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ORIGINAL RESEARCH ARTICLE

Eco-friendly dyeing of fabric using banana sap mordant and mahogany sawdust extract natural dye

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Abstract: Synthetic dyes and mordants are widely used in the textile industry, contributing significantly to environmental degradation. While natural substances offer environmental advantages, their application processes are often not well-documented. This study explores the potential of banana sap mordant and mahogany sawdust extract natural dye as an eco-friendly dyeing approach, with an emphasis on ecological sustainability. The effectiveness of these natural substances was analyzed against conventional chemical and synthetic agents by examining the color strength, reflectance, and fastness properties of polyester fabric. The aqueous extraction of natural mordant and dye from locally sourced banana stems and mahogany sawdust, a form of bio-waste, resulted in improved yields (20% and 25%, respectively), highlighting both the efficiency of the process and a reduction in waste volume. Fourier-transform infrared spectroscopy analysis confirmed the presence of identical peaks in the natural dye, indicating strong molecular bonding. Polyester fabric treated with the natural mordant demonstrated satisfactory color strength (Kubelka–Munk [K/S] value of 1.1) and reflectance (28), supporting these materials' potential to mitigate the severe environmental impact associated with synthetic dye. In addition, the fabric displayed high rubbing and wash fastness ratings (4/5 and 5, respectively) as well as satisfactory bursting strength, indicating superior resistance to fading and adequate durability. Shade uniformity was verified through evenness, based on the Color Measurement Committee Delta E and K/S values across prominent areas of the test sample. All results were statistically significant ($R^2 \geq 0.9$).

Keywords: Natural dye; Natural mordant; Color fastness; Bursting strength; Kubelka-Munk value; Environmental sustainability

1. Introduction

The application of dyes for fabric pigmentation in the textile sector is one of the oldest known techniques, dating back to the origin of human civilizations.[1] However, the extensive use of synthetic dyes and chemicals in textile industries, particularly in the wet processing sector, has led to severe damage to aquatic ecosystems.[2] A dye is a substance used to alter the color of materials, making it one of the earliest textile techniques. Synthetic dyes are favored in the textile industry due to their availability, wide range of hues, low production cost, and ease of use. Despite this, synthetic dyes pose significant environmental hazards, including toxic, allergic, and carcinogenic effects.[3] In contrast, natural dyes—derived from renewable, sustainable, biodegradable, and non-toxic resources[4] such as plants, animals, and minerals—have gained prominent research interest.[5]

Mordants are essential compounds used to fix dyes to fibers, improving the fabric's ability to absorb dye and enhancing color intensity and light fastness. Common mordants comprise metallic salts of copper, iron, chromium, aluminum, and tin, along with substances like tanning chemicals. Natural mordants include banana stems, wood ash, aloe vera gel, old urine, and acidic fruit extracts such as lime.[6] In addition to improving dye absorption and color fastness, applying different mordants to natural dyes can result in a range of hues and tones.

Synthetic dyes are widely used in the textile sector due to their affordability, consistent qualities, vivid colors, and ease of application. Nonetheless, concerns about environmental sustainability and the hazardous effects of synthetic dyes persist.[7] Textile wastewater contains numerous organic or inorganic compounds, including dyes, which are harmful to environmental elements, especially to surface water bodies in many countries.[8] Removing dye contaminants from wastewater is crucial, as these dyes can cause chronic toxicity and may be mutagenic, teratogenic, and carcinogenic. However, the removal of synthetic dyes is hindered by behavioral complexities and thermodynamics. Biological and physicochemical treatment methods, such as coagulation-flocculation and adsorption, often exhibit poor dye degradation due to low biodegradability, occupy extensive space, and generate chemical-laden sludge requiring further treatment. Membrane filtration processes such as ultrafiltration, nanofiltration, and reverse osmosis produce high-quality reusable permeate and are considered effective[9]; however, they face limitations in synthetic dye removal due to membrane fouling, significant energy consumption, and high operational costs.[10]

At present, the application of environmentally friendly dyes and natural raw materials in textile production is of paramount importance. Plant-based natural bio-colorants are gaining increasing attention amid industrial growth, as sustainable products have become essential.[11] However, natural substances are not readily available commercially, and their market presence remains limited.[12] The antibacterial, antioxidant, and anti-inflammatory properties of natural substances,[13] which depend on the biochemical compositions of the dyes,[14] should be considered. Textile researchers have investigated the performance of plant-based natural colorants such as gardenia yellow, black rice,[15] *Butea monosperma*,[16] *Alkanna tinctoria* roots,[17] and *Curcuma longa*,[18] focusing on addressing the severe environmental concerns associated with synthetic dyes as well as their antibacterial properties.[19] Researchers also explored dye extraction from mahogany (*Swietenia mahagoni*), a historically well-known tree for its use in furniture manufacturing in producing durable and attractive furniture.[20] Natural dyes have been extracted from mahogany bark, the *S. mahagoni* plant, and mahogany seed pods[15,21]; however, dye extraction from mahogany sawdust—a byproduct of mahogany wood sawing, abundantly available as bio-waste in sawmills—remains poorly documented.

