

NATURAL DYES FROM THE AMAZON FLORA USED IN TEXTILE DYEING

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ABSTRACT

The textile industry are among the sectors that contribute most significantly to water pollution. It is estimated that approximately 90% of the dyes used globally are of synthetic origin, which have high toxicity, contaminating potential, and low biodegradability. In this context, natural dyes emerge as promising alternatives to mitigate the environmental impacts associated with synthetic dyes. This research aimed to evaluate the dyeing potential of the species Jatobá (*Hymenaea courbaril*), Muricizinho (*Byrsonima crassifolia*), and Crajirú (*Arrabidaea chica* Verlot), as well as to determine the colorimetric characterization of the dyed fabrics. Samples of cotton and silk were subjected to a dyeing process by immersion in aqueous solutions containing plant extracts at concentrations of 25%, 50%, and 100%, at temperatures of 25 °C, 70 °C, and 95 °C, with immersion times of 1 and 24 hours. Greater dyeing affinity was observed in silk fabrics, attributed to their more organized fibrous structure and more open weave, compared to cotton. Spectrophotometric analyses showed slight color variation after the fastness tests, but the values remained close to the initial ones, indicating good fixation and stability of the shades obtained. The results indicated that the natural dyes evaluated present satisfactory performance and constitute a viable alternative to synthetic dyes, contributing to more sustainable practices in the textile production chain.

Keywords: colorimetric study, amazon rainforest, environmental impact, tannins.

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1. INTRODUCTION

Over millennia, the use of natural resources for dyeing textile fibers has been a widespread practice among various civilizations, playing a fundamental role in imparting color and identity to garments (Andrietti; Ibsch, 2022, p. 100). Although its exact origin is difficult to determine, natural dyeing techniques are estimated to date back at least 6,000 years. However, over the centuries, these methods were gradually replaced by the synthetic dye industry, which, in addition to offering a color range not found in nature, enabled large-scale textile production (Demarchi; Santana, 2022, p. 2).

Among the various industrial sectors, the textile industry stands out for its socioeconomic and environmental relevance, particularly in clothing production. This production chain exerts significant pressure on the environment due to the high consumption of resources and the generation of waste and effluents (Berlim, 2012, p. 20). The textile industry is also among the main sources of water pollution and is frequently associated with significant environmental impacts resulting from the use of synthetic dyes containing heavy metals and other potentially toxic compounds (Narimatsu *et al.* 2021, p. 5). The intensive use of these pigments, combined with the improper disposal of dyeing effluents, leads to water bodies contaminated with high levels of coloration, suspended solids, and biochemical oxygen demand (Andrietti *et al.* 2022, p. 101).

In light of this context, contemporary fashion has been seeking more sustainable alternatives for textile production, driven especially by a new consumer profile that values ecological practices and the responsible use of natural resources (Narimatsu *et al.* 2021, p. 5–7). In this scenario, natural dyeing re-emerges as a promising strategy for developing production processes with lower environmental impact. This technique involves obtaining dyes from biological sources while respecting ecological cycles and avoiding the depletion of natural resources (Demarchi; Santana, 2022, p. 14).

Therefore, this study aimed to investigate the dyeing potential of the extracts obtained from Amazonian species Jatobá (*Hymenaea courbaril*), Muricizinho (*Byrsonima crassifolia*), and Crajirú (*Arrabidaea chica* Verlot) on cotton and silk fabrics on different concentration and temperature, and immersion time conditions as well as to assess color changes after the application of the modifiers and fastness tests. It also sought to determine the color characteristics of dyed fabrics through colorimetric analyses performed using spectrophotometry. Evaluating the dyeing potential of these species contributes to the development of ecological dyeing processes, promoting the use of renewable natural resources and minimizing environmental impacts. Furthermore, the characterization of the colors obtained provides relevant data for future applications in biotechnology, fostering innovation and strengthening the interface between science, technology, and sustainability.

2. THEORETICAL FRAMEWORK

Natural dyes present intrinsically favorable characteristics from environmental and toxicological perspectives, as they are largely biodegradable, hypoallergenic, non-toxic, and non-carcinogenic. Furthermore, because they are free of heavy metals and other xenobiotic compounds, they require less complex and lower-cost treatment of effluents generated during the dyeing process (Santos *et al.* 2023, p. 20). These pigments are obtained directly from plant organisms and exhibit wide color variability, influenced by local floristic diversity (Santos, 2024, p. 32).

