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Color Fastness and Tensile Properties of Cotton Fabric Dyed with Extract from *Albizia Procera* Sawdust

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Abstract: Natural dye was extracted from *Albizia procera* sawdust by an aqueous extraction process. The extracted dye was applied to cotton fabric, and the dyeing techniques were evaluated. The metallic mordants $FeSO_4$ and $CuSO_4$ were used as dye fixing agents in this dyeing process. Different parameters, such as dye concentration, dyeing temperature, dyeing time, type of mordant, mordant concentration, and dyeing method, were evaluated. It was observed that the dye exhaustion on cotton fabric significantly increased with $FeSO_4$ mordant over that with $CuSO_4$. The shades of the dyed fabric were found to be dark olive when the $FeSO_4$ mordant was used and brown when the $CuSO_4$ mordant was used. Pre-, meta-, and post-mordanting dyeing methods were used to dye the fabric, but the meta-mordanting method was the most suitable for dyeing fabric with sawdust extract. Fourier transform infrared (FTIR) spectroscopy was performed on the extracted dyes and the dyed cotton fabric. The color fastness and tensile properties of all the dyed fabrics were evaluated and compared. The fabric treated with $FeSO_4$ as a mordant showed better color fastness and color strength (*K/S*) than the fabric treated with $CuSO_4$ mordant. However, the fabric treated with $CuSO_4$ showed better tensile properties than the $FeSO_4$ treated fabric and the undyed fabric.

Keywords: Eco-friendly dyeing technique, Natural dye from *Albizia procera* sawdust, Ferrous sulfate mordant, Color fastness, Tensile properties of dyed fabric

Introduction

In recent years, research has shown that natural dyes are nontoxic, nonallergenic, noncarcinogenic, sustainable, and environmentally friendly. In contrast, synthetic dyes are suspected to release harmful chemicals that are toxic, cause allergic reactions, and are carcinogenic and harmful to human health and the environment; therefore, interest in the use of natural dyes has been growing rapidly due to the stringent environmental regulations against synthetic dyes imposed by many countries [1]. Natural dyes produce very uncommon, soothing, soft shades on fabrics, in contrast to synthetic dyes, which are widely available at an affordable price and produce a wide variety of colors; however, these synthetic dyes release hazardous chemicals into the environment during synthesis and application [2]. Vast amounts of waste and unfixed colorants from synthetic dyes pose serious health hazards and disturb the eco-balance of nature. Natural dyes are more eco-friendly than synthetic dyes, but dyeing with natural dyes has associated problems, such as lower extraction of natural colorants and poor fastness. Metallic salts are used as mordants to overcome these problems, as they produce different shades from the same dye and improve the fastness [3,4]. Nature has gifted us more than 500 dye-yielding plant species that can be used for the coloration of textiles by using the extracted coloring agents from various parts of the plants, including the roots, leaves, barks, flowers, and fruits [5]. The different colors and properties of natural dyes depend on their chemical structure and composition; these dyes mainly contain flavonoid, anthraquinone, and indigoid structures. The most common flavonoids, which exhibit a variety of yellow, brown, and green shades, are flavonols, flavanones, and anthocyanins [5,6]. Natural dyes from plants, animals, and minerals sources have been used for coloring textiles made from natural fibers such as silk, wool, and cotton [7]. Different types of metallic salt mordants from aluminum, iron, chromium, tin, zinc, potassium, aluminum, and copper are normally employed to obtain a high color yield, different color shades, and good fastness by forming coordination bonds with the dye molecules [7]. Potassium dichromate and alum mordants significantly improved the color fastness of silk fabrics dyed with used tea leaves, and the research results also showed that the post-mordanting method was found to result in better color fastness and visual properties [8]. Assessment of the antimicrobial effectiveness of naturally dyed fabrics showed reasonably good wash fastness; hence, natural dyes have practical potential for adding both antibacterial properties and vibrant colors to textiles for medical and other delicate uses [3]. Cotton fabric dyed with natural extracts of *Alkanna tinctoria* via a continuous dyeing technique produced a variety of green shades with different dyeing auxiliaries [9]. Walnut dye from bark can be used to dye cotton fabric using common

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mordants such as alum, $FeSO_4$, $CuSO_4$, and chrome to obtain a number of shades with good fastness properties [10]. Dyeing cotton fabric with substantive dyes extracted from the stem bark of *Albizia coriaria* without the use of mordants exhibited a very good wash fastness of 4-5, an excellent dry and wet rub fastness of 5, and a moderate light fastness of 4, and the dye yielded various color shades with different mordants [11].