Mordanting agents, or color adhesives, are also widely employed in the textile industry to bond dyes to fibers and achieve a vibrant appearance. Selective substances, chemical or metallic, oil-type, and natural are applied as mordants, with chemical mordants such as alum, chrome, copper, or iron being more commonly associated with synthetic dyes. Although chemical substances are more effective in improving color fastness and adhesion, safety, and versatility, they are associated with severe environmental hazards.[22] Today, sustainable natural or bio-mordants are rapidly substituting traditional chemical mordants to mitigate adverse environmental impacts, particularly to safeguard aquatic ecosystems. Natural mordants have demonstrated satisfactory performance in terms of biodegradability, non-toxicity, simplicity of processing, color fastness, and dye adsorption. While researchers have explored the performance of mordants extracted from natural sources such as microorganisms, plants, fungi, chitosan, and tannin, the extraction and application of natural mordants from locally available banana stems remains undocumented.

Therefore, this research study investigated the potential performance of a natural mordant extracted from banana stem and a natural dye extracted from mahogany sawdust on pretreated polyester fabric, focusing on environmental sustainability. Banana stems and mahogany sawdust are abundantly available bio-wastes generated from transplantation and mahogany timber sawing, respectively. Their efficient reuse as mordant and natural dye offers promising avenues to replace harmful chemicals and promote sustainable waste management. This article describes the performance of these natural mordants and dyes, including yield analysis through the employed extraction method, Fourier-transform infrared spectroscopy (FTIR) analysis results, color fastness and reflectance values, as well as rubbing and bursting strength data, compared to standard benchmarks. The outcomes reveal that polyester fabric dyed with mahogany sawdust dye exhibited excellent color fastness. FTIR spectroscopy confirmed the presence of identical dye elements on the fabric surface. Hence, the application of natural mordant from banana sap and natural dye acquired from mahogany sawdust may be effective substitutes for chemical substances for coloring polyester fabrics, contributing positively to environmental concerns.

2. Materials and methods

2.1. Extraction of natural dye

Mahogany is a natural dye-bearing tree and a well-known locally available timber in Bangladesh. The sawdust generated as a byproduct of sawing mahogany timber is commonly regarded as bio-waste. For natural dye extraction, mahogany sawdust was collected in an airtight bag from a reputable and large timber factory, Gazipur Sawmill, between January and April 2022. The collected sawdust was promptly transported to the laboratory and thoroughly washed with distilled water. The washed sawdust was sun-dried for 3 h. A total volume of 5L of distilled water was added to an aluminum foil-covered stainless-steel container containing 100 g of sun-dried sawdust. The dye component was extracted at 85°C for 55 min. Aluminum foil covering prevents solvent loss through evaporation. After optimum boiling, the solution was allowed to cool down for another 60 min. Subsequently, 0.45 μm filter papers were used to separate the extracted dyes from the sawdust wet mixture (Figure 1). Finally, the resulting liquid dye solution obtained through the aqueous extraction method[23] was preserved for further use in this study.

2.2. Extraction of natural mordanting agent

Banana sap was extracted from banana stems as a natural mordant, following previous research with modifications.[24] Fresh banana stems were collected from the garden (near Vanua, Gazipur City Corporation, Gazipur, Bangladesh) and washed thoroughly in the laboratory immediately after transportation. Fifty grams of washed stems were peeled off, thinly sliced, and kept in the container to be mixed with 100 mL of fresh water. The aqueous mixture of banana stems was boiled at 85°C for 50 min. After optimum boiling and proper cooling of the mixture, it was filtered with a 0.45 μm filter paper to squeeze the banana sap as a mordant.

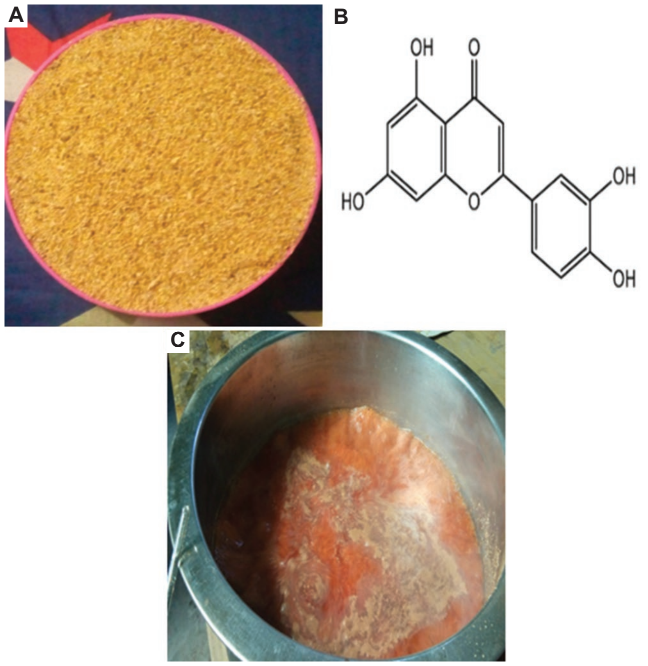

Figure 1. Images of mahogany sawdust and extracted natural dye. (A) Mahogany sawdust, (B) molecular structure of mahogany, and (C) extracted natural dye.

