



TEXTILE PROPERTIES OF NATIVE COTTON FROM PACHACHACA VALLEY - APURIMAC, PERU, DYED WITH BUDDLEJA CORIACEA DYE

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ABSTRACT

Objective: This study investigates the properties of native cotton from Pachachaca, Apurímac, Peru, dyed with Buddleja coriacea and metallic mordants, evaluating its textile properties for the textile industry.

Theoretical Framework: Key concepts related to textile fibers, natural dyes like Buddleja coriacea, and the importance of metallic mordants in the dyeing process are presented, highlighting the relevance of sustainable practices in the contemporary textile industry.

Method: The research analyzed textile characteristics with OFDA 2000, morphology with SEM, and the chemical composition of fibers with FT-IR spectroscopy. Dyeing treatments varying in pH were applied.

Results and Discussion: FT-IR of the dye identified flavonoid bands with N-H and O-H groups. The pH of treatments: T2 (5.22), T3 (3.18), T4 (2.58). DMF: T1 (15.03 μm), T5 (13.73 μm). IC: T3 (70.33 %/mm). Luminosity (L*): T1 (94.25), T5 (51.12). Chroma (C*): T4 (58.55). SEM-EDS showed variations in carbon, nitrogen, and oxygen: T5 stood out in carbon (53.4%) and had lower oxygen (38.3%). FTIR of the dyed sample revealed key bands: 3342 cm^{-1} (N-H, O-H), 2917 cm^{-1} , and 2840 cm^{-1} (C-H). Treatments and mordants enhance the sustainability and quality of eco-friendly cotton.

Research Implications: The findings suggest a high potential of native cotton for use in sustainable textile production, promoting practices that value biodiversity and cultural conservation.

Originality/Value: This study evidences the unique properties of Peruvian cotton, revitalizing traditional techniques and creating innovative and sustainable textile products.

Keywords: Textile Characteristics, Morphology, Chemical Bands, Native Cotton Fiber, Buddleja Coriacea.

PROPRIEDADES TÊXTEIS DO ALGODÃO NATIVO DO VALE DE PACHACHACA - APURIMAC, PERU, TINGIDO COM CORANTE DE BUDDLEJA CORIACEA

RESUMO

Objetivo: Este estudo investiga as propriedades do algodão nativo de Pachachaca, Apurímac, Peru, tingido com Buddleja coriacea e mordentes metálicos, avaliando suas propriedades têxteis para a indústria têxtil.

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Marco Teórico: São apresentados conceitos-chave relacionados às fibras têxteis, corantes naturais como Buddleja coriacea e a importância dos mordentes metálicos no processo de tingimento, destacando a relevância das práticas sustentáveis na indústria têxtil contemporânea.

Método: A pesquisa analisou as características têxteis com OFDA 2000, a morfologia com SEM e a composição química das fibras com espectroscopia FT-IR. Foram aplicados tratamentos de tingimento variando o pH.

Resultados e Discussão: O FT-IR do corante identificou bandas de flavonoides com grupos N-H e O-H. O pH dos tratamentos foi: T2 (5.22), T3 (3.18), T4 (2.58). DMF: T1 (15.03 μm), T5 (13.73 μm). IC: T3 (70.33 %/mm). Luminosidade (L): T1 (94.25), T5 (51.12). Chroma (C): T4 (58.55). SEM-EDS mostrou variações em carbono, nitrogênio e oxigênio: T5 destacou-se em carbono (53.4%) e menor oxigênio (38.3%). O FT-IR da amostra tingida revelou bandas-chave: 3342 cm^{-1} (N-H, O-H), 2917 cm^{-1} e 2840 cm^{-1} (C-H). Os tratamentos e mordentes melhoram a sustentabilidade e a qualidade do algodão ecológico.

Implicações da Pesquisa: Os resultados sugerem um alto potencial do algodão nativo para ser utilizado na produção de têxteis sustentáveis, promovendo práticas que valorizam a biodiversidade e a conservação cultural.

Originalidade/Valor: Este estudo evidencia as propriedades únicas do algodão peruano, revitalizando técnicas tradicionais e criando produtos têxteis inovadores e sustentáveis.

Palavras-chave: Características Têxteis, Morfologia, Bandas Químicas, Fibra de Algodão Nativo, Buddleja Coriacea.

PROPIEDADES TEXTILES DEL ALGODÓN NATIVO DEL VALLE DE PACHACHACA- APURIMAC PERU TEÑIDO CON TINTE DE BUDDLEJA CORIÁCEA

RESUMEN

Objetivo: Este estudio investiga las propiedades del algodón nativo del valle de Pachachaca, Apurímac, Perú, teñido con tinte de Buddleja coriacea y mordientes metálicos, evaluando sus propiedades textiles para la industria textil.

Marco Teórico: Se presentan conceptos claves relacionadas con las fibras textiles, los tintes naturales como el Buddleja coriacea y la importancia de los mordientes metálicos en el proceso de teñido, destacando la relevancia de las prácticas sostenibles en la industria textil contemporánea.