Brazil, which holds one of the richest floras on the planet, encompasses species used for multiple purposes, including food, the production of aromas and condiments, extraction of active compounds, formulation of medicines, and the production of fibers, timber, and natural pigments (Coradin *et al.* 2011, p. 19–20). From dyes extracted from biological sources, it is possible to develop unique textile pieces whose shades vary according to the chemical characteristics of the plant raw material, the extraction methods employed, and the conditions under which the dye is applied to the textile substrate (Narimatsu *et al.* 2021, p. 7). In this context, the color diversity obtained through natural dyeing can be quantified and compared using colorimetric techniques.

Color perception results from the reflection of incident light by a substrate and its subsequent interpretation by the visual system within the visible spectrum. As it is a phenomenon

dependent on physical stimuli associated with neurophysiological interpretation, visual color determination is inherently subjective and limited in precision (Holtzschue, 2011, p. 18–22). With scientific advances, the study of color has expanded beyond purely optical aspects of perception to incorporate instruments and methods of quantitative analysis, among which colorimetry stands out.

Colorimetry, developed from studies conducted by the International Commission on Illumination (CIE) between 1927 and 1964, established standardized systems for the measurement and representation of color, often associated with the use of spectrophotometry (Ferreira *et al.* 2017, p. 210). Spectrophotometry, in turn, is an analytical technique that enables the identification of components not visually perceptible by measuring light absorption at specific wavelengths, resulting in characteristic spectra in the ultraviolet, infrared, or visible regions (Bossu *et al.* 2006, p. 740).

3. METHODOLOGY

3.1 Preparation of Fabric Samples

Cotton and silk fabrics were used, standardized to dimensions of 20 × 20 cm. The samples were subjected to a scouring step, using a neutral liquid soap to remove gums, waxes, and other impurities that could interfere with the subsequent dyeing stage.

Cotton fiber, of a cellulosic nature, is composed of repeating units of cellobiose, which exhibit extensive intra- and intermolecular hydrogen bonding. These interactions favor the formation of crystalline regions, making cellulose insoluble in water and in most organic solvents (Defalco, 2023, p. 33). This high crystallinity hinders the diffusion and fixation of dyes in the fiber, unlike silk fibers, whose protein structure presents more reactive functional groups, greater dye affinity, and a more open weave (Babu, 2015, p. 66–67). Due to this structural difference, only the cotton fabrics were subjected to an additional pre-mordanting step.

In the pre-mordanting of cotton fibers, phenolic compounds were used to promote efficient chemical bonding between the fiber and the dyes, increasing color fixation on the textile substrate (Gomes, 2022, p. 20). Two tannin sources were tested: mistletoe extract (*Struthanthus flexicaulis*) and tannic acid solutions at 1% and 2%, in order to define the most suitable concentration for consequent assays. The material was then over dried at 60° C for

72 h until constant mass, both cotton and silk were treated with the mordant. The mordant, by forming complexes between its metal ions, the natural dye, and the fiber, acts as a binding agent (Samanta *et al.* 2009, p. 385), providing greater color intensity, durability, wash resistance, and light stability. Potassium alum was used as the mordant to ensure adequate fixation of the dye to the fabric.

3.2 Preparation of Raw Material and Natural Dyeing

For the dyeing process, bark from the jatobá fruit (*Hymenaea courbaril*) and leaves of muricizinho (*Byrsonima crassifolia*) and crajirú (*Arrabidaea chica* Verlot) were used, collected in the metropolitan region of Manaus. The plant samples were ground in a mill and sieved to standardize particle size and increase specific surface area. Subsequently, they were dried in an oven at 60 °C for 72 h to obtain a stable dry mass (Chakraborty, 2014, p. 233–261).

The dried and standardized plant material was subjected to aqueous extraction. A 3:1 ratio (water:biomass) was adopted, with the biomass mass equivalent to the mass of the fabric to be dyed. The samples were immersed in water heated to 70 °C and left to stand for 24 h. After cooling, the extracts were filtered using a Chinoy-type filter to separate solid residues.

The obtained extracts (100%) were used to prepare solutions at 25%, 50%, and 100%. Cotton and silk samples were immersed in these solutions at temperatures of 25 °C, 70 °C, and 95 °C, with immersion times of 1 and 24 h. The fabrics were then dried in the shade.