Conversely, 50 g of aloe vera was collected (Sreepur, Gazipur), and the gel was extracted from the leaf by boiling at 85°C with 100 mL of fresh water to be applied as a mordant. The purpose of the mordanting is to induce an electric charge in clothes to prepare them for the adsorption of dyes and the removal of dirt, grease, oil, or starch. In addition to providing better color and light fastness, mordants are essential for binding dyes to textiles and improving the quality of color absorption.

2.3. Pretreatment of polyester fabric

The grey fabric was bleached in an open bath for 60 min at 100°C, with a material-to-liquor ratio of 1:15. The bleaching process was performed by applying 5 g/L hydrogen peroxide, 5 g/L sodium hydroxide, 1 g/L sequestering agent, 1 g/L stabilizer, 1 g/L wetting agent, and 1 g/L peroxide killer.

After completing the bleaching process, the fabric was hot-washed using 1 g/L detergent. The experimental fabric was washed with cold water after 10 min of hot washing and then kept for air drying (Figure 2).

2.4. Mordanting of fabric samples

After the pretreatment process, the ready-to-dye polyester fabric was subjected to a 60-min mordanting procedure, applying banana sap natural mordant with a weight of 10% of fabric weight and 5 g/L mordanting agent with a 1:15 liquor ratio. The process temperature was maintained at 100°C. The cloth was washed in cold water after the mordanting procedure and then dried in a dryer.

2.5. Dyeing of fabric sample with natural dye extract from mahogany sawdust

After the mordanting procedure, the mordanted polyester fabric was dyed with the natural dye through an oscillating sample dyeing machine at 100°C for an hour in an aqueous solution and in a controlled environment. The dyeing procedure was performed in a closed bath. Figure 3 displays the schematic diagram of the dying process.

2.5.1. Dyeing procedure

The material-to-liquor ratio was 1:20 during the dying process. The required materials and parameters for dyeing the polyester fabric are mentioned in Table 1. First, 150 cc of mahogany dye liquor was used to color the polyester fabric at 100°C for 60 min without the use of any other chemicals or auxiliaries. Following dying, three hot washes were conducted with a soaping agent. Fabric weight was 10% of natural dye solution, 2 g/L of leveling agent, 1 g/L of wetting agent (DYNOPOL NHT), 1 g/L stabilizer silicon tetrachloride, 1 g/L peroxide killer (catalase tetrameric amino-terminal peroxidase), and 1 g/L of sequestering agent.

The dyed polyester fabric was washed in cold water after the coloring process and dried in a dryer. Then, two cold washes with regular water were performed, even though the shades were consistent. To remove water, samples were finally dried using a drying machine. Table 1 shows the materials and parameters required for the dyeing process.

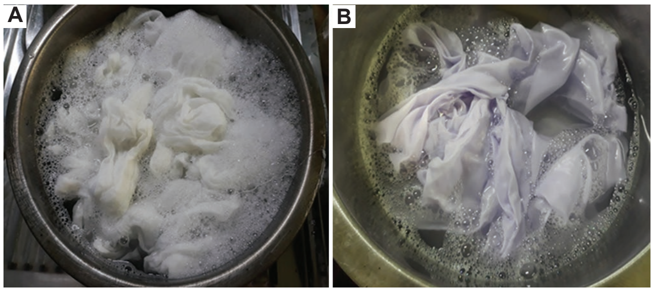

Figure 2. Pretreatment of the polyester fabric sample

2.6. Analytical procedure

2.6.1. Analysis of yield

Following the extraction procedure, the dye and mordant samples were filtered and placed in dried and weighed glass plates. The extracts were completely dehydrated in a hot air oven, and after complete cooling in a desiccator, the dishes were weighed again. The weight of the extracted dye and mordant was ascertained after obtaining a consistent weight by repeating drying, chilling, and weighing. The yield (%) of extracted dye and mordant was determined based on the raw mahogany sawdust used, applying the following formula in Equation 1:

$$\%\ \text{Yield of natural dye / mordant} = \frac{\text{Natural dye extracted from mahogany sawdust (g)}}{\%\ \text{weight of raw mahogany sawdust (g)}} \quad (1)$$

The yield (%) analysis outcome indicates the process efficiency.

2.6.2. FTIR analysis

After being appropriately diluted and well-prepared, dye samples from mahogany sawdust and dyed

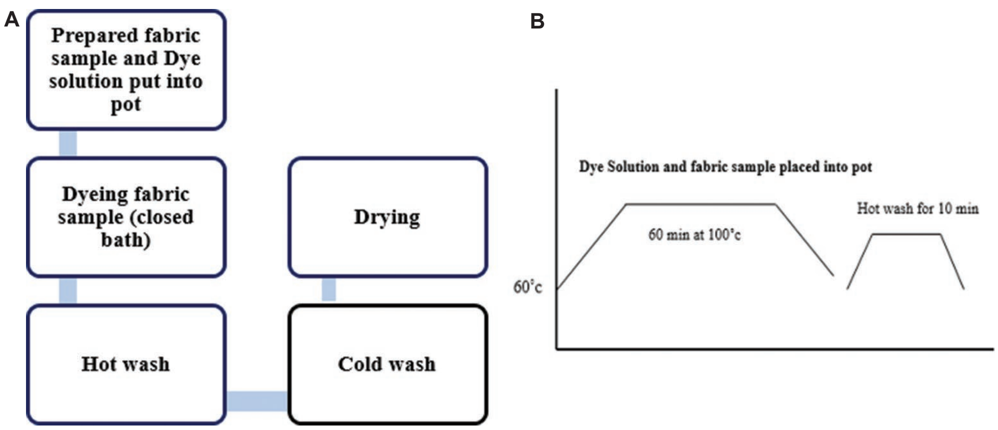

Figure 3. Flow chart of the dyeing process. (A) Dyeing of the fabric sample. (B) Temperature graph of the process.