Método: La investigación analizó las características textiles con equipo OFDA 2000, la morfología con MEB y la composición química de las fibras con espectroscopia FT-IR. Se aplicaron tratamientos de teñido variando el pH.

Resultados y Discusión: El FT-IR del tinte identificó bandas de flavonoides con grupos N-H y O-H. El pH de tratamientos: T2 (5.22), T3 (3.18), T4 (2.58). DMF: T1 (15.03 μm), T5 (13.73 μm). IC: T3 (70.33 %/mm). Luminosidad (L*): T1 (94.25), T5 (51.12). Cromo (C*): T4 (58.55). MEB-EDS mostró variaciones en carbono, nitrógeno y oxígeno: T5 destacó en carbono (53.4%) y menor oxígeno (38.3%). El FTIR de la muestra teñida reveló bandas clave: 3342 cm^{-1} (N-H, O-H), 2917 cm^{-1} y 2840 cm^{-1} (C-H). Los tratamientos y mordientes mejoran la sostenibilidad y calidad del algodón.

Originalidad/Valor: Este estudio evidencia las propiedades únicas del algodón peruano, revalorando técnicas tradicionales y creando productos textiles innovadores y sostenibles.

Palabras clave: Características Textiles, Morfología, Bandas Químicas, Fibra de Algodón Nativo, Buddleja Coriacea.

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1 INTRODUCTION

The textile industry faces a major challenge in finding sustainable alternatives to synthetic fibers, which have a considerable negative impact on the environment and public health (Naser et al., 2024). In this context, natural fibers, such as native Peruvian cotton, emerge as a viable option. Peru, recognized for its exceptional biodiversity, is home to several varieties of native cotton, highlighting the cotton from the Pachachaca Valley, which offers natural shades ranging from white to brown. However, the production of this cotton has decreased in recent decades due to the predominance of synthetic fibers in the market (Tausif et al., 2018). The renewed interest in sustainability has led to a resurgence in the use of natural textile products, justifying the need for this research .

This study investigates how dyeing native cotton from the Pachachaca Valley with the natural dye *Buddleja coriacea*, using different metallic mordants, affects its textile, chemical and morphological properties. This research is crucial to expand knowledge about native cotton and promote its sustainable use in the textile and craft industry. By characterizing the textile and chemical properties of native cotton, the study provides valuable information for designers, artisans and textile companies, helping to integrate this natural resource into their productions and to sustainably conserve and revitalize the production of this unique fiber.

The main objective is to evaluate the textile and chemical properties of native cotton from the Pachachaca Valley dyed with natural dye from *Buddleja coriacea*, using metallic mordants.

2 THEORETICAL FRAMEWORK

Native cotton from the Pachachaca Valley of Peru is known for its long tradition and diversity, being highly valued for both its unique properties and its cultural and economic importance. Despite this, its use has declined due to competition with cheaper synthetic fibers. Preservation of this cotton is crucial, given its historical value and environmental benefits (Zhang & Cai, 2011).

Cellulose makes up approximately 88-96.5% of cotton fiber, while the remainder is composed of proteins, pectins, waxes, inorganic substances, organic acids, sugars and pigments. This composition gives it unique properties such as high absorbency, comfort and strength. Cotton has a fineness that varies between 16 to 20 microns and an elongation of 3 to 7%, allowing it to be flexible and resistant. In addition, its high hygroscopicity allows it to absorb



up to 27% of its weight in water, making it ideal for clothing and towels. The structure of cotton fiber includes a cuticle, primary wall, secondary wall and lumens, which contributes to its robustness and ability to withstand tensile forces (Wang & Memon, 2020).

The use of natural dyes, such as *Buddleja coriacea*, in textiles offers environmental and health benefits, being a sustainable alternative to synthetic dyes. *Buddleja coriacea* stands out for its chemical properties and effectiveness as a dye (Ticona et al., 2022).

Metallic mordants, such as potassium alum and ferrous sulphate, are essential in the dyeing process, acting as bridges between fibres and dyes, improving colour fixation and durability. Studies have shown that the use of these mordants in combination with natural dyes, such as *Buddleja coriacea*, increases the sustainability and quality of the final product (Mathur & Gupta, 2003).

Sustainability in the textile industry is vital to reduce environmental impact. The use of natural fibers and organic dyes promotes eco-friendly practices, reduces pollution and conserves resources, aligning with sustainability principles and promoting environmental preservation and human well-being (Andrés Daniel Zambrano Macías, 2022).

Studies such as this one (Haji & Haji, 2019) analysed the effectiveness of metallic mordants in dyeing cotton with natural dyes, showing that the concentration of mordants significantly influences the intensity and durability of the colour (Haji & Haji, 2019). Another author (Repon et al., 2017) compared the use of banana flower stem sap versus reactive dyes, showing that the sap provides comparable colour durability with economic advantages, thus highlighting the sustainability of natural dyes over traditional reactive ones.