3.3 Expansion of the Color Palette

To diversify the tones obtained, the fabrics with the highest dye absorption were cut into four parts and treated with chemical modifiers: citric acid ($C_6H_8O_7$), sodium carbonate (Na_2CO_3), and ferrous sulfate ($FeSO_4$). For each solution, 7 g of the reagent were dissolved in 300 mL of distilled water, and the fabric samples were immersed for 15 minutes, a sufficient time to allow color alteration and uniformity.

To evaluate the stability and quality of the dyeing, the previously modified samples were subjected to color fastness tests (Mussak, 2009, p. 334). The tests performed were: perspiration fastness (ISO 105 E04-2013), using a solution of 15 g of NaCl per liter at 37 °C; and seawater fastness (AATCC TM 106:2013), using a solution of 30 g of NaCl per liter at 37

°C. In this stage, the samples were cut into dimensions of 4 × 10 cm, immersed in 100 mL of each solution for 30 minutes, and subsequently dried at 60 °C for 24 h.

3.4 Colorimetric Analysis of the Samples

Finally, after the modification and fastness tests, the cotton and silk fabric samples were cut into dimensions of 4 × 4 cm for colorimetric analysis. The samples were evaluated using a digital spectrophotometer, and the parameters of the CIELAB system were recorded: lightness (L*), green/red component (a*), yellow/blue component (b*), chroma (C*), and hue angle (H*).

In the CIELAB system, L* ranges from 0 (black) to 100 (white); negative values of a* indicate a tendency toward green, while positive values indicate red; negative values of b* indicate a tendency toward blue, while positive values indicate yellow; C* represents color saturation; and H* (in degrees) corresponds to the hue angle, defining the type of color perceived.

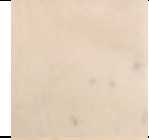
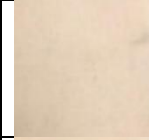
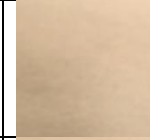
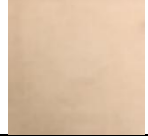
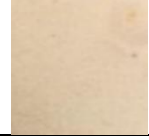
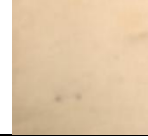
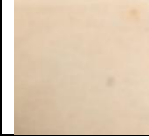
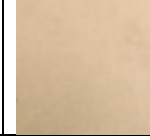
4. RESULTS AND DISCUSSION

Overall, the results demonstrate that silk exhibited higher dye affinity and color homogeneity than cotton across all three plants extracts, especially under higher temperatures and longer immersion times.

When using mistletoe as a pre-mordant on cotton fiber, color variations limited to light yellow tones were observed. After the dyeing process with muricizinho dye, the fabrics exhibited distinct coloration, predominantly in pinkish hues. It was also found that lower concentrations of the dye solution (25%), applied at 95 °C, favored the production of lighter colors, while intermediate concentrations (50%), applied at 70 °C, resulted in medium shades.

Regarding immersion time, exposure for 1 h produced softer colors, whereas extending the duration to 24 h intensified the depth of the tones. In the other treatments evaluated, no significant color changes were identified, as shown in Frame 1.

Frame 1 – Cotton fabrics pre-mordanted with erva-de-passarinho and dyed with muricizinho at 25 °C, 70 °C, and 95 °C.

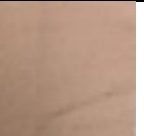
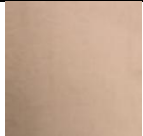
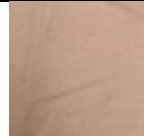
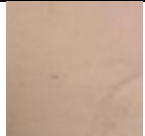
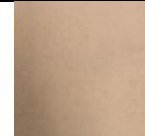
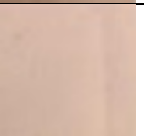
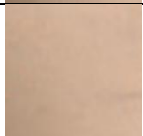
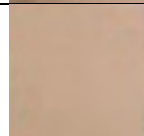
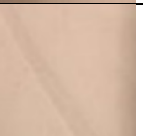
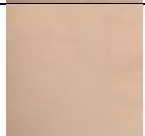
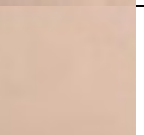
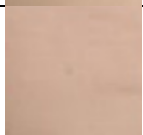
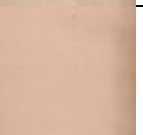
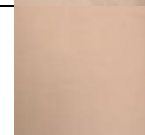
	25%		50%		100%	
	1 hour	24 hours	1 hour	24 hours	1 hour	24 hours
25°C						
70°C						
95°C						

Source: prepared by the authors.

