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Extraction, Application and Characterization of Dyed Fabric from *Ptericarpus erinaceous*

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Abstract

Growing environmental and health concerns regarding synthetic dyes have renewed interest in natural colorants for textile applications. This study aimed to extract dye from the stem of *Pterocarpus erinaceus*, apply it to cotton fabric, and characterize the resulting dyed material. The dye was extracted through maceration, producing a yield of 16%. The extract was initially applied without a mordant and subsequently using pre-mordanting, simultaneous mordanting, and post-mordanting techniques with $CuSO_4$, $KAl(SO_4)_2 \cdot 12H_2O$, and $FeSO_4 \cdot 7H_2O$. Post-mordanting produced the most attractive shades, including dark brown, brown, and gray, with dye-absorption values of 0.07, 0.07, and 0.05 for $CuSO_4$, $KAl(SO_4)_2 \cdot 12H_2O$, and $FeSO_4 \cdot 7H_2O$, respectively. The dyed fabrics exhibited moderate-to-good color fastness to washing, rubbing, and light, with ratings ranging from 3.0 to 5.0; mordanted samples generally demonstrated superior performance. Scanning electron microscopy and thermogravimetric analysis further indicated a strong relationship between the surface morphology and thermal behavior of the dyed cotton fabrics. These findings demonstrate the potential of *P. erinaceus* stem extract as a natural dye

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for cotton textiles and provide a basis for further research evaluating natural mordants as alternatives in sustainable textile coloration.

Keywords: Color Fastness; Cotton Fabric; Mordanting; Natural Dye; *Pterocarpus erinaceus*

INTRODUCTION

A meaningful glimpse into our reality is provided by color. They provide the most appealing appearance to commonplace items like paper, plastics, paints, textiles, and food. According to Kumar et al. (2021) A colorful substance with an affinity for the substrate it is applied on is called a dye. People are aware of the environmental effects of synthetic dyes because of the significant health dangers linked to their use in the textile sector. Consequently, the textile industry has shifted from using synthetic colors to using natural ones, particularly those derived from plants (Thadepalli and Roy, 2022).

Natural dyes are substances derived from plants and animals that give food, cosmetics, medications, hair, fur, and polymers color. According to Osabohien (2009), Various items are dyed to enhance their appearance and attract buyers. Natural dyes can be derived from botanical components such as flowers, roots, leaves, bark, insect excretions, and minerals. Although dyes are abundant in nature, the processes used to make them can also give them varied shapes and uses (Nwonye and Ezema 2017).

To improve their appearance and draw in customers, a variety of things are dyed. Plant parts like flowers, roots, leaves, bark, insect secretions, and minerals can all be used to create natural dyes. Even while dyes are found in large quantities in nature, their manufacturing procedures can provide them a variety of forms and applications (Thakker and Sun 2021). The demand for natural dyes is rising since they are less dangerous than their synthetic counterparts. Synthetic colors are dangerous, carcinogenic, and possibly lethal. It requires an extensive duration to decompose when released into the natural environment (Ismail et al., 2019).

Accorrding to Ayele et al. (2020) indicated that dyes obtain from natural sources have high degree of color fastness and can provide a diverse array of visually appealing hues. As a result, research is being done worldwide on the application of plant dye in the textile sector and the resurgence of natural dye as a substantial alternative to synthetic dyes (Slama et al., 2021)

There are thousands of plants and animals which contain colourants that can be used as natural dyes. *Ptericarpus erinaceous* as known as Afican rosewood belonging to the family of Legum or papilionoideae. The stem bark is scaly and dark grey. Its blossoms are yellow. There are winged outgrowths on the fruits. The kidney-shaped to oblong seed is typically curved and narrowed close to the minute hilum. The bark and resin are used as an astringent for severe diarrhea and dysentery, as well as for urethral discharge. As a cough cure, the grated root is combined with tobacco and smoked through a pipe (Orwa, 2009). The trunk and root bark are used in malnutrition, debility, pregnancy and anaemia (Nadro & Modibbo, 2014). This present study is therefore focused on the extraction, application and characterization of dyed fabric from *Ptericarpus erinaceous*.