Table 1. Parameters for the dyeing process

Parameters	Values
Reactive dye (cold brand)	1%, 0.6%
Soda ash	12 g/L
Glubar salt	40 g/L
Leveling agent	1 g/L
Wetting agent (DYNOPOL NHT)	1 g/L
Sequestering agent (COMPLEXANT-P)	1 g/L
Time	45 min
pH	11.5
Temperature	65°C
Material-to-liquor ratio	1:15

polyester fabric were analyzed using a Shimadzu-FTIR (Japan) spectrometer under a resolution of 4 cm^{-1} to determine the identical organic functional groups. A spectrum IR Tracer-100 Series FTIR (Shimadzu, Japan) outfitted with a diamond attenuated total reflection mechanism performed the FTIR analysis using a potassium bromide pellet within the standard range of 4,000–600 cm^{-1}, applying the Omic TM software tool (version 1.8 in tandem.[25] The ultimate outcome spectrum was acquired from analyzing at least three spectra for the sample. Transmittance peaks were recognized particularly from the dye sample and fabric, and the wavelength for transmittance measurement guided the choice of the average value of the corresponding color of the natural dye.

2.6.3. Measurement of reflectance using a spectrophotometer

The reflectance value of the dyed fabric is expressed in fractional form, that is, Kubelka-Munk value (K/S), which depends on the light absorption of the dyed fabric at the maximum absorption wavelength allied with the dyed fabric reflectance. However, dyed fabric valuation is accomplished by measuring color strength values (K/S) obtained through a spectrophotometer, which eventually determines the depth of color of a dyed fabric.[26] The spectrophotometer uses light transmittance or reflectance measurements to determine the color strength. A light source, a monochromator, and a detector are the three main components of a spectrophotometer. The reflectance of testing the polyester fabric was measured using a spectrophotometer at intervals of 400 nm to 700 nm.[23] A color system built by the International Commission on Illumination, called CIELAB, analyzed the study outcomes through the following empirical formula in Equations 2 and 3.

$$C^* = (a^{*2} + b^{*2})^{1/2} \quad (2)$$

$$H_{ab} = \tan^{-1}(b^*/a^*) \quad (3)$$

The values of a* and b* represent the color's orientation in Equations II and III. a* indicates red, −a* indicates green, b* indicates yellow, −b* indicates blue, and C* indicates the symbols for chroma. The hue angle (H_{ab}) (Equation III) is defined as the angle of the anticlockwise movement from the axis of the +a* direction, where +a* = 0°, +b* = 90°, −a*=180°, and −b* = 270°. Standard deviations were found as a* = 0.00114 and b* = 0.0057.

The Kubelka-Munk equation defines a relationship between spectral reflectance R (%) of the sample, its absorption (K) and scattering (S) characteristics, as follows (Equation 4):

$$K/S = (1-R)^2/2 \quad (4)$$

Color evaluation of the conditioned dyed samples was conducted instrumentally using a DataColor 650 spectrophotometer equipped with a 10° long area view observer under three distinct standard International Commission on Illumination illuminants (D65, TL83, and A). D65 represents the corrected color temperature of natural daylight of 6,500 K. The tri-band fluorescent light, represented by illuminant TL83, has a corrected color temperature of 3,000 K. Illuminant A, representing incandescent (tungsten halogen) light, has a corrected color temperature of 2,856 K. Two software programs, DataColor Tool (DCI-Tool; version 7.6.2 and DataColor Match (DCI-Match; version 5.2, were utilized to assess the measurement of various hues. The DataColor 650 spectrophotometer was used to measure the color strength (K/S value) and reflectance (R; %) of the colorant samples.[27]

2.6.4. Analysis of color fastness

Color fastness characteristics of the dyed samples were evaluated using several standard test methods, including fastness to rubbing, washing, drying, and perspiration. Using the ISO 105 C06:2010 technique, the GyroWash machine (James Heal, United Kingdom) was used to assess color fastness to washing. Test specimens measured 40 mm × 100 mm. The GyroWash operated on a 220 VAC electric supply with a 3 kW heater. It was equipped with six containers, each having a 550 mL capacity. The machine rotated at a speed of 40 rpm and included a timer adjustable from 0 to 99 min. The unit had a net weight of 50 kg. Rubbing (crocking) fastness was evaluated using a crockmeter (Dongguan Astrand Electronic Technology Co., Ltd, China) following ISO

105-X12, under both dry and wet conditions, with specimen dimensions of 140 mm × 50 mm.[28] Figure 4 displays the overall flow chart of this research study.