In the dyeing of cotton with muricizinho extract, using a 2% tannic acid solution as the tannin source, no significant color variations were observed among the different treatments evaluated. However, in contrast to the results obtained with mistletoe, the use of 2% tannic acid promoted the development of predominantly brownish and grayish tones. This effect is attributed to the higher concentration of tannins in the solution, which tends to intensify and mask the color of the dye extract, as shown in Frame 2. Overall muricizinho extract showed better visual performance on silk than cotton, suggesting greater dye affinity for the protein fiber under the tested conditions.

In light of this behavior, 1% tannic acid was selected for subsequent experiments, as the lower concentration reduces the risk of interference in the color expression of the extract on the fabric, allowing for a more accurate evaluation of the color imparted by the dye.

Frame 2 – Cotton fabrics pre-mordanted with 2% tannic acid and dyed with muricizinho at 25 °C, 70 °C, and 95 °C.

	25%		50%		100%	
	1 hour	24 hours	1 hour	24 hours	1 hour	24 hours
25°C						
70°C						
95°C						

Source: prepared by the authors.

In the dyeing of cotton fiber with jatobá extract, using 1% tannic acid as the tannin source, tones ranging from light pink to light brown were observed, especially in treatments carried out at 100% concentration at 25 °C for 1 h and at 50% concentration at 70 °C for 1 h. Additionally, immersion time directly influenced color intensity: exposures of 1 h resulted in darker tones, while extending the duration to 24 h produced lighter shades. It is noteworthy that the use of 1% tannic acid caused less interference in the final coloration of the extract compared to the previous treatment, in which a 2% concentration was used.

In silk, dyeing with jatobá extract showed a different behavior. Although the tones were generally lighter, the fabrics exhibited more saturated, and visually intense colors than cotton, indicating greater dye affinity for the protein fiber. The darkest shades were obtained in treatments subjected to 24 h of immersion at the highest temperature (95 °C) and at 100% concentration, resulting in a dark brown that was homogeneous, uniform, and free of staining across the entire surface of the fabric samples. Frame 3 presents a comparison between cotton and silk fabrics dyed with jatobá extract.

Frame 3 – Cotton fabrics pre-mordanted with 1% tannic acid and silk mordanted with potassium alum, dyed with jatobá at 25 °C, 70 °C, and 95 °C.

	25%		50%		100%	
	1 hour	24 hours	1 hour	24 hours	1 hour	24 hours
Cotton (25°C)						
Silk (25°C)						
Cotton (70°C)						
Silk (70°C)						
Cotton (95°C)						
Silk (95°C)						

Source: prepared by the authors.

When cotton fiber pre-mordanted with 1% tannic acid was dyed with crajirú extract, color distribution across the fabric was not uniform. This behavior was particularly evident in treatments carried out for 1 h at 50% concentration, at temperatures of 25 °C, 70 °C, and 95 °C. The resulting shades ranged from light to dark pink, indicating low color uniformity in cotton.

In contrast, dyeing silk with crajirú extract showed greater efficiency and homogeneity. The protein fiber exhibited more intense and saturated pink tones, with noticeable variations depending on concentration, temperature, and immersion time. Among the treatments evaluated, the one that most influenced tonal depth was the application of the solution at 100%

concentration at 95 °C, for both exposure times, resulting in deeper and more consistent colors. Frame 4 presents the cotton and silk fabrics dyed with cajirú.

Frame 4 – Cotton fabrics pre-mordanted with 1% tannic acid and silk mordanted with potassium alum, dyed with cajirú at 25 °C, 70 °C, and 95 °C.

	25%		50%		100%	
	1 hour	24 hours	1 hour	24 hours	1 hour	24 hours
Cotton (25°C)						
Silk (25°C)						
Cotton (70°C)						
Silk (70°C)						
Cotton (95°C)						
Silk (95°C)						

Source: prepared by the authors.