Plate 1: *Ptericarpus erinaceous*

Sampling and Sample Preparation: The stem bark sample of *Ptericarpus erinaceous* was gathered from Noma village, Wukari Local Government, Taraba State. Before being extracted, the sample was dried at room temperature and pulverized with a metallic mortar and pestle into a powder.

Extraction: After 200 g of the powdered material has been weighed into a beaker and to this, 500 mL of absolute methanol was added to a container. Following a week of standing for efficient extraction, the mixture was filtered, the filtrate was dried off by evaporation, and the extract was gathered, weighed and pulverized with a metallic mortar and pestle into a powder (Abuh et al.,2022).

Dyeing The Cotton Fabric: The fabric was submerged in the dye solution until the color has been absorbed after the dye bath has been gently heated. The dyeing process began at 100^{O}C and ran for one hour. Following the dyeing process, the materials was taken out of the dye bath and given ten minutes to air oxidize. The dye fabric was then rinsed with cold water to get rid of any loose dye particles that might have stuck to the dyed materials' surface. The dyed cotton fabric was allowed to air dry at room temperature (Dass et al.,2016).

Pre-Mordanting: A 3% solution of each of the chosen mordants was made in water. In the mordant solution, the cotton cloth was heated to 100°C for 60 minutes. The cotton fabric won't be washed; it was dried. Now, the pre-mordanted cotton fabric was dried and put in the dyebath to begin the dying process (Moniruzzaman et al.,2018).

Simultaneous Mordanting: The dye solution was prepared and also 3% of each of the chosen mordants. The dry cotton fabric was submerged in the solution of the dyed mordant mix and allowed to simmer for 60 minutes at 100°C. After being colored, the cotton cloth was taken out and allowed to cool at room temperature (Moniruzzaman et al.,2018).

Post Mordanting: The aforementioned dyeing procedure was applied to the cloth and nylon. The cotton fabric was dried after dying. After dissolving 3% of each of the chosen mordants in water, the dyed cotton fabric was mordanted in the solution for 60 minutes at 100°C. After being colored, the cotton cloth was taken out and allowed to cool at room temperature (Moniruzzaman et al.,2018).

Determination of Color Fastness of the Dyed Fabric

Color Fastness to Washing: After the dyed cotton fabric was cut (4 by 2 cm), the undyed cotton fabric was cut (4 by 2 cm) and machine-stitched to form a single piece of fabric. After accurately measuring 100 milliliters of water with a measuring cylinder, 3 grams of detergent (Viva Plus) was weighed using a weighing balance and dissolved in the water. Following ten minutes of vigorous stirring in the detergent solution, the stitched cotton cloth was rinsed and left to air dry at room temperature (Joshua et al.,2023).

Color Fastness to Rubbing: First, 4 by 2 cm of the dyed cotton fabric was cut, and then 4 by 2 cm of the undyed white fabric for both dry and wet rubbing. The undyed cotton fabric was rubbed for ten minutes on the dyed cotton fabric's surface in order to perform dry rubbing. Wet rubbing involved soaking the undyed cotton cloth in water and then rubbing it against the dyed cotton fabric for ten minutes (Joshua et al.,2023).

Color Fastness to Light: The dyed fabric was expose to sun light for two days. The dyed fabric was allowed for 10 hours per day in the sun. Following exposure to sunlight, the cotton cloth that had been dyed was inspected (Ezeokonkwo et al.,2018).