3 METHODOLOGY

3.1 MATERIALS AND METHODS

3.1.1 Materials

In the community of Saywite, located in the province of Abancay, Apurímac, Peru, at an altitude of 4100 meters above sea level, flowers of the endemic shrub *Buddleja coriacea* were collected. These flowers were dried and pulverized to obtain a fine powder. During the dyeing process, mordants commonly used in the artisanal textile industry were used, such as: collpa (sodium sulfate, Na_2SO_4), alum (potassium aluminum sulfate dodecahydrate, $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$) and lemon salt. (oxalic acid, $\text{C}_2\text{H}_2\text{O}_4$), all purchased at a local market in



Abancay. Native white cotton fiber was used, from the Pachachaca valley in the Apurímac region, at an altitude of 2100 meters above sea level.

3.2 MEASUREMENT OF COLORIMETRIC PARAMETERS

Colorimetric parameters of dyed yarn samples were determined using the CIELab system (L^* , a^* , b^*) and a ULS2048CL-RS-EVO spectrometer (AVANTES). The spectrometer was coupled to an integrating sphere with 50 mm halogen illumination and a 10° observation angle, together with a D65 illuminant to simulate daylight. Three color measurements were made per sample, using 2 cm² fabrics made from the yarns. These fabrics were placed in the sample holder of the equipment to measure the reflected light in reflectance mode. In the CIELab system, lightness (L^*) varies from 0 (black) to 100 (white), a^* from green (-) to red (+), and b^* from blue (-) to yellow (+) (Atodiresei et al., 2013).

3.3 EVALUATION OF TEXTILE CHARACTERISTICS

To evaluate the textile characteristics of the samples, an optical fiber diameter analyzer (OFDA 2000), calibrated according to the IWTO-47 standard, was used. The following parameters were measured: the Mean Fiber Diameter (MFD), which represents the average of the diameters in the sample; the MFD Coefficient of Variation (MFD CV), which evaluates the uniformity of the diameters; the Comfort Factor (CF), which reflects the softness and comfort; and the Curvature Index (CU), which indicates the curvature of the fibers (Quispe Peña et al., 2013). The analyses were carried out at the Fiber Laboratory of the National University of San Antonio Abad del Cusco. In addition, the fineness of yarn (FH) was calculated using the equation proposed by Butler and Dolling (1995) (Butler & Dolling, 1995):

$$FH = 0.881 \times DMF \sqrt{1 + 5 \left(\frac{CV}{100} \right)^2} \quad (1)$$



3.4 SEM-EDS MORPHOLOGICAL STUDY OF COTTON FIBER SAMPLES

To analyze the morphology and elemental composition of the cotton samples, a Thermo Fisher Scientific Prisma E scanning electron microscope (SEM) was used. The samples were cut and separated into 3 mm long fibers, and then mounted on graphite tape adhered to the sample holder of the equipment. The observations were made under low vacuum conditions, using a voltage of 25 kV and a spot size of 5, at a pressure of 0.23 Torr. Micrographs of the cotton fiber samples were obtained in order to study both the morphology of the fibers and their elemental composition by means of energy-dispersive X-ray spectroscopy (EDS) analysis (Barani, 2020). The measurements were carried out at the Laboratory of the Faculty of Physics of the Universidad Nacional Mayor de San Marcos. EDS analysis was used to identify and quantify the elements present in the cotton fiber. This is especially useful for detecting the mordants used in the dyeing process.

3.5 FOURIER TRANSFORM INFRARED SPECTROSCOPY ANALYSIS

To record the chemical bands of the samples, an FT-IR spectrophotometer (Thermo NICOLET iS50, USA) was used, operating in a range of 400 to 4000 cm^{-1} and performing 64 scans per spectrum. The FTIR-ATR technique was applied according to the protocols in references (McGregor et al., 2018). In sample preparation, a 2 cm^2 piece of tissue was placed on the ATR crystal and, during data acquisition, pressure was applied to ensure proper contact. The infrared light beam passed through the crystal towards the sample, and the transmitted light was detected to generate the spectrum. Finally, in data analysis, the spectrum was examined to identify the chemical bands of the sample. Measurements were performed at the General Chemistry Laboratory of the Micaela Bastidas National University of Apurímac.

3.6 STATISTICAL ANALYSIS

A comprehensive statistical analysis was carried out to evaluate the colorimetric indices (L^* , a^* , b^* , and C^*) and textile characteristics (DMF, FC, IC, and FH) of native cotton fibers dyed with natural dye from *Buddleja coriacea* and treated with metallic mordants. The statistical software R, version 4.1.3, was used for the analysis. The results were presented as mean $\pm$ standard deviation, with a number of samples of three replicates ($n=3$). A simple analysis of variance (ANOVA) was performed to compare the quantitative variables between the two



procedures (dyeing with and without metallic mordants). In addition, a Pearson correlation was performed to determine the relationship between all the mentioned parameters, considering p values < 0.05 as statistically significant and p values > 0.05 as non-significant.