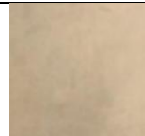
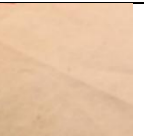
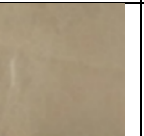
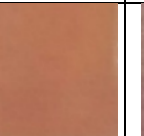
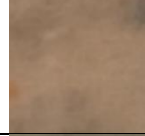
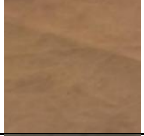
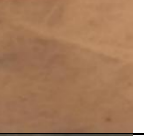
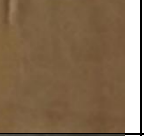
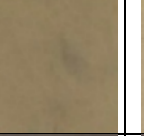
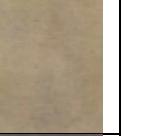
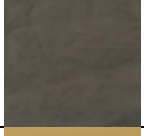
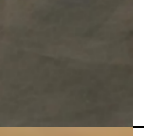
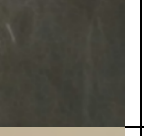
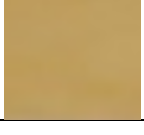
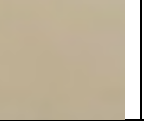
Overall, the dye extracts showed greater affinity for silk than the cotton fabrics. This behavior may be associated with the more reactive functional groups of the protein fiber and its relatively more open structure compared with cotton (Mussak, 2009, p. 178). However, Simões *et al.* (2024, p. 278), when using andiroba (*Carapa guianensis*) sawdust as a dye source for silk, observed non-uniform coloration with the occurrence of stains in several treatments. This contrast highlights that natural dyes may exhibit different behaviors depending on the interaction between the type of mordant, the substrate, and the chemical composition of the raw material.

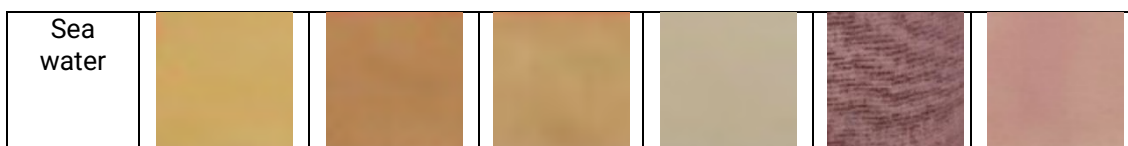
After dyeing, the samples subjected to color modifiers exhibited color changes in both cotton

and silk, varying according to the species used. In cotton, citric acid produced lighter, slightly pinkish tones; sodium carbonate intensified color, and shifted in toward brownish shades; whereas ferrous sulfate promoted marked darkening grayish, resulting in grayish tones close to black. In silk, citric acid resulted in tones ranging from gray to dark purple; sodium carbonate produced darkened shades between brown and gray; and ferrous sulfate produced deeper shades, in some case similar to navy blue.

In the tests for perspiration and seawater resistance, notable differences were observed regarding the color stability of the samples. In some cases, there was an intensification of the original color, as seen in cotton and silk fibers dyed with muricizinho and jatobá. In contrast, other samples showed fading, such as silk dyed with crajirú, indicating lower color fastness. For cotton dyed with crajirú, no perceptible changes were identified, suggesting good resistance to the simulated agents. These variations were likely related to the affinity between the dye and the fiber, the type of tannin used, the fixation mechanism, and the specific properties of each natural dye when in contact with salts (Mussak, 2009, p. 203). Frame 5 illustrates the color modifications observed in the different treatments.

Frame 5 – Color modifiers applied to cotton and silk fabrics.

	Cotton pre-mordanted with era-de-passarinho and dyed with muricizinho	Cotton pre-mordanted with 2% tannic acid and dyed with muricizinho	Cotton pre-mordanted with 1% tannic acid and dyed with jatobá	Silk mordanted with potassium alum and dyed with jatobá	Cotton pre-mordanted with 1% tannic acid and dyed with crajirú	Silk mordanted with potassium alum and dyed with crajirú
Citric acid						
Sodium carbonate						
Ferrous sulfate						
Perspiration						



Source: prepared by the authors.

Colorimetric analysis of cotton fibers dyed with muricizinho showed predominantly high lightness (L^*) values for most samples, except for one that exhibited more pronounced darkening. The color coordinates a^* and b^* remained positive across all treatments, indicating a predominance of reddish and yellowish tones, with ferrous sulfate particularly enhancing the yellow component. The hue angle (H^*) showed little variation among the mordants, remaining within the same hue range. Although perspiration and seawater fastness values were not recorded, the colorimetric results suggest good consistency in color responses across the different treatments.