Characterization of the dyed Cotton fabric

Scanning Electron Microscope (SEM): A Quanta 250, FEI, Netherlands Scanning Electron Microscope was used to examine the size and shape of dyed cotton fabric at various stages. Gold was sputtered onto the colored cotton fabric using a plasma sputtering machine under vacuum at 20 mA for two minutes after it has been placed on aluminum stubs using conductive carbon tape. Next, the cotton fabric that has been dyed was examined and photographed (Cheran et al.,2022).

Thermogravimetric Analysis (TGA): The thermal properties of dyed cotton fabric was analyzed using thermogravimetric analyzer model Shimadzu TGA-50H (El-Zaher et al.,2021).

RESULTS AND DISCUSION

Extraction of Dye from *Ptericarpus erinaceous*

Table 1: Extraction of dye from *Ptericarpus erinaceous*

Extraction method	Sample	Weight of sample before extraction(g)	Weight of sample after extraction (g)	Amount of Dye extracted (g)	Percentage yield of Dye extract (%)
Maceration	Ptericarpus erinaceous	200	167	32	16

Table 1 shows the extraction of dye from *Ptericarpus erinaceous* via maceration method of extraction. 200 g each of the sample was use to carry out this extraction. The percentage yield obtained was 16%. According to Azwanida (2015) in a review on the extraction methods use in medicinal plants, principle, strength and limitation. To obtained a high percentage yield, this can be attributed to the high temperature which increase the kinetic energy in the solvent, thereby increasing the solubility and diffusion of compounds leading to more efficient extraction. This claim was also supported by (Sutrisna, et al., 2020). Natural dye extracted from mango leaf and sappan barks via maceration, soxhlet and reflux method of extraction.

Application of dye extact from *Ptericarpus erinaceous* on cotton fabric

S/N	Fabric	Weight of fabric before dyeing (g)	Weight of fabric after dyeing and mordanting (g)	Amount of dye absorbed (g)	Color shade
1	Unmordanted	0.60	0.65	0.05	light brown
2	Premordanting				
I	$CuSO_4$	0.60	0.64	0.04	Dark brown
ii	$KAl(SO_4)_2.12H_2O$	0.60	0.64	0.04	Brown
iii	$FeSO_4.7H_2O$	0.60	0.63	0.03	Grey
3	Simultaneous mordanting				
I	$CuSO_4$	0.60	0.62	0.02	Dark brown
ii	$KAl(SO_4)_2.12H_2O$	0.60	0.62	0.02	Brown
iii	$FeSO_4.7H_2O$	0.60	0.61	0.01	Grey
4	Post mordanting				
I	$CuSO_4$	0.60	0.67	0.07	Dark brown
ii	$KAl(SO_4)_2.12H_2O$	0.60	0.67	0.07	Brown
iii	$FeSO_4.7H_2O$	0.60	0.65	0.05	Grey

The results of the application of dye extract from *Ptericarpus erinaceous* on cotton fabric as presented in Table 2. An increase in fabric weight after dyeing was observed for all samples, indicating successful absorption of the dye by the cotton fabric. The unmordanted fabric recorded a dye uptake of 0.05 g and produced a light brown shade, suggesting that the dye extract possesses inherent affinity for cellulose fibres due to possible interactions between the dye molecules and hydroxyl groups present in cotton (Dass et al., 2016).

The use of mordants significantly influenced both dye uptake and colour shade. In the premordanted samples, dye uptake ranged between 0.03 and 0.04 g, with copper and aluminium potassium sulphates producing brown to dark brown shades, while iron sulphate yielded a grey shade. This variation in colour shade can be attributed to differences in the coordination behaviour of the metal ions with the dye molecules. Simultaneous mordanting resulted in relatively lower dye uptake values (0.01–0.02 g), compared to premordanting and post-mordanting methods. This may be due to competition between the dye molecules and mordant ions for active binding sites on the fibre during dyeing.

Post-mordanting produced the highest dye uptake values (0.07–0.08 g), particularly for copper and aluminium potassium sulphates, accompanied by deeper and more intense colour shades. This observation suggests that post-mordanting enhances dye fixation through the formation of stable dye metal fibre complexes after initial dye absorption (Jabar et al., 2020).