A natural colorant from Arjun bark (*Terminalia arjuna*) was used to dye cotton using ultrasonic rays as an isolation tool, which is a cost-, time-, energy-, and labor-effective tool. Extracts of plants such as harmel (*Peganum harmala*), neem (*Azadirachta indica*), zeera (*Cuminum cyminum*), and elaichi (*Elettaria cardamomum*) have been employed as biomordants with Arjun bark extract [12]. Black carrot (*Daucus carota L.*) plant residues have been used as an ecofriendly and cost-effective source of natural dyes for textiles. Bio mordants, such as turmeric (*Curcuma longa L.)*, henna (*Lawsonia inermis L.*), pomegranate (*Punica granatum L.*) rind, golden shower plant (*Cassia fistula L.*) bark, and onion (*Allium cepa L.*) peel and chemical mordants such as tannic acid, copper sulfate, iron sulfate, and potassium dichromate were employed to improve color strength [13]. Environmentally friendly and time-effective microwave treatment was performed during the dyeing and extraction of natural color for silk fabric using biomordants (henna and turmeric) [14,15]. Bio-colors from durum (*Triticum durum Desf.*) and bread wheat (*Triticum aestivum L.*) husk and biomordants of pomegranate rind have been used as eco-friendly sources of natural dye for fabrics [16].

Many research projects on the development of a standard method of dyeing are ongoing; the aim is to develop a dyeing method that uses different types of mordants and a method of extracting natural dyes from various sources. To date, no research has been conducted on dyeing fabric with the colorant derived from *Albizia procera* (local name: shil koroi) sawdust extract, so this work was undertaken to study this method. Sawdust from *Albizia procera* is an abundant waste product in Bangladesh. In the present work, cotton fabric was dyed with *Albizia procera* sawdust extract. Appropriate dyeing techniques have been developed using different types of mordants and mordanting methods. The color fastness and tensile properties of all dyed and undyed fabrics were evaluated and are reported in this paper.

Experimental

Materials

Copper sulfate ($CuSO_4$) (min. 99 %), ferrous sulfate ($FeSO_4$) (99 %), sodium carbonate (Na_2CO_3) (≥99.8 %), and methanol (CH_3OH) (min. 99.9 %), were purchased from Merck (Germany). Sawdust from the *Albizia procera* plant was collected from a local sawmill located in Mirpur, Dhaka. Undyed 100 % cotton fabric (thread count of approximately 140) was collected from Shabana Textile (Dhaka).

Methods

Sawdust was dried in an oven at 60 °C. The moisture content was measured by calculating the weight of the sample before and after drying. The moisture content was found to be 9.06 %. The sample was stored in a polybag until analysis. The dyeing of the cotton fabric with the extract of *Albizia procera* sawdust can be divided into the following steps:

a) Extraction of dyes from *Albizia procera* sawdust
b) Scouring of cotton fabric before dyeing with extracted dye
c) Mordanting & Dyeing

Extraction of Dyes from Albizia Procera Sawdust

Dye was extracted from the sawdust through continuous aqueous and methanol extraction.

Aqueous Extraction

Aqueous extraction was performed with water as the solvent, which removed the dye extract when it was heated to a definite temperature. First, the prepared sample was weighed and placed in a beaker, and the beaker was filled with water. The sample and water ratio was 1:6, the temperature was 100 °C, and the time was 2.5 h. Continuous stirring was performed during the extraction process. After extraction, the water-soluble dye extract was filtered and then concentrated. The concentrated dye extract was dried in an oven at 60 °C. Dyeing of cotton fabric was performed using an aqueous dye extract.