4 RESULTS AND DISCUSSIONS

4.1 FT-IR SPECTRAL ANALYSIS AND pH OF EXTRACTED DYE

Figure 1 shows the results obtained by Fourier transform infrared spectroscopy (FTIR), where several important chemical bands are identified. The band at 3342 cm^{-1} is related to the absorption of NH and OH groups, while the bands at 2917 cm^{-1} and 2840 cm^{-1} correspond to the stretching vibrations of CH bonds in methylenes and aliphatic compounds, respectively. Furthermore, the band at 2157 cm^{-1} is attributed to $\text{C}\equiv\text{C}$ bonds in alkynes, the band at 1628 cm^{-1} to stretching vibrations of $\text{C}=\text{O}$ and $\text{C}=\text{C}$ bonds, the band at 1324 cm^{-1} to deformation or stretching vibrations of CN bonds, the band at 1364 cm^{-1} to deformations in CH_3 groups, and the band at 664 cm^{-1} to out-of-plane deformations of CH bonds in aromatic compounds (Erra et al., 1997; Yao et al., 2008).

Analogous results were reported by Safapour (2023) in a research on the sawdust extract of *M. laurentii*. In this analysis, significant chemical bands were identified in the FT-IR spectrum, located mainly at 1622 cm^{-1} (elongation vibrations of the aromatic $\text{C}=\text{O}$ bond in flavonoid nuclei with quinone-type structures) and at 1449 and 1213 cm^{-1} (elongation and bending vibrations of the OH group in the polyphenolic system). These bands characterize flavonoids, responsible for pigmentation in many plants (Erra et al., 1997).

The band at 3342 cm^{-1} in infrared spectroscopy, attributed to the absorption of hydroxyl (OH) groups, is linked to flavonoids responsible for the yellow coloration in *Buddleja coriacea*. Flavonoids are recognized by their phenolic structures, and OH absorption is distinctive of these compounds. Furthermore, the band at 1628 cm^{-1} , associated with carbonyl bond stretching vibrations ($\text{C}=\text{O}$), could also be related to flavonoids, since these bonds are present in the carbonyl structures of flavonoids that contribute to pigmentation (Ke et al., 2021).



Figure 1

FTIR spectroscopy of Buddleja coriacea flower extract.

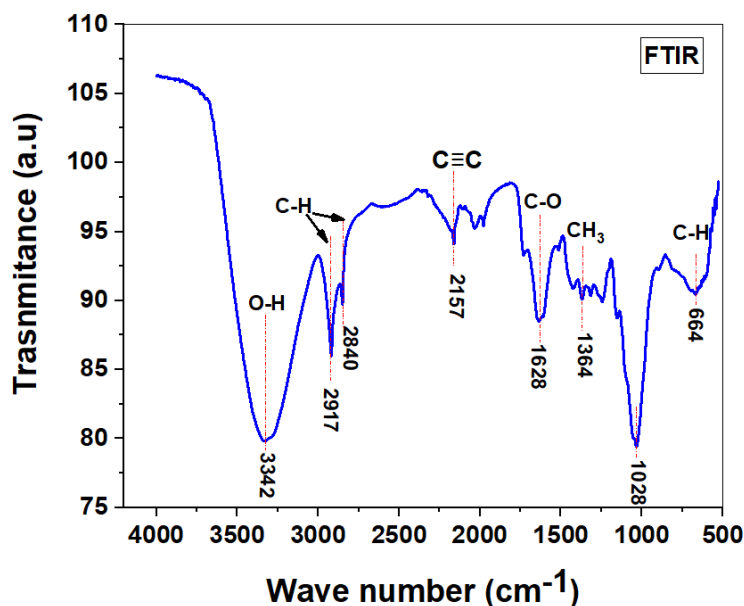


Table 1 and Figure 2 present the results of alpaca fibres dyed with various mordants, highlighting how these affect the pH of the dye solutions. In treatment T2, which employs Buddleja coriacea without mordants, the average pH is 5.22, indicating a more neutral condition compared to other treatments and possibly resulting in less effective colour fixation. On the other hand, treatment T3, which includes Buddleja coriacea and $KAl(SO_4)_2 \cdot 12H_2O$ (alum), shows an average pH of 3.18, suggesting that alum reduces the pH and could improve colour fixation in the wool. Treatment T4, with Buddleja coriacea and $C_2H_2O_4$ (oxalic acid), records the lowest pH at 2.58, indicating significant acidity that may favour fixation and colour intensity due to oxalic acid. Finally, treatment T5, combining Buddleja coriacea and Na_2SO_4 (sodium sulfate), maintains a pH of 3.18, equal to that of treatment T3, implying that sodium sulfate has no significant impact on the pH of the dye solution.