Determination of Color Fastness of *Ptericarpus erinaceous* Dyed Cotton fabrics

SN	Fabrics	Color change	Color staining	Wet Rubbing	Dry Rubbing	Light
1	Unmordanted	3.0	3.5	4.0	3.5	4.0
2	Postmordanted					
I	$CuSO_4$	4.5	4.5	5.0	4.5	4.5
II	$KAl(SO_4)_2.12H_2O$	4.0	4.5	4.5	4.0	4.5
III	$FeSO_4.7H_2O$	4.5	4.5	5.0	4.5	5.0

Key: 1-Very poor;2-Poor;3-Fair;4-Good;5-Excellent

The colour fastness results for *Ptericarpus erinaceous* dyed fabrics as presented in Table 3.

The unmordanted fabric exhibited good colour fastness ratings, with values ranging from 3.0 to 4.0 for washing, rubbing, and light fastness. This indicates reasonable stability of the dye on cotton fibres even without the use of mordants. Post-mordanted samples demonstrated improved fastness properties across all parameters. Fabrics mordanted showed an excellent fastness rating of 4.5-5.0. The enhanced performance is attributed to the formation of strong coordination bonds between the dye molecules, metal ions, and fibre, which reduces dye leaching and photodegradation (Jabar et al., 2020).