Methanol Extraction

Hot extraction was performed with methanol as the solvent. Hot extraction was carried out in a Soxhlet apparatus. To start the Soxhlation process, sawdust (73 g) was placed in the Soxhlet, and then methanol (600 m*l*) was added. Extraction was performed for 72 h at 60 °C. The extracted dye was collected in a rotary evaporator, and the methanol was recovered. The extracted dye was dried in an oven at 60 °C. Methanol and aqueous extracted dyes were compared by FTIR spectroscopy.

Scouring of Cotton Fabric Before Dyeing with Extracted Dye

In the conventional scouring process, the cotton fabric was treated with 10 g/*l* sodium hydroxide, 5 g/*l* sodium carbonate, and 2 g/*l* wetting agent at boil for 2-3 h [17]. In this work, the scouring of cotton cloth was performed by washing it in a solution containing 4 g/*l* sodium carbonate and detergent (0.5 g) at 50 °C for 25 min. The material-to-liquor ratio was 1:40. After that, the scoured cotton was thoroughly washed with tap water and then soaked in clean water for 30 min. Then, the scoured material was dried at room temperature prior to dyeing and mordanting.

Dyeing and Mordanting

The traditional dyeing process was carried out in (i) a single bath process and (ii) a double bath process. The double bath process was carried out in one of two ways: (i) dyeing followed by mordanting (post-mordanting) or (ii) mordanting followed by dyeing (pre-mordanting). The single bath process involved the meta-mordanting process, where the fabric, mordant, and dye materials are immersed in the same bath [18]. In this work, a traditional method for dyeing and mordanting was followed [11,18]. Cotton cloth was accurately weighed and treated with different metal salts (the mordants were copper sulfate and ferrous sulfate). The percentages of dye and mordant were used to determine the weight of fabric (owf). The processes of mordanting were as follows:

1) Pre-mordanting
2) Post-mordanting, and
3) Meta-mordanting

Pre-mordanting

Pre-mordanting is a technique that involves application of the mordant prior to adding dye to the material. The fabrics were dipped into a mordant bath containing a mixture of ferrous sulfate. The total volume of the mordant solution was just sufficient for immersing the fabric. The temperature of the bath was gradually raised to 90 °C, and the mordanting was continued for 45 min. The fabric was then removed from the mordant bath, squeezed, and transferred unwashed into a dyeing bath containing dried *Albizia procera* sawdust extract in water. The fabric-to-dyeing solution ratio was maintained at 1:30, the temperature of the dyeing bath was gradually raised to 100 °C, the pH was 6.5-7, and the sample was dyed for 1 h.

Meta-mordanting

In meta-mordanting, the dye and mordant are combined first, and then the mixture is applied to the material that is to be dyed. In this study, the cotton fabric was placed in a cold dye bath containing a mixture of the dye material and mordant. The fabric-to-liquor ratio was maintained at 1:30, the temperature of the bath was gradually raised to 80 °C, the pH was 6.5-7, and the cotton fabric was dyed for 1 h with occasional shaking.

Post-mordanting

Post-mordanting involves dyeing the fabric first and then exposing the material to mordant as a final treatment. The fabric-to-dyeing solution ratio was maintained at 1:30, the temperature of the dyeing bath was gradually raised to 100 °C, the pH was 6-6.5, and the sample was dyed for 1 h with occasional shaking.

After dyeing, all the dyed materials were washed with cold water, dried at room temperature, and their fastness was tested.

Dyeing Technique

The dyeing parameters used in different types of dyeing techniques are presented in Tables 1-8 below:

In the meta-mordanting process, experiments showed that

Table 1. Meta-mordanting process for dyeing and mordanting

Dye	Mordant	Material:Liqour	Temp.	Time
4 %	2 %	1:30	80 °C	1 h

Table 2. Meta-mordanting process (varied concentrations)

Sl no.	Dye (owf)	Temp. (°C)	Time (h)	Shade	Code number of the sample
1	4 %	80	1	Light olive	S-1
2	6 %			Medium olive	S-2
3	8 %			Medium olive	S-3
4	10 %			Deep olive	S-4

Table 3. Meta-mordanting process (varied temperatures)