Table 1

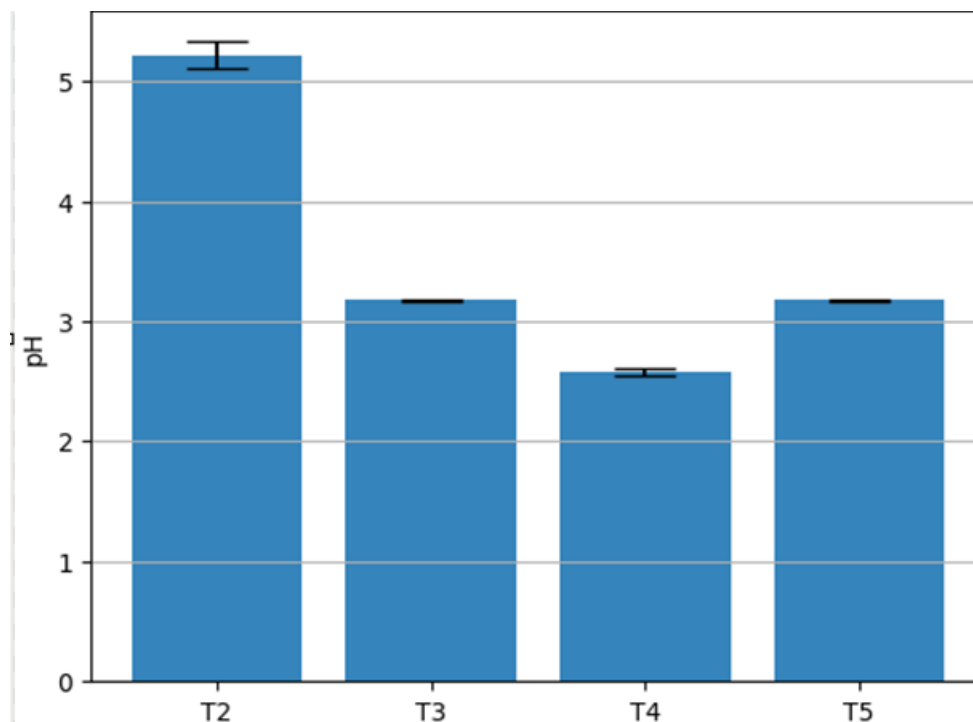
Quantification of pH of Buddleja coriacea dye with different mordants.

Sample	Variable	Number of measures	Mean $\pm$ SD
Tint (T2)	pH	3	5.22 $\pm$ 0.11
Dye (T3)	pH	3	3.18 $\pm$ 0.01
Dye (T4)	pH	3	2.58 $\pm$ 0.03
Dye (T5)	pH	3	3.18 $\pm$ 0.01



Figure 2

*Quantification of pH of *Buddleja coriacea* dye with different mordants.*



4.2 TEXTILE CHARACTERISTICS

The results presented in Table 2 reveal how dyeing native cotton fibers with *Buddleja coriacea* flower dye and the application of different mordants modify the textile properties of the native cotton fiber. The individual evaluation of each property reveals that treatment T1 has the highest Median Fiber Diameter (MFD) with 15.03 μm , significantly differentiating itself from the others. Treatments T2, T3 and T4 present lower and similar MFDs among themselves, while T5 stands out with the lowest MFD of 13.73 μm . In terms of the Coefficient of Variation (CV), all treatments exhibit high variability without significant differences, suggesting consistency in the variability of fiber diameter across treatments. The Comfort Factor (CF) remains at 100% for all, showing fibers smaller than 30 μm and, therefore, are comfortable regardless of the treatment. Regarding the Curvature Index (CI), T3 shows the highest value with 70.33 %/mm, significantly surpassing T1 and T4, which have similar and lower values. T2 and T5 present CI values that are in a medium range, and no significant differences are observed with T1 and T4. Finally, the lowest Yarn Fineness (FF) is observed in T5 with 13.85 μm , which implies a higher fineness than the rest of the treatments, which show similar and higher values. These results show how each treatment influences the properties of the fibers in a different way, which is essential to determine the quality and applicability of cotton in the textile industry.



Similar results were reported by Lozano et al. (2024), who found that the mean fiber diameter (MFD) and spinning fineness (SF) of colli-dyed and mordant-treated yarns increased significantly. The largest increases were observed with the addition of lemon salt, reaching an increase of 30.09 μm in MFD and also showing the greatest improvement in FH (Lozano et al., 2024).

Textile characteristics such as mean fiber diameter (MFD), coefficient of variation (CV), comfort factor (CF), curvature index (CI), fineness of cotton yarn dyed with natural dye and metallic mordants

Figure 3

Comparison diagram of textile characteristics treatment of native cotton samples.

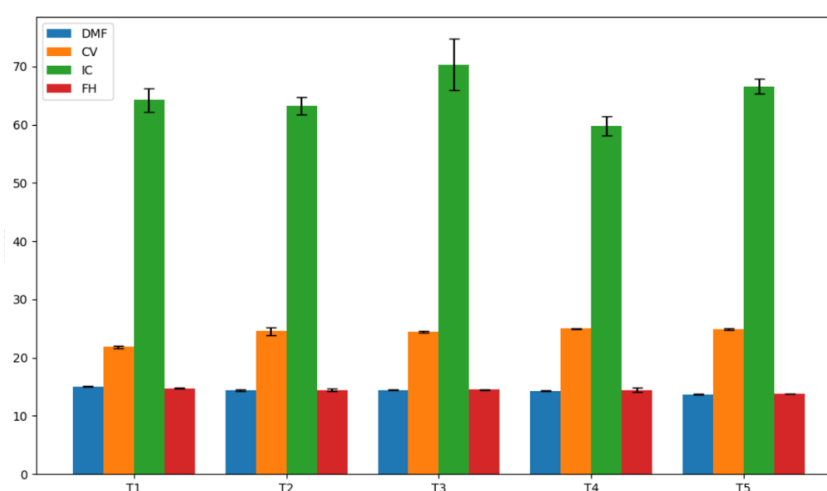


Table 2

Textile characteristics in native cotton fiber dyed with Buddleja coriacea flowers and use of mordants

