistical analysis evidenced that the treatment with the nanoproduct did not result in a significant change in roughness. This shows that the surface treatment with the nanoproduct, with regard to surface roughness, acts differently depending on the species.

Colorimetry

Figure 6 shows the color of the wood samples before and after surface treatment with nanoproduct. A slight change in color tone was observed in all samples after treatment.

The average and standard deviation of the colorimetric values obtained (L*, a*, b*, C*, and h) before and after surface treatment are presented in Table 5.

From a colorimetric grouping suggested by Camargos and Gonzalez (2001) it was possible to define the color for each species studied. According to the grouping, Paricá is classified as a greyish-white wood, as it presents high clarity (L*), due to the presence of yellow chromaticity and low red chromaticity (Melo et al., 2013).

According to Ferreira and Spricigo (2017), high L* values represent lighter colors while lower values indicate darker colors. Arruda et al. (2011) reported similar results for the colorimetric parameters of Paricá, in which higher values of h (hue angle) indicate the positioning of the species near the b*(yellow) axis, corroborating the influence of this coordinate on the color of this wood. Thus, the low value of a* (red) compared to the higher value of b* (yellow) and the high value of h indicate the tendency of the species to yellow color.

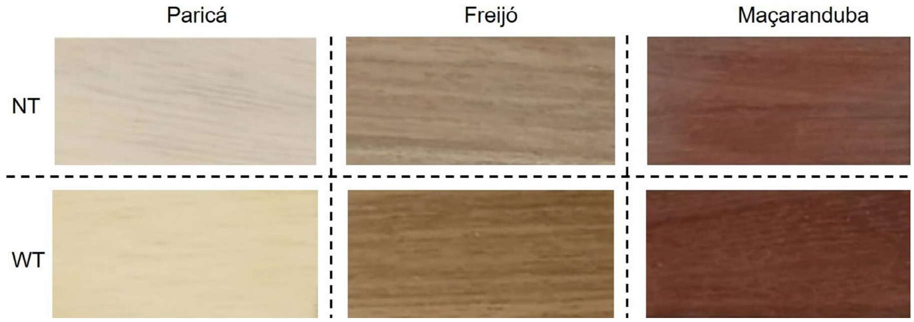

Figure 6: Wood samples of the species before (NT) and after (WT) surface treatment.

Table 5: Colorimetry of species before (NT) and after (WT) treatment with nanoproduct.

Species	Colorimetric Parameters					
	L*	a*	b*	C*	h	ΔE
Paricá NT	86.8 (1.5) a	3.1 (0.9) a	18.3 (1.5) a	18.6 (1.6) a	80.6 (2.0) a	10.1
Paricá WT	86.2 (1.8) a	2.8 (0.5) a	28.4 (3.7) b	28.5 (3.9) b	84.3 (1.1) b	
Freijó NT	64.2 (8.7) a	6.5 (1.3) a	21.4 (2.5) a	22.5 (2.2) a	72.7 (4.1) a	10.6
Freijó WT	55.0 (5.2) b	9.0 (0.6) b	25.8 (2.3) b	27.3 (2.3) b	70.6 (1.9) a	
Maçaranduba NT	42.4 (3.0) a	12.2 (1.6) a	14.9 (2.5) a	19.2 (2.9) a	50.7 (1.5) a	3.6
Maçaranduba WT	40.9 (2.3) a	13.3 (0.7) b	18.0 (1.6) a	22.4 (1.7) a	53.5 (1.8) a	

Values followed by equal lowercase letters in the same column, within species, did not differ statistically (p <0.05) by the T-test. Average and (standard deviations). L: lightness; a*: green/red axis; b*: blue/yellow axis; C*: Color saturation; h*: hue angle; and ΔE: the color variation between treatment and control.