Characterization of Dyed Cotton Fabric

SEM of *Ptericarpus erinaceous* Unmordanted Dyed Cotton Fabric

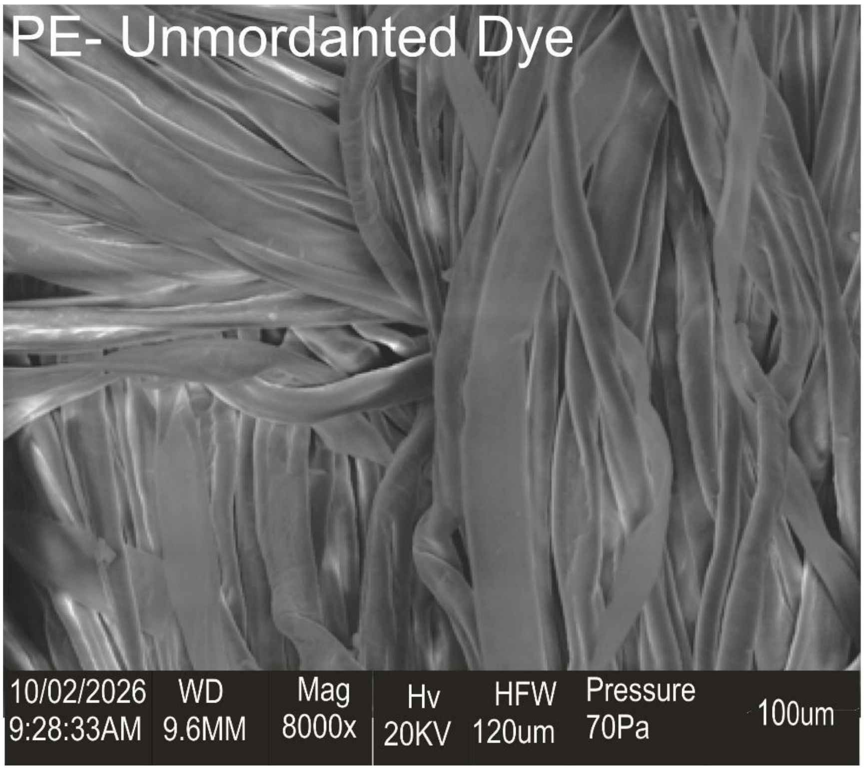

Figure 1: SEM of Ptericarpus erinaceous of unmordanted Dyed Cotton Fabric

The SEM of the unmordanted dyed fabric in Fig 1 shows partial and discontinuous surface coverage of the cotton fibers. The natural ribbon-like morphology of cellulose remains visible, with dye particles appearing as scattered deposits along the fiber surface. This observation indicates that dye fixation occurs primarily through weak intermolecular forces such as hydrogen bonding and van der Waals interactions between cellulose hydroxyl groups and flavonoid/quinonoid chromophores present in *Pterocarpus erinaceus*. Because no metal ion is present to act as a bridging agent, dye adsorption is largely superficial. Similar SEM findings have been reported for unmordanted natural dye systems, where dye molecules form thin surface films without significant fiber penetration (Samanta & Agarwal, 2009). The limited and uneven distribution observed suggests lower fixation strength and potentially reduced wash fastness compared to mordanted samples.

SEM of *Ptericarpus erinaceous* Dyed Cotton Fabric with *$CuSO_4$*

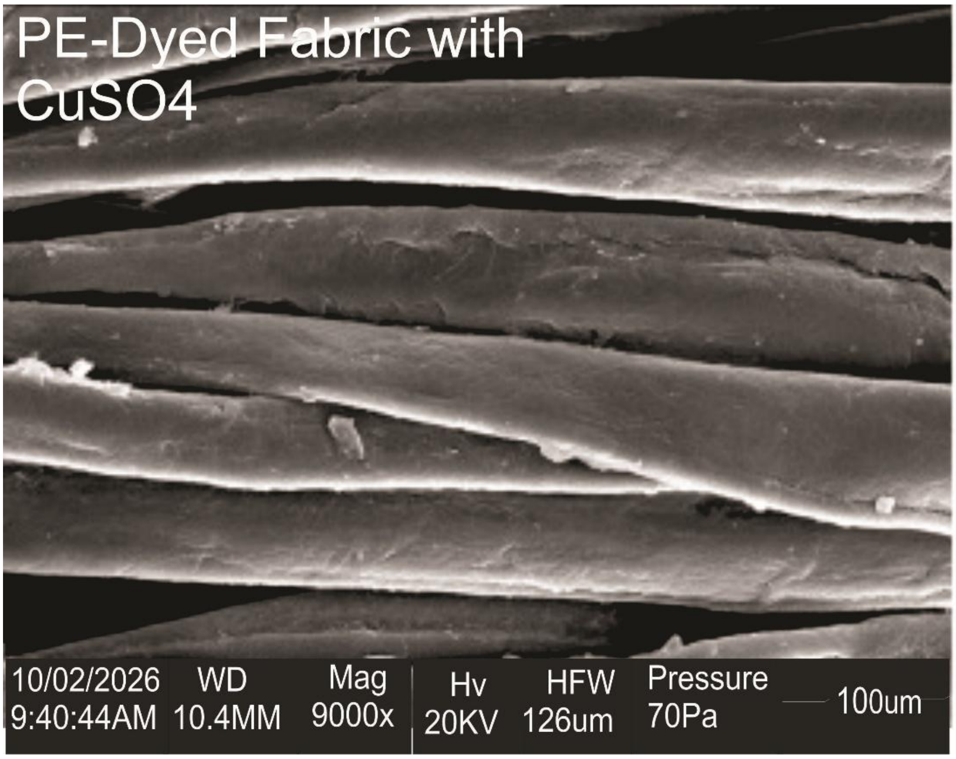

Figure 2: SEM of Ptericarpus erinaceous Dyed Cotton Fabric with $CuSO_4$

The SEM of *Ptericarpus erinaceous* dyed cotton fabric with *$CuSO_4$* as shown in fig 2 exhibits significantly enhanced surface coverage. The fiber surface appears uniformly coated, and dye deposition is more continuous and compact compared to the unmordanted sample. The SEM micrograph likely shows reduced exposure of the underlying fiber structure due to the formation of a coherent dye metal complex layer. Copper is known to form stable five or six membered chelate rings with flavonoids, thereby increasing dye molecular weight and reducing solubility (Bechtold & Mussak, 2009). The smoother and more consolidated coating observed supports the formation of metal dye fiber coordination complexes, which are stronger than simple hydrogen bonding interactions