Treatments	DMF (μm)	CV(μm)	FC(%)	IC(°/mm)	FH(μm)
T1	15.03±0.06 ^c	21.83±0.16 ^a	100	64.23±2.00 ^{ac}	14.74±0.06 ^b
T2	14.40±0.10 ^b	24.53±0.61 ^b	100	63.23±1.46 ^{ab}	14.47±0.17 ^b
T3	14.43±0.06 ^b	24.40±0.17 ^b	100	70.33±4.38 ^c	14.49±0.03 ^b
T4	14.30±0.06 ^b	25.03±0.06 ^b	100	59.77±1.65 ^a	14.44±0.36 ^b
T5	13.73±0.06 ^a	24.93±0.12 ^b	100	66.57±1.29 ^{bc}	13.85±0.04 ^a

Undyed white wool (T1); white wool dyed with Buddleja coriacea (T2); white wool + Buddleja coriacea + alum (T3); white wool + Buddleja coriacea + lemon salt (T4); white wool + Buddleja coriacea + clay lick (T5); Mean fibre diameter (MFD); coefficient of variation of MFD (CV); comfort factor or fibres < 30 μm (CF); curvature index (CI); yarn fineness (FH); superscripts with different letters per column show significant differences (P<0.05).



4.3 COLORIMETRY PARAMETERS

Table 3 and Figure 4 show how different dyeing treatments with *Buddleja coriacea* dye and the application of mordants affect the native cotton fiber. A significant decrease in lightness (L^*) is observed from undyed white wool (T1) to wool treated with *Buddleja coriacea* and sodium sulphate (Na_2SO_4) (T5), reflecting the impact of the treatments on fiber reflectance. In terms of chromaticity (a^* and b^*), the values increase remarkably from T1 to T4, indicating a higher presence of red and yellow tones. However, T5 shows a reduction in a^* , which could indicate a lower intensity of red compared to T4. Chroma (C^*) increases from T1 to T4 and decreases in T5, suggesting that sodium sulphate (Na_2SO_4) modifies the color intensity compared to other mordants. In terms of hue (h°), dyed treatments show lower tones than undyed wool, with T4 showing the most reduced hue, indicating a transition towards warmer colours due to the dyeing and mordants used. In summary, treatments with *Buddleja coriacea* flowers and various mordants significantly alter the colour properties of native cotton fibre, affecting lightness, saturation and hue in a statistically significant manner, with each mordant contributing differently to the final chromatic characteristics of the fibre.

Similar results were reported by Čorak et al. (2022), who found that cochineal-dyed cotton fibers showed uniform lightness (L), a balance of red and green hues (a), a variation of blue and yellow hues (b), and high color saturation (C), resulting in vibrant and uniform colors (Čorak et al., 2022).

Figure 4

Comparative diagram of the treatments in the colorimetric parameters of the native cotton samples.

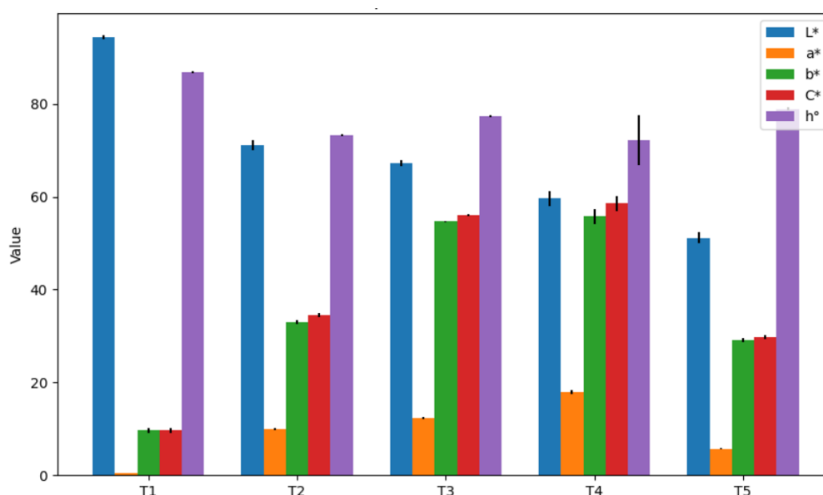




Table 3

Color quantification in native cotton fiber dyed with Buddleja coriacea flowers and use of mordants.