Sl no.	Dye (owf)	Temp. (°C)	Time (h)	Shade	Code number of the sample
1	4 %	60	1	Light olive	S-5
2		80		Light olive	S-6
3		100		Medium olive	S-7

Table 4. Meta-mordanting process (varied time)

Sl no.	Dye % (owf)	Temp. (°C)	Time (h)	Shade	Code number of the sample
1	4	80	1	Light olive	S-8
2			2	Light olive	S-9
3			3	Medium olive	S-10
4			4	Medium olive	S-11

Table 5. Pre-mordanting process with $FeSO_4$

Sl no.	Dye % (owf)	Temperature (°C)	Time (h)	Shade	Code number of the sample
1	10	80	1	Medium olive	S-12

Table 6. Pre-mordanting process (varied temperature) with $FeSO_4$

Sl no.	Dye % (owf)	Temperature (°C)	Time (h)	Shade	Code number of the sample
1	10	60	1	Light olive	S-13
2		80		Light olive	S-14
3		100		Medium olive	S-15

Table 7. Post-mordanting process with $FeSO_4$

Sl no.	Dye % (owf)	Temperature (°C)	Time (h)	Shade	Code number of the sample
1	10	80	1	Medium olive	S-16

Table 8. Post-mordanting process (taking temperature as a variable) with $FeSO_4$

Sl no.	Dye % (owf)	Temperature (°C)	Time (h)	Shade	Code number of the sample
1		60		Light olive	S-17
2	10	80	1	Light olive	S-18
3		100		Medium olive	S-19

among all variables, 10 % owf of the dye concentration resulted in the best shade of color. Therefore, among the pre-, meta-, and post-mordanting processes, the meta-mordanting process was selected and applied. The experiments and observations are given below.

Color Fastness Test of Dyed Cotton Fabric

Color fastness tests were conducted for each dyed fabric, and the methods are provided below.

Washing Fastness

The color fastness of dyed cotton fabrics during washing was measured as per ISO 105-C03:1989-12-15, and the results were recorded.

Light Fastness

The lightfastness of dyed cotton fabrics was determined by a Light Fastness Tester, 200 Trufade, James Heal, UK as per ISO 105-B02:1994-09-15, and the results were recorded.

Perspiration Fastness

Color fastness of the dyed cotton fabrics to perspiration was determined by a persiprometer and an incubator (HX 30, Carbolite Ltd., UK) as per ISO 105-E04:1994-09-15, and the results were recorded.

Rubbing Fastness

The dyed cotton fabrics were rubbed briskly against a white cloth/undyed cotton fabric, and any transfer of color was recorded [18].

Evaluation of the Color Strength (*K/S*) of Dyed Cotton Fabric

The color strength (*K/S*), CIE$L^*a^*b^*$ and C^* h values of the selected dyed fabrics were evaluated based on the color fastness results using a Datacolor 850 spectrophotometer (USA).

FTIR Spectroscopy

FTIR spectra of the natural dye extracted from *Albizia procera* sawdust were recorded on an FT-IR/NIR spectrometer (Frontier, PerkinElmer, USA). FTIR spectra of both the aqueous and methanol-extracted dyes and the dyed cotton fabric were obtained and investigated. A very small powdered sample was mixed thoroughly with a small amount of dried potassium bromide powder in a small agate mortar and ground with a pestle. The mixture was pressed into a die of specific dimensions. Pellets were made by applying vacuum pressure. FTIR spectra showing the absorbance data were obtained.

Tensile Properties of Dyed and Undyed Cotton Fabric

Tensile tests were performed on a computerized universal testing machine (Model-Titan 5, Brand-James Heal, UK) for all dyed and undyed specimens. Tests were performed according to ASTM D 5035-06 (Standard test method for breaking force and elongation of textile fabrics). The speed was 300 mm/min. The length and width of the specimens were 150 mm and 25 mm, respectively. The jaw separation was 75 mm. The conditioning temperature and relative humidity of the fabric specimens were 21±1 °C and 65±2 %, respectively, in the conditioning room, but the testing temperature and relative humidity were 25.1 °C and 56 %, respectively, in the testing room. Six to seven specimens of each composition were tested, and the average values were calculated from a maximum of five values. The load vs. elongation curves were obtained from the instrument.