The colorimetric analysis of cotton fibers dyed with jatobá revealed high lightness (L^*) values for most samples, except for those treated with ferrous sulfate, which showed significant darkening. Regarding colority, the a^* and b^* coordinates remained positive, indicating a predominance of reddish tones. The hue angle (H^*) showed little variation among treatments, except for ferrous sulfate, which caused a slight shift in hue. Samples subjected to perspiration and seawater fastness tests exhibited values close to those of the standard sample, suggesting good color stability. However, for silk dyed with jatobá, high lightness (L^*) values were observed, especially in fabrics treated with sodium carbonate, reflecting lighter and less saturated coloration. In contrast, ferrous sulfate significantly reduced L^* values, producing markedly darker tones. The samples showed high hue angle (H^*) values, with predominantly positive a^* and b^* coordinates, indicating a greater tendency toward red than yellow. Perspiration and seawater fastness tests confirmed good dye fixation on silk, as the samples maintained high hue angle (H^*) and chroma (C^*) values after exposure to test conditions.

The spectrophotometric analysis of cotton fabrics dyed with crajirú revealed high lightness (L^*) values for most samples, except for those treated with ferrous sulfate, which exhibited pronounced darkening. The color coordinates a^* and b^* remained close to zero, indicating low saturation and positioning of the samples near the center of the color space, between the yellow and red axes. The hue angle (H^*) showed little variation among treatments, clustering around 30° , suggesting preservation of the original hue of the dye; more pronounced deviations

were observed only in samples modified with sodium carbonate and ferrous sulfate. In the fastness tests, perspiration caused darkening and a slight reduction in color intensity, while seawater resulted in minimal changes, indicating good resistance under this condition. Furthermore, for silk fabrics dyed with crajirú, spectrophotometric analysis indicated a reduction in lightness (L^*) values, especially in samples treated with sodium carbonate and ferrous sulfate, reflecting greater darkening. The a^* and b^* coordinates showed significant increases, although remaining positive, indicating intensification of warm tones. Chroma (C^*) values remained relatively stable across treatments. Samples subjected to perspiration and seawater fastness tests exhibited slight darkening and moderate reduction in intensity, but preserved a hue close to the original, as shown in Table 1.

Table 1 – Spectrophotometry on cotton and silk fibers dyed with jatobá at 100% at 95 °C and 50% at 95 °C, respectively, for 24 hours.

	Standard sample	Citric acid	Sodium carbonate	Ferrous sulfate	Perspiration fastness	Seawater fastness
COTTON - Muricizinho						
L	68,1	78,18	78,03	54,93	–	–
a	11,96	5,79	8,54	3,75	–	–
b	22,27	20,39	27,5	12,85	–	–
c	25,28	21,2	28,8	13,39	–	–
H	61,76	74,17	72,74	73,73	–	–
COTTON - Jatobá						
L	72,07	72,08	68,11	49,36	69,51	67,92
a	9,57	9,49	11,67	4,19	9,25	9,59
b	19,86	19,85	27,72	14,35	18,45	18,88
c	22,04	22,04	30,07	14,95	20,64	21,18
H	64,26	64,31	67,17	73,73	63,37	63,08
SILK - Jatobá						
L	71,34	70,90	80,07	48,35	67,10	68,74
a	4,10	6,22	3,99	4,2	6,33	6,57
b	15,93	16,93	12,20	13,54	17,21	18,21
c	16,46	18,04	12,84	14,59	18,34	19,36
H	75,58	69,84	71,91	72,63	69,81	70,16
COTTON - Crajirú						
L	54,15	54,46	57,57	39,74	41,92	51,84

a	22,17	15,25	3,93	5,36	13,61	16,29
b	14,12	11,41	17,28	10,29	9,53	10,41
c	26,28	19,05	17,72	11,61	16,62	19,34
H	32,49	36,79	77,17	62,47	35,01	32,57

SILK - Crajirú

L	56,66	48,76	35,71	31,57	47,38	40,23
a	22,23	20,31	5,34	4,3	19,26	17,11
b	20,11	22,66	15,99	10,15	16,34	14,63
c	29,98	30,43	16,85	11,03	25,26	22,52
H	42,12	48,13	71,54	67,05	40,32	40,53

Source: prepared by the authors.

5. FINAL CONSIDERATIONS

The study achieved its objectives by demonstrating that extracts from jatobá, muricizinho, and crajirú can be used as a natural dye for cotton and silk fibers, under different experimental conditions. Overall, silk showed a greater dye affinity and better color uniformity than cotton, while the effects of concentration, temperature, and immersion time and the use of modifiers varied according to the botanical species and textile substrate. These findings reinforce the potential of Amazonian plant resources as alternatives to synthetic dyes and provide a basis for future studies involving additional Amazonian species.

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