Treatments	L*	to*	B*	C*	h°
T1	94.25 ^e ±0.45	0.53 ^a ±0.03	9.65 ^a ±0.58	9.66 ^a ±0.58	86.82 ^e ±0.23
T2	71.06 ^d ±1.04	9.95 ^c ±0.24	33.00 ^c ±0.34	34.47 ^c ±0.39	73.22 ^b ±0.23
T3	67.24 ^c ±0.65	12.31 ^d ±0.21	54.63 ^d ±0.18	55.99 ^d ±0.14	77.30 ^c ±0.25
T4	59.64 ^b ±1.59	17.92 ^e ±0.41	55.74 ^e ±1.63	58.55 ^e ±1.63	72.17 ^a ±5.32
T5	51.12 ^a ±1.19	5.73 ^b ±0.17	29.15 ^b ±0.42	29.71 ^b ±0.42	78.87 ^d ±0.32

Undyed white wool (T1); white wool dyed with Buddleja coriacea (T2); white wool + Buddleja coriacea + alum (T3); white wool + Buddleja coriacea + lemon salt (T4); white wool + Buddleja coriacea + lick (T5). Where: L= Luminosity; a*= variation from green (-) to red (+); b*= variation from blue (-) to yellow (+); C= is the chroma (color saturation); h°= is the hue); superscripts with different letters per column show significant differences (P<0.05).

4.4 SEM-EDS CHARACTERIZATION

The characterization of cotton fibers by SEM-EDS (Scanning Electron Microscopy with Energy Dispersive Spectroscopy) is an analytical technique that provides detailed information on the morphology and elemental composition of the fibers.

4.4.1 Elemental Composition

According to table 4, for Carbon (C), sample T5 (white wool + Buddleja coriacea + collpa) has the highest percentage of carbon (53.4%), suggesting a higher retention of organic matter compared to the other samples. The other samples have similar carbon percentages, around 45-46%. As for Nitrogen (N), sample T4 (white wool + Buddleja coriacea + lemon salt) has the highest percentage of nitrogen (11.2%), which could indicate a greater interaction with the lemon salt mordant. Sample T5 has the lowest percentage of nitrogen (6.7%). For Oxygen (O), sample T5 has the lowest percentage of oxygen (38.3%), while sample T3 (white wool + Buddleja coriacea + alum) has the highest percentage (44.2%). This could reflect differences in oxidation or water retention . Regarding Sodium (Na), sample T5 and T2 (white wool dyed with Buddleja coriacea) have a notable percentage of sodium (0.7% and 0.2% respectively), which could be due to the presence of salts in the dyeing process. For Aluminum (Al), sample T2 has a higher percentage of aluminum (0.6%), which is expected since alum was used as a mordant. Silicon (Si) is present in very small or undetectable quantities in all samples, suggesting that it is not a significant component in the dyeing process. Regarding Chlorine (Cl), sample T5 has a notable percentage of chlorine (0.5%), which could be related to the



composition of the clay lick used. Potassium (K) is present in very small and similar quantities in all samples (0.1%). In summary, the results show how different mordants and dyeing processes affect the elemental composition of wool. Sample T5 stands out for its high carbon and chlorine content, while sample T4 has a high nitrogen content.

Similar results were reported by Liu, Y. (2018), who identified the key chemical components such as cellulose, proteins and minerals, and the correlation of these compositions with the physical and structural properties of cotton fibers. This analysis provides a deeper understanding of the structure and composition of cotton fibers, which may be useful for improving their processing and industrial applications (Liu, 2018).

Table 4

Elemental composition of treated and untreated samples

Items	Atomic % (T1)	Atomic % (T5)	Atomic % (T2)	Atomic % (T4)	Atomic % (T3)
C	46.1±0.1	53.4±0.2	46.5±0.1	45.9±0.1	45.4±0.2
N	10.5±0.4	6.7±0.6	8.7±0.8	11.20±0.4	8.9±0.8
O	43.1±0.2	38.3±0.2	43.9±0.2	42.7±0.2	44.2±0.2
Na	0.0±0.0	0.7±0.0	0.2±0.0	0.1±0.0	0.7±0.0
Al	0.1±0.0	0.2±0.0	0.6±0.0	0.1±0.0	0.2±0.0
If	0.2±0.0	0.1±0.0	0.0±0.0	0.0±0.0	0.0±0.0
Cl	0.0±0.0	0.5±0.0	0.1±0.0	0.0±0.0	0.4±0.0
K	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0

Undyed white wool (T1); white wool dyed with Buddleja coriacea (T2); white wool + Buddleja coriacea + amber (T3); white wool + Buddleja coriacea + lemon salt (T4); white wool + Buddleja coriacea + collpa (T5).