There were no significant changes in the luminosity (L*) and red pigmentation values (a*) after surface treatment with nanoproduct on Paricá wood. For the other parameters there was a small increase, mainly for b*, indicating the yellow aspect of the surface after treatment, in addition to the increase in saturation (C*), and color intensity, with statistically evidenced increases and the significant difference in color between the treated and untreated woods.

Freijó wood, according to the colorimetric grouping table, presents an olive-yellow coloration. The results of the analyses for the colorimetric parameters (Table 5), show the main influence of lightness (L*) and the parameter b* (yellow) on the coloration of the species, a result also evidenced by Gonçalez et al. (2010).

After applying the surface treatment to the species, a decrease in lightness y (55.0) was observed, which indicates the darkening of the treated surface. Likewise, an increase in the b* parameter (25.8), responsible for the yellow color, was observed, being the highest value among the species analyzed.

Similarly, Gonçalez et al. (2010), studied the coloration of Freijó wood with and without treatment, using finishing products, after performing the tests Freijó wood was characterized by yellow pigmentation, b* coordinate, and lightness (L*). According to the authors, finishing products can alter the color of wood and cause it to darken.

According to the statistical results for the species, all parameters, except for hue angle, showed significant differences after surface treatment. Teles et al. (2016) performed colorimetric analyses to evaluate the influence of CCA preservative treatment on the surface of three tropical wood species. According to the authors, the color of the woods studied was significantly altered, obtaining a darker color after the treatment.

Finishing products can cause darkening of the wood surface and the decrease in L* values indicates that the nanoproduct can alter the color of the studied woods by low lightness. Maçaranduba wood according to the colorimetric grouping table was classified as dark brown due to the low lightness value (42.4), a value close to that found by Maia et al. (2018). Lima et al. (2021) reported purplish-brown coloration for *M. elata* wood, corroborating a shade closer to brown for this species. The low value of h* (50.7) corresponds to red and indicates the little influence of the parameter b* (14.9) in relation to its color. After the treatment of the species, it was observed that there was a decrease in lightness (40.9) of the wood and an increase in the parameters a*(13.3), b*(18.0), and h* (53.5).

The chromatic a*(12.2), reddish color, exerts a greater influence on the characterization of the color of maçaranduba wood compared to the species of Paricá (3.07) and Freijó (6.5), being evidenced after performing the surface treatment significant difference. For the other parameters, no significant changes were observed after treatment.

Table 5 is based on levels of perception and classifies the total color variation (ΔE) of wood (Lima et al., 2013). Based on the ΔE values (see Table 5), the total color variation was higher for Paricá (ΔE = 10.1) and Freijó (ΔE = 10.6), being classified as very appreciable changes (6.0 to 12.0). The ΔE value obtained for maçaranduba wood (ΔE = 3.6) showed lower total color change compared to the other species and was classified as an appreciable change (3.0 to 6.0).

The colorimetry indicated that the Paricá species showed a significant change for the b* (yellow) parameter and influenced the color of the species after receiving the treatment, giving a yellowish appearance. The lightness and the b* parameter are the main parameters that influenced the color of the Freijó species, darkening the surface from the decrease in luminosity. A significant increase in the a* (red) parameter was observed for maçaranduba, being the species that showed the least color variation after surface treatment.

CONCLUSION

Nanoproduct application alters the surface characteristics of Amazonian woods. The contact angle of the three species was altered after surface treatment. Thus, the species presented lower hydrophilicity, with emphasis on the Paricá species which had an increase of 117%.

The average roughness of Paricá wood after application of the nanoproduct was significantly higher than in untreated wood. The Freijó and Maçaranduba wood did not show significant changes.

Differences were observed in the colorimetric parameters analyzed for the three species studied after the application of nanoproduct. However, the colors of the woods showed no changes based on the colorimetric grouping table.

Nanoproducts can be indicated for low, medium, and high-density wood species that need to maintain their natural color and decrease their hydrophilicity. Such effects may promote important gains in industry, such as cost reduction and higher turnover of wood and capital.

AUTHORSHIP CONTRIBUTION

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