3. Results and discussion

3.1. Yield analysis of extracted natural dye

Extraction of natural dye from mahogany sawdust bio-waste was performed by applying water as a solvent. Results indicated a significant improvement in the yield (25%) of dye compared to other approaches, such as ultrasound or control methods.[24] The existing chemical constituents of plant materials and diverse levels of bonding of coloring substances to plant cell membranes are the key influential factors for the differences in dye yield and their solubility nature. The presence of the basic chromophore group with the hydroxyl group accelerates the dye extraction with aqueous solvents. Based on the yield performance, it can be declared that mahogany sawdust can be a potential biomass source for extracting natural dye, which eventually ensures better bio-waste management through reducing the volume of discarded waste.

This study effectively separated natural mordant from banana sap by implementing an eco-friendly aqueous solution process. Despite having adverse environmental impacts, chemical mordants such as copper sulfate, sodium alginate, along with some others, are widely used in the textile sector. This study, however, demonstrates that the extraction and implementation of banana sap mordant can be an effective alternative to chemicals.

3.2. Spectrum analysis of natural dye and dyed fabrics

Given that it is not possible to provide a similar infrared spectrum for two different compounds, FTIR analysis is commonly used for qualitative analysis of multiple materials. Infrared spectroscopy confirms the presence of certain functional groups and provides information on their relative quantities through peak intensities. FTIR analysis outcomes of this study confirmed the molecular structure of the mahogany sawdust extracted natural dye (Figure 5A). The FTIR analysis of reddish natural color exhibited a broader peak at 3,415 cm^{-1}, due to the absorbed wavelength being moderately reliant on bond strength, which indicates the stretching vibration of the hydroxyl group (–OH) of the benzene nucleus.[2] A smaller peak at 3,055 cm^{-1} indicated the aromaticity (C–H bond) for both methylene and methyl functional groups. Transmittance bands were also observed at 1,615 cm^{-1}, corresponding to the carbonyl group (>C=O bond), which is coupled with unsaturated alkane groups at wavelengths 1,548 cm^{-1}, 1,458 cm^{-1}, and 1,436 cm^{-1} (C=C). These identical FTIR wavelengths collectively indicate the presence of flavonoid structures.

Figures 5B and C display the FTIR analysis outcomes for bleached and banana sap mordanted mahogany sawdust-dyed polyester fabric, respectively. The FTIR spectra of 100% bleached polyester fabric showed a broader peak at 1,715 cm^{-1}, 1,409 cm^{-1}, and 967 cm^{-1}, which indicates the existence of C=O vibration, aromatic ring, and C=C stretching, respectively (Figure 5B).

Moreover, peaks at 1,331 cm^{-1} and 1,021 cm^{-1} indicated the presence of carboxylic ester and a secondary alcohol, respectively, while the peak at 869 cm^{-1} showed the substituted H atoms in benzene. A trivial variance was observed at the peaks of the FTIR spectra of the polyester fabric with banana sap mordant and natural dye (Figure 5C).

Broader and more intense peaks at 1,735 cm^{-1}, 1,380 cm^{-1}, 1,110 cm^{-1}, and 770 cm^{-1} were identified, indicating the presence of organic double bonds, that is, C=O vibration, C=C stretching, aliphatic, and N–H bending, respectively (Figure 5C).[29] These peaks eventually confirmed the presence of the phenolic group, which is vital for the reddish shade in the fabric while applying the natural dye. The existence of phenols in the following wavelengths is an indicator of the incidence of flavanols (catechins or carthamine) commonly available in plant-based natural colorants. A smaller peak was observed at 3,157 cm^{-1}, indicating the hydroxyl group (O–H stretched), which is likely to shift from the natural dye. Moreover, an insignificant shifting in the peaks at 1,331 cm^{-1}, 1,021 cm^{-1}, and 869 cm^{-1} was also observed due to the presence of natural mordant and mahogany sawdust extract dye.

3.3. Analysis of color strength

Table 2 displays the color strength (K/S) and reflectance values of dyed and mordanted polyester fabrics,