4.5 FT-IR ANALYSIS

Figure 5 shows the chemical components present in cotton fibres, as determined by FTIR spectroscopy. Cotton is mainly composed of cellulose, but also contains hemicelluloses, pectins, proteins and waxes. In the FTIR spectrum, it is observed that the peak at 3320 cm^{-1} is associated with the stretching band of the hydroxyl group (OH) present in cellulose, lignin and water. The peak at 3215 cm^{-1} corresponds to the stretching band (NH). The peak at 1645 cm^{-1} is related to the absorption band corresponding to the stretching of the C=O (carbonyl) functional group or, in some cases, to the stretching of the C=C double bond in organic compounds. The peak at 1423 cm^{-1} is generally associated with the CH₂ (cis-striction) deformation band, which is related to the methylene groups in the cellulose structure, the main component of cotton. Similarly, the peak at 1320 cm^{-1} is commonly associated with the CH stretching band (strain), specifically related to methylene (CH₂) groups in the cellulose

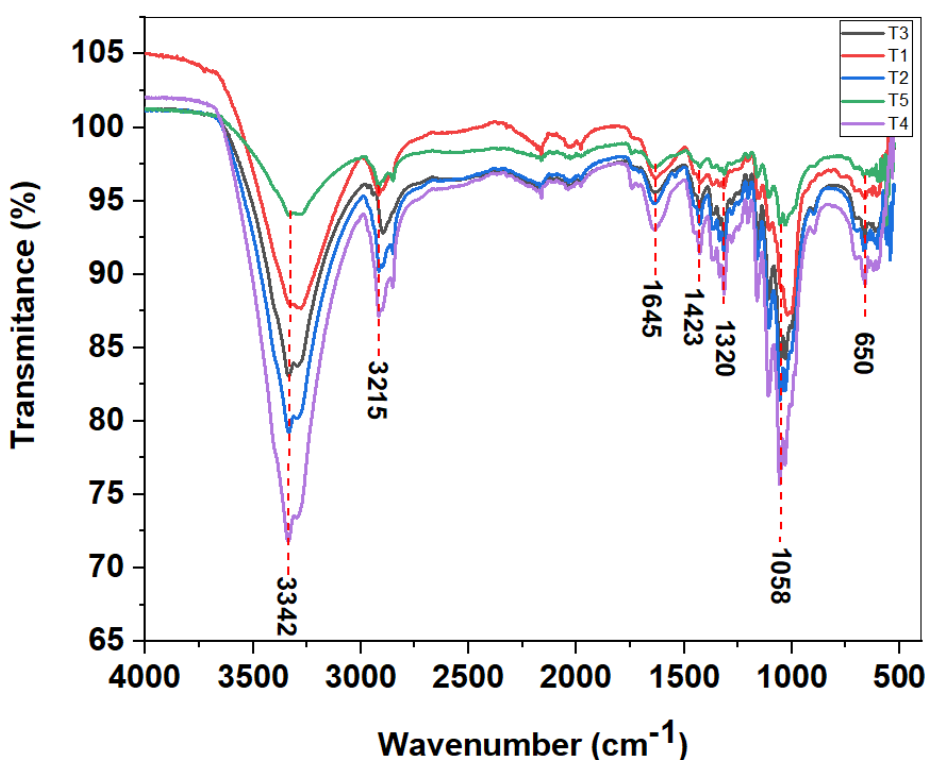


structure. This band may also reflect the presence of CO bonds in cellulose functional groups. Finally, the peak at 1058 cm^{-1} is typically associated with the CO stretching band, which corresponds to the vibration of CO bonds in cellulose functional groups such as ether groups (COC) and hydroxyl groups (C-OH).

He et al. (2022) reported similar results, identifying six key spectral bands in the lower wavenumber range (1730 , 1620 , 1525 , 1235 , 1050 , and 895 cm^{-1}), which correspond to C=O stretching, Amide I and Amide II bonds of proteins, OH/NH deformation, total COC stretching, and β -glycosidic bond in cellulose. The intensities of the bands at 1620 , 1525 , 1235 , and 1050 cm^{-1} were significantly correlated with the levels of protein (Amide I), protein (Amide II), cellulose, and hemicellulose, respectively, while the band at 1730 cm^{-1} showed a negative correlation with ash content (He et al., 2022).

Figure 5

FTIR spectroscopy of dyed cotton samples





5 CONCLUSION

FT-IR spectral analysis of the extracted dye showed the presence of relevant functional groups, such as NH and OH, related to flavonoids, confirming the effectiveness of the natural dye and its potential in sustainable textile applications.

It was found that textile characteristics including Median Fiber Diameter (MFD), Coefficient of Variation (CV), Comfort Factor (CF) and Curvature Index (CI) revealed how the applied treatments significantly affect the cotton quality. The results showed that T1 had the highest FMD (15.03 μm), thus becoming a reference standard for the evaluation of other treatments.

Colorimetry parameters, where significant differences in lightness (L^*) and chroma (C^*) were identified between the different dyeing treatments. This underlines the versatility of native cotton in obtaining vibrant colours, which has important implications in the production of high-end textiles that value sustainability and the use of natural dyes.

SEM-EDS characterization allowed to identify the morphology and elemental composition of the fibers, which contributes to the understanding of the interactions between the dye and the fiber [15]. The presence of different elements in the treated and untreated samples shows the effects of the mordants on the fixation and color quality.

FTIR analysis provided detailed information on the chemical composition of cotton, revealing the characteristic bands of the functional groups present. This aspect is essential to understand the interaction between the natural dye and the fiber, which can help improve dyeing processes and create unique and sustainable textile products, thus boosting the development of the Peruvian textile industry.

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