Results and Discussion

Dyeing Method and Visual Inspection of Dyed Cotton Fabric

In this work, natural dye was extracted from *Albizia procera* sawdust and then applied to dye colorless scoured cotton fabric using $FeSO_4$ and $CuSO_4$ as a mordant. The yield of dye obtained through aqueous extraction was approximately 2.72 %, and that obtained through methanol extraction was approximately 2.81 %. Aqueous extracted dye was used to establish the dyeing technique. Pre-, post-, and meta-mordanting processes were applied, and the parameters of the dyeing techniques were selected. The color fastness, color strength, and tensile properties of the dyed fabrics were investigated and reported.

According to the experimental results, the meta-mordanted samples had a better depth of shade than the other two samples. Mordant $FeSO_4$ gives good color under all conditions of the cotton dyeing techniques. However, mordant $CuSO_4$ gives good color under selected dyeing conditions only. Different types of dyeing experiments were performed with variations of dyeing parameters to obtain good results. The results showed that higher concentrations of dye, temperatures, and dyeing times yielded the darker color shades and improved color fastness.

Selected Conditions for Dyeing

Different types of experiments with different variable conditions were performed, and the selected conditions for dyeing, the shade and images of dyed fabrics are presented in Table 9.

Color Fastness of Dyed Cotton Fabric Using Natural Dye Extracted from Sawdust

Tables 2-8 show that medium and deep olive-colored

Table 9. Selected dyeing conditions for the meta-mordanting process with $FeSO_4$ and $CuSO_4$

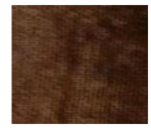
Sl no.	Mordant	Dye % (owf)	Mordant % (owf)	Temperature (°C)	Time (h)	Shade	Code number and image of the sample
1	Ferrous sulfate ($FeSO_4$)	10	8	100	1	Very deep olive	S-20 
2	Copper sulfate ($CuSO_4$)	10	8	100	1	Very deep brown	S-21 

Table 10. Color fastness of the dyed samples

Code no. of the sample	Wash fastness		Lightfastness	Perspiration		Rubbing
	Color change	Color staining		Acidic	Alkali	
S-4	4-5	4-5	5	4-5	4-5	5
S-7	4	4	4-5	4-5	4-5	4-5
S-11	4	4	4-5	4-5	4-5	4-5
S-12	4	3-4	4-5	4-5	4-5	4-5
S-15	4	3-4	4-5	4-5	4-5	4-5
S-16	4	3-4	4-5	4-5	4-5	5
S-19	4	3-4	4-5	4-5	4-5	5
S-20	5	5	5	5	5	5
S-21	5	4-5	5	5	5	5

fabric were obtained for samples S-4, S-7, S-11, S-12, S-15, S-16, and S-19, respectively. Table 9 also shows that very deep olive and very deep brown fabrics were obtained from samples S-20 and S-21. Therefore, these 9 samples (S-4, S-7, S-11, S-12, S-15, S-16, S-19, S-20, and S-21) were taken to analyze the color fastness properties, and the obtained results are presented in Table 10. It is evident from the experimental results presented in Table 10 that very good dyeing of cotton fabrics is achieved with natural dye extracted from *Aibizia procera* sawdust. Table 10 shows that the fastness grades of samples S-4, S-20, and S-21 are better than those of all other samples. Table 10 also shows that cotton fabric meta-mordanted with ferrous sulfate showed better results for washing fastness, lightfastness, perspiration fastness, and rubbing fastness. Similar results were observed when ferrous sulfate was used as the mordant for lyocell fabric dyed with natural colorants, and there was no change in color and no color fading [19].