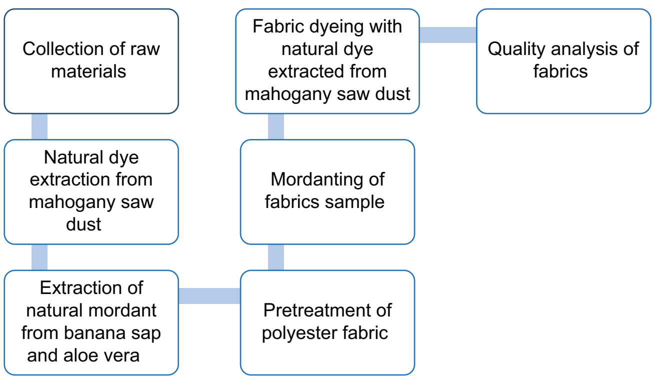

Figure 4. Flow diagram of the research methodology

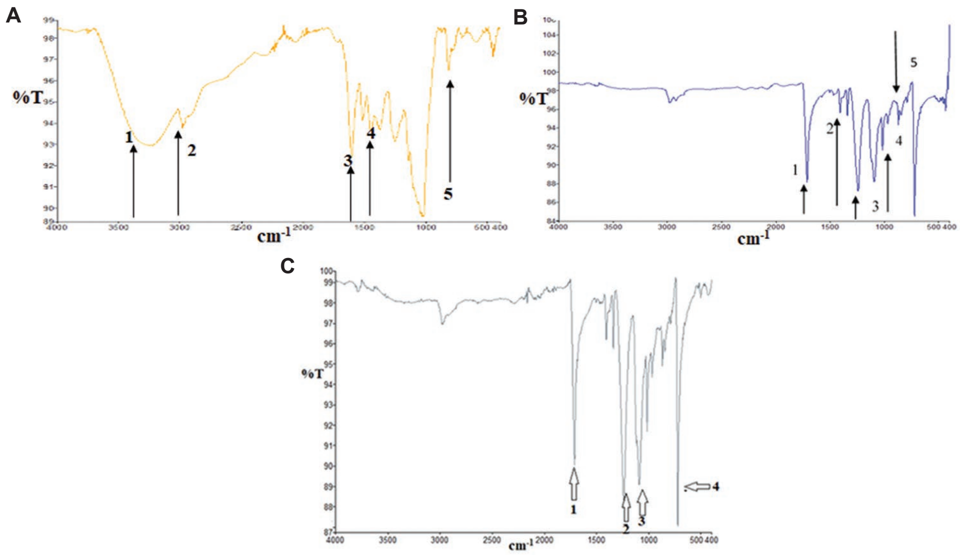

Figure 5. Fourier-transform infrared spectroscopy spectrum analysis. (A) Extracted dye, (B) 100% polyester scoured and bleached fabric, and (C) banana sap mordanted natural dyed polyester fabric.

Table 2. Assessment of color strength and reflectance values

Sample	Wavelength (nm)	Color strength (K/S value)	Reflectance value
Polyester only dye	530	0.95	28
Polyester mordant (banana sap)	530	1.11	28
Copper sulfate	510	1.25	15
Sodium alginate	530	0.8	30

compared to natural and chemical mordants. The affinity of the fabric for the dye material is a key factor influencing the color strength (K/S) of a dyed fabric. The color strength of dyed polyester fabric samples was evaluated using Equation IV. According to Table 2, a difference in the K/S values was observed. The table displays the lowest and highest color strength for sodium alginate and copper sulfate mordant fabric, respectively. However, the naturally dyed polyester fabric with banana sap mordant displayed a satisfactory color strength value of 1.11.

The interactions between fabrics and dye are the driving factor for color strength. Providing more functional groups through mordants accelerates the interactions between dye and fabric, ultimately improving the color strength.[23] In the present study, banana sap natural mordant enhanced the color strength of polyester fabric compared to the dyed fabric without mordant (0.95). However, copper sulfate displayed comparatively better color strength as it is proven that certain mordants with metal ions, such as copper sulfate, ferrous sulfate, and aluminum, are able to form robust interfaces among fabrics and dye. However, copper sulfate is a toxic heavy metal and severely harmful to aquatic life, while banana sap mordant is an eco-friendly, non-toxic natural mordant, which can be easily extracted from bio-waste. Hence, despite the lower K/S value of banana sap mordant compared to copper sulfate, it is considered satisfactory as the value is higher than sodium alginate. Optimization of the dyeing process may enhance the color strength of natural mordant. Figure 6 demonstrates the comparison of color strength among cotton and viscose fabric, while Figure 7 displays the images of polyester fabrics with copper sulfate, sodium alginate, and banana sap mordants.

The highest K/S value of the polyester fabric with banana sap mordant was 380–400 nm, while cotton and viscose fabrics did not show satisfactory color strength. The maximum color strength for cotton and viscose was found at 460 to 520 nm. Meanwhile, the polyester fabric showed a satisfactory appearance after applying the banana sap natural mordant in comparison with conventional copper sulfate and sodium alginate chemical mordants.

3.4. Color fastness to rubbing and washing

The colored fabric samples were evaluated for color fastness to rubbing and washing in accordance with

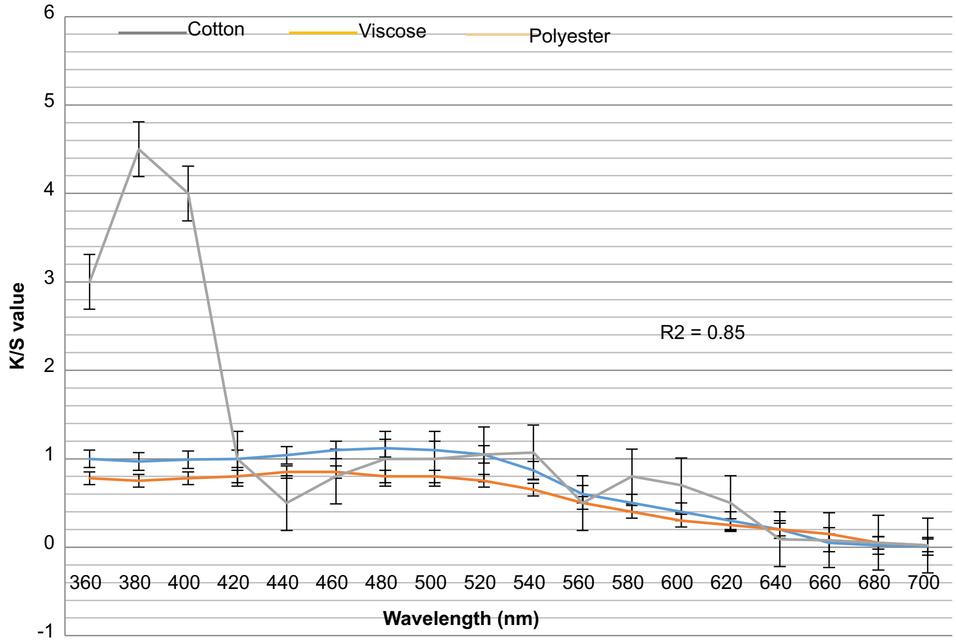

Figure 6. Comparison of color strength (K/S values) for dyed cotton, polyester, and viscose fabric.

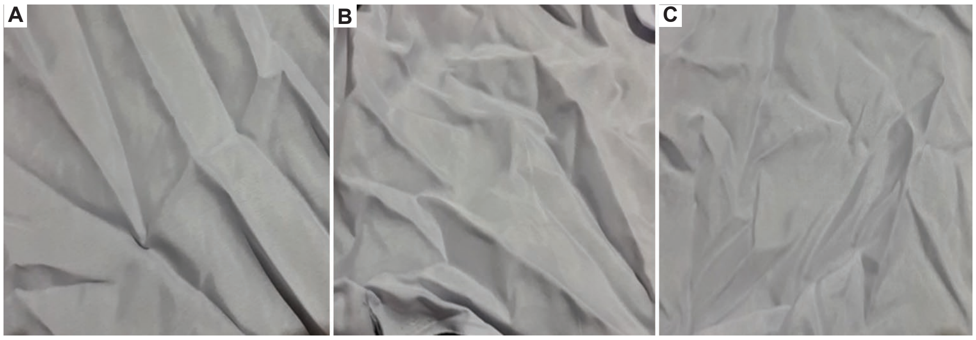

Figure 7. Polyester fabric with different mordants. (A) Sodium alginate mordant, (B) copper sulfate mordant, and (C) banana sap mordant.

ISO 105-X12:2016. A fastness tester applying the ISO 105C06:2006 method was implemented to assess the color fastness to washing. A multi-fiber adjacent fabric incorporating diacetate to wool was employed to illustrate the fastness to washing outcomes. Figure 8A and B display the comparison of polyester and viscose fabrics dyed with mahogany sawdust natural dye, while Tables 3 and 4 display the color fastness values to rubbing and washing, respectively. These tests were carried out through X and Y (length and width) directions using both dry and wet rubbing. Four hours were needed for conditioning the testing item and rubbing the samples. A couple of rubs were then applied to the specimen in each direction.

Evaluation of the rubbing cloth staining of adjacent fabrics and color change was performed by applying the

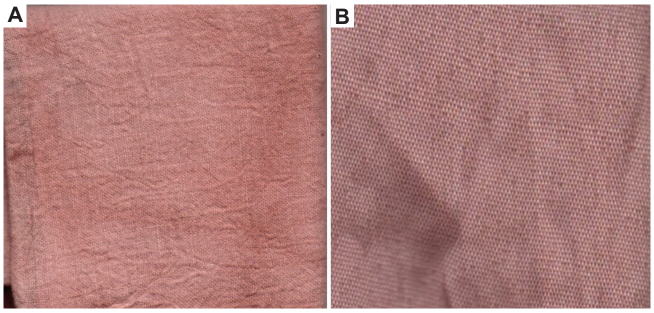

Figure 8. Mahogany sawdust dyed fabrics. (A) Polyester fabric and (B) viscose fabric.

grayscale in the optimum lighting in accordance with ISO 105 A04 and ISO 105 A05 regulations. A grading scale from 1 to 5 was applied to specify the outcomes regarding quality, where 1 represents very poor quality and 5 represents the highest quality. The outcomes clearly showed that banana sap mordant and mahogany sawdust extract dye particles correlate constructively with polyester fabric samples, whereas it was evident that fastness properties vary with the diverse properties and concentrations of mordants.

The assessments of banana sap mordanted polyester fabric with natural dye indicated that both color fastness to rubbing and color fastness to washing values were 4–5, revealing greater washing fastness and effectiveness of mahogany sawdust dye and banana sap mordant. A small shift in the shade was observed according to the scale in the dyed fabric with extracted dyes and mordants. However, the moist color change rubbing fastness rating was found to be comparatively insufficient compared to the dry color change rating for rubbing. The water-soluble dye functional group could be the influential factor for the differences in rubbing fastness.[23] The color fastness evaluation outcomes revealed that the mordanting of fabrics created a relatively higher color gravity since the mordanting process supplemented additional dye stains. However, the existence of ionized functional groups in natural dyes such as HCO_2 and –OH could be the accelerating factor as these groups become soluble in an aqueous solution. A comparative analysis regarding the color strength and fastness attributes among different dyed fabrics was performed to assess the effectiveness of the dyed polyester fabric with banana sap mordant and mahogany sawdust extract (Table 4).