Color Strength of Dyed Cotton Fabric Using Natural Dye Extracted from Sawdust

The color developed and color strength (*K/S*) value, CIE $L^*a^*b^*$ and C^* *h* values on the dyed fabrics were evaluated for selected dyed samples (S-4, S-20 and S-21) from the color fastness (Table 10) results. The color strength (*K/S*), CIE $L^*a^*b^*$ and C^* *h* values are presented in Table 11, which shows that the color strength (*K/S*) value was good for fabric dyed with ferrous sulfate mordant by the meta-mordanting process. The higher color strength values indicate strong bonds of applied dyeing chemicals and fabric, and the low color strength might be due to the aggregation of dye molecules and mordant onto cotton fabric [13]. The interactions of the dye, mordant and fabric are shown in

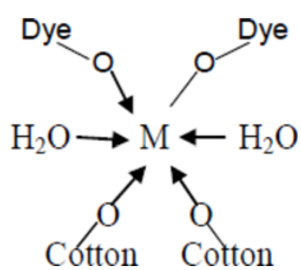


Figure 1. Interaction of dye, mordant and cotton fabric.

Table 11. Color strength (*K/S*), CIE$L^*a^*b^*$ and C^*h values of color fast dyed samples

Code no. of the sample	*K/S* at 400 nm	C^*	h	CIE L^* a^* b^* system		
				L^*	a^*	b^*
S-20	11.04	25.18	53.69	39.74	14.91	20.29
S-21	8.98	13.20	65.02	39.35	5.57	11.96
S-4	5.23	8.93	75.52	45.23	2.23	8.64

Figure 1. The metal mordants formed coordination bonds with the dye molecules [7]. Figure 1 shows that the mordant (M) can form a complex with the hydroxyl groups of the extracted dyes and cotton fabrics. Similar results were reported for the dyeing of wool with metal mordant and dye extracted from *Rheum emodi* root [20].

FTIR Spectroscopy of Extracted Dye of Sawdust and Dyed Cotton Fabric

The FTIR spectra of methanol and aqueous extracted dye of *Albizia procera* sawdust and cotton fabric dyed by aqueous extract of sawdust are shown in Figures 2, 3, and 4, respectively. The peak assignments of the absorption bands corresponding to various groups are summarized in Table 12. The dye extracted with methanol and that extracted with water had similar FTIR spectra.

Figures 2-4 show that the dyed cotton fabric (Figure 4) and the dye extracted from *Albizia procera* saw dust (Figures 2, 3) had the same functional groups. The peak assignments of the absorption bands corresponding to various groups are summarized in Table 12. Dye extracted from argy wormwood with ethanol showed similar FTIR spectra, which indicated the presence of flavonoids, eupatilin, and chlorophyll in the extracts that imparted colors to the dyed cotton fabrics [21]. The FTIR spectra show characteristic bands of the aldehyde group in the region of 2931-2850 cm^{-1} due to C-H stretching and in the region near 1640-1524 cm^{-1} due to C=C bending, which conjugates with the -C=O- stretch of flavonoid groups [21]. The IR spectrum shows characteristic bands at 3420-3423 cm^{-1} due to the -OH stretching vibration of polyhydroxyl groups (polyphenols) and methylol groups of the phenolic structures such as flavonoids [21]. Isolated color from *Albizia lebbeck* showed similar absorbance bands for hydroxyl (O-H) and aromatic (C=C) groups [22]. It is evident that the extracted *Albizia procera* saw dust dye contains flavonoids, chlorophyll, and polyphenols. Therefore, we can assume that *Albizia procera* contains components that are responsible for color.

Tensile Properties of Dyed and Undyed Cotton Fabric

A total of 12 experiments were carried out to measure the breaking force (N) and extension (%) of different types of fabrics to investigate the tensile properties of the dyed and undyed cotton fabric. For these tests, the appropriate ASTM strip method was followed. The load vs. elongation curves

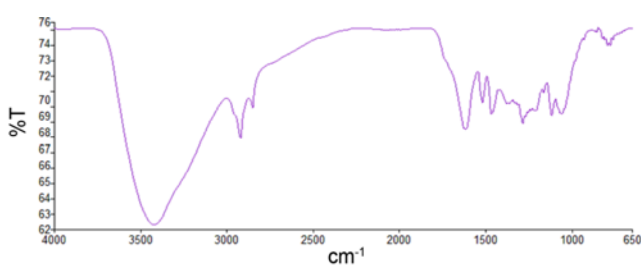


Figure 2. FTIR spectrum of dye extracted from *Albizia procera* sawdust with methanol.

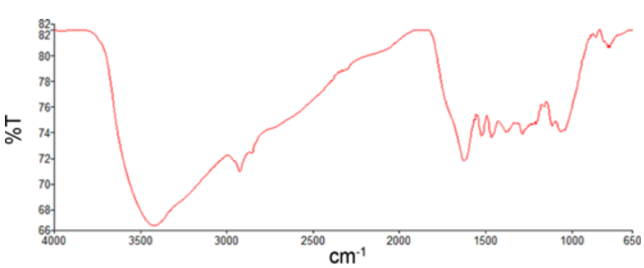


Figure 3. FTIR spectrum of dye extracted from *Albizia procera* sawdust with water.

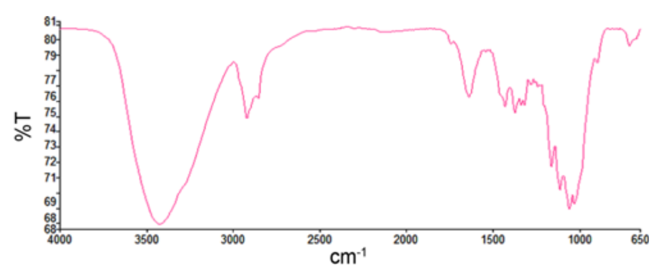


Figure 4. FTIR spectrum of cotton fabric dyed with *Albizia procera* sawdust extract.

Table 12. FTIR data of dye extracted from *Albizia procera* sawdust and dyed cotton fabric (Figures 2-4)

Position (cm^{-1})	Assignment	References
3420-3423	Alcohol/phenol O-H stretch	21, 22
2931-2850	Alkyl C-H stretch	21
1640-1524	Aromatic C=C bending	21, 22
1285-1286	Carboxylic acids (C-O bonds)	21
1115-1117	Fluoroalkanes (C-X bonds)	23, 24

Table 13. Breaking force and extension of dyed and undyed cotton fabric

Sl. no.	Code no. of the sample	Dyeing process of fabric	Breaking force (N)	Extension (%)
1	-	Undyed cotton fabric	177.03	15.70
2	S-20	Cotton fabric dyed with 10 % extracted dye using $FeSO_4$ as the mordant in the meta-mordanting process	159.70	19.02
3	S-21	Cotton fabric dyed with 10 % extracted dye using $CuSO_4$ as the mordant in the meta-mordanting process	199.02	16.96
4	S-19	Cotton fabric dyed with 10 % extracted dye using $FeSO_4$ as the mordant in the post-mordanting process	189.13	24.61
5	S-15	Cotton fabric dyed with 10 % extracted dye using $FeSO_4$ as the mordant in the pre-mordanting process	170.47	18.30
6	S-1	Cotton fabric dyed with 4 % extracted dye using $FeSO_4$ as the mordant in the meta-mordanting process	155.59	15.93
7	S-2	Cotton fabric dyed with 6 % extracted dye using $FeSO_4$ as the mordant in the meta-mordanting process	148.19	22.64
8	S-3	Cotton fabric dyed with 8 % extracted dye using $FeSO_4$ as the mordant in the meta-mordanting process	169.53	27.06
9	S-5	Cotton fabric dyed with 4 % extracted dye at 60 °C using $FeSO_4$ as the mordant in the meta-mordanting process	169.67	20.74
10	S-7	Cotton fabric dyed with 4 % extracted dye at 100 °C using $FeSO_4$ as the mordant in the meta-mordanting process	177.01	21.08
11	S-9	Cotton fabric dyed with 4 % extracted dye for 2 h using $FeSO_4$ as the mordant in the meta-mordanting process	161.69	19.97
12	S-10	Cotton fabric dyed with 4 % extracted dye for 3 h using $FeSO_4$ as the mordant in the meta-mordanting process	167.11	27.41

were obtained from the instrument for all fabrics. The results obtained from the instrument are provided in Table 13.