Table 3. Color fastness to rubbing values of only dyed and banana sap mordant dyed polyester fabric

Sample	Dry condition	Wet condition
1	4–5	2–3
2	4–5	3–4
3	4–5	3–4
4	4–5	3–4
5	4–5	2–3

The dyeing effectiveness assessment displayed the firm color strength and the satisfactory range of fastness to wash attributes of the polyester fabric in comparison with only dyed cotton, wool, or acrylic samples. Therefore, the application of natural mordant and dye products from banana stems and mahogany sawdust bio-waste to dye polyester fabrics might be a sustainable and eco-friendly substitute for chemical substances in the emerging textile industry.

3.5. Bursting strength

Although bursting strength is not directly associated with the fabric coloring process, it is a significant consideration for the dyed fabric quality. The bursting strength of dyed fabric determines its consistency, durability under heat and chemical exposure, resistance to defects, ability to withstand stress, and overall post-dyeing performance of the final product. A higher initial bursting strength of fabrics ensures adequate strength after dyeing. The standard test to ascertain the bursting strength of textiles is the ASTM D3787. This technique is especially helpful for materials with a high degree of final elongation. Pounds per square inch (psi) or kilopascals (KPa) are commonly used as the unit of measurement for bursting strength. Table 5 displays the bursting strength of samples. This unit shows the amount of pressure that was exerted on the cloth at the rupture. The sample used in this study had a diameter of 45 mm, a test speed of 300 mm/min, a per load of 5 N, and a necessary test specimen size of 10 cm × 10 cm.

Depending on the types of cloth and its intended application, there might be wide variations in the permitted limits for bursting strength. For thin cloth, it is usually between 50 and 150 psi (345 and 1,034 KPa).[30]

Heavyweight materials sometimes surpass 300 psi (2,068 KPa), whereas medium-weight fabrics typically fall between 150 and 300 psi (1,034–2,068 KPa). The study outcomes revealed that fabric with natural mordant and dye can also gain satisfactory bursting strength compared to synthetic dyes, and this

Table 4. Color fastness to washing of only dyed fabric and banana Sap mordant dyed fabric

Sample no.	Color changing scale	Staining scale					
		Diacetate	Cotton	Polyamide	Polyester	Acrylic	Wool
1	4/5	5	4	5	5	5	4/5
2	4/5	5	4/5	5	5	4/5	4/5
3	4/5	5	4/5	5	5	5	5
4	4/5	5	4/5	5	5	5	5
5	4/5	5	4/5	5	5	5	5

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Table 5. Bursting strength of different samples

Sample no	Bursting strength (psi)
1	338.00
2	315.50
3	275.71
4	302.90
5	320.70
6	345.30

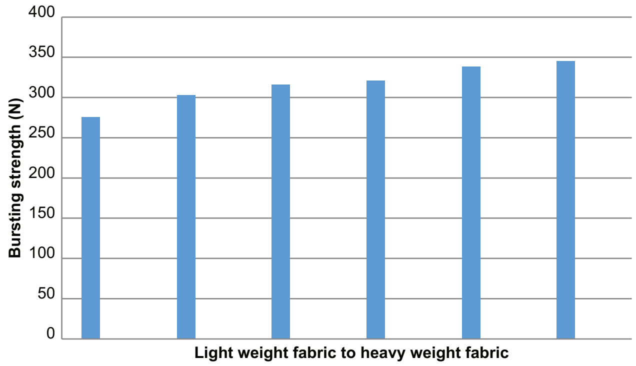

Figure 9. Bursting strength of samples with different weights

parameter is only related to the fabric weight (increases from lighter fabric to heavier fabric), regardless of its mordant or dye (Figure 9).

4. Conclusion

The scientific community increasingly favors natural sources and focuses on developing practical, affordable, and energy-saving approaches. This study investigated the performance of a polyester fabric combined with natural mordant and dye for the 1st time. The proposed method using mahogany sawdust for natural dye extraction achieved the above requirements, yielding 25% in a comparatively lower time. The extraction of natural mordant from locally available bio-waste, banana stems, is also a remarkable achievement of this study. A similar distinctive peak from the FTIR analysis at around 1,400 cm^{-1} indicated a sufficiently strong bonding between the dye and the fiber. Mahogany sawdust extract dyed samples displayed supreme fastness qualities for rubbing and washing. The K/S value of natural mordant fabric was almost similar to synthetic mordant, indicating a greater depth of shade. Shade uniformity was confirmed by closely aligned Color Measurement Committee Delta E and K/S values. Moreover, this study revealed satisfactory bursting strength of the tested fabric after applying natural mordant and dye, indicating the higher retaining capability of the fabric against stresses. Future work may explore the process optimization for natural dye as well as mordant extraction, and the antibacterial and anti-inflammatory properties of the fabric. This study, using locally available natural dye mordant, demonstrated promising results, highlighting significant potential for energy and cost savings in the textile sector while promoting environmental sustainability.

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Conflict of interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Investigation: All authors
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Availability of data

Data from this study are available on request from the corresponding author.

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