Table 13 shows that the maximum force applied to undyed cotton fabric was 177.03 N, and the extension was 15.70 %. Cotton fabric dyed with 10 % extracted dye mordanted with $FeSO_4$ via meta-mordanting experienced a maximum force is 159.70 N, and its extension was 19.02 %. It was observed that the maximum force required to break the specimen of undyed cotton fabric is higher than that of dyed cotton fabric. The cotton fabric lost its strength when dyed with this dyeing method and when $FeSO_4$ was used as the mordant.

Table 13 also shows that the maximum breaking force of the fabric was 199.02 N when $CuSO_4$ was used as the mordant; this breaking force is higher than that of undyed cotton fabric. The tensile properties of other post- and pre mordanted cotton fabrics were also determined under the abovementioned conditions, and it was found that although the post-mordanting process results in a lower color fastness than the meta-mordanting process, it leads to better tensile properties. The maximum breaking force increased to 189 N when post-mordanting was applied, and this value is higher than that of undyed cotton. The cotton fabric gained strength when dyed with this dyeing method when $FeSO_4$ was used as the mordant and a post-mordanting process was applied.

The breaking force of the cotton fabric dyed with 10 % extracted dye pre-mordanted with $FeSO_4$ was lower than that of the undyed cotton fabric. The cotton fabric lost its strength when dyed with this dyeing method. According to Shahnaz *et al*. [9], most of the dyeing formulas that include natural extracts of *Alkanna tinctoria* lower the tensile strength of dyed cotton samples. However, an increase in strength was also observed for some of the dye formulas. Therefore, dyeing cotton fabric with the extracted *Albizia procera* sawdust dye decreases the fabric strength when $FeSO_4$ is used as the mordant, but it increases the fabric strength when $CuSO_4$ is used as the mordant. Their study also found that the application of post-mordanting using $FeSO_4$ improves the tensile properties of the dyed fabric. All other dyeing experiments on cotton fabrics resulted in decreased tensile strength of the dyed cotton fabric compared with that of the undyed cotton fabric, as presented in Table 13. Table 13 shows that the tensile properties of the dyed cotton fabrics did not increase compared with those of the undyed cotton fabric. Therefore, it is clear from the tensile properties of all of these dyed and undyed fabrics that all post-mordanting dyeing methods and only meta-mordanting dyeing with $CuSO_4$ improved the tensile properties of the dyed fabrics compared with those of the undyed fabric.

Conclusion

Dyeing cotton fabric with an aqueous extract of *Albizia* *procera* sawdust yields shades of olive and brown. The olive shades were obtained when ferrous sulfate was used as the mordant, and brown shades were obtained when copper sulfate was used as the mordant. The yield of dye from the aqueous extraction of *Albizia procera* sawdust was 2.72 %. FTIR spectroscopy of the extracted dye showed characteristic bands of aldehyde groups and polyhydroxyl groups (polyphenols), which indicates that the extracted dye of *Albizia procera* saw dust contains flavonoids, chlorophyll, and polyphenols. It was observed that the fastness of the dyed fabric samples improved with the application of mordants. Among the different mordanting methods, the samples meta-mordanted with ferrous sulfate appeared to have high color fastness and color strength (*K/S*). The fastness of the pre- and post-mordanted samples was found to be good. It was observed that ferrous sulfate was more suitable than copper sulfate under all conditions. However, with the application of 8 % mordant owf, copper sulfate was also found to be suitable for color fastness. It was also found that the color fastness of the dyed fabrics increases with increasing time and temperature. The FTIR spectra of the dyed cotton fabric indicated the presence of characteristic bands that were similar to those in the FTIR spectrum of the dye extracted from *Albizia procera* sawdust. The tensile strength of the dyed cotton fabric was lower than that of the undyed cotton fabric when ferrous sulfate was used as the mordant in the dyeing process. When copper sulfate was used as the mordant, the tensile strength of the dyed cotton fabric was higher than that of the undyed cotton fabric. Synthetic dyes and pigments are harmful to human health and the environment, but dyeing textile fabric with natural dyes is safe and eco-friendly. It can be concluded that textile grade dye was obtained from the natural waste material of *Albizia procera* sawdust extract, and by applying this dye on cotton fabric, an easy, cost-effective, safe and eco-friendly dyeing technique was established through this research.

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Conflicts of Interest

There are no conflicts of interest to disclose.

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