SEM of *Ptericarpus erinaceous* Dyed Cotton Fabric with *$KAl(SO_4)_2.12H_2O$*

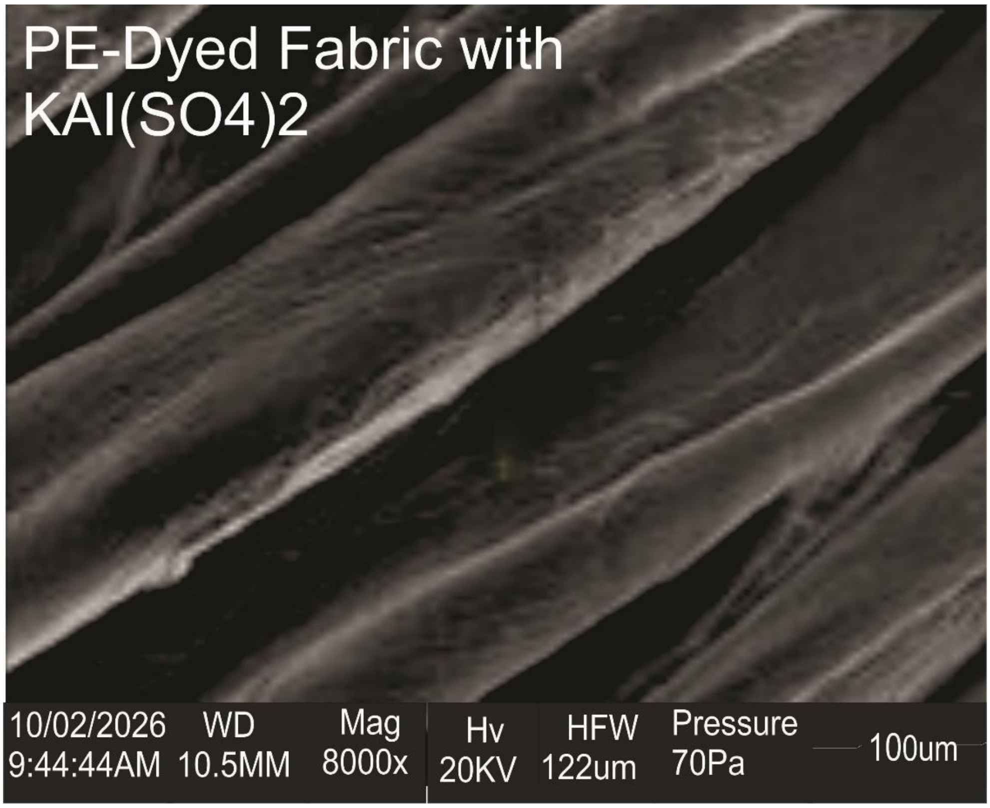

Figure 3: SEM of *Ptericarpus erinaceous* Dyed Cotton Fabric with *$KAl(SO_4)_2.12H_2O$*

The SEM of alum mordanted dyed cotton fabric of *Pterocarpus erinaceus* as shown in fig 3 displays moderate but uniform dye coverage. Compared to copper mordanting, the surface appears less densely packed but more evenly distributed than the unmordanted dyed fabric. Literature reports that alum enhances brightness and improves dye uptake without causing excessive fiber surface roughening (Samanta & Agarwal, 2009). The morphology observed here aligns with this behavior, indicating balanced dye fixation and surface smoothness. Mechanistically, alum acts as a trivalent crosslinking agent, improving binding while maintaining fiber morphology.

SEM of *Ptericarpus erinaceous* Dyed Cotton Fabric with *$FeSO_4.7H_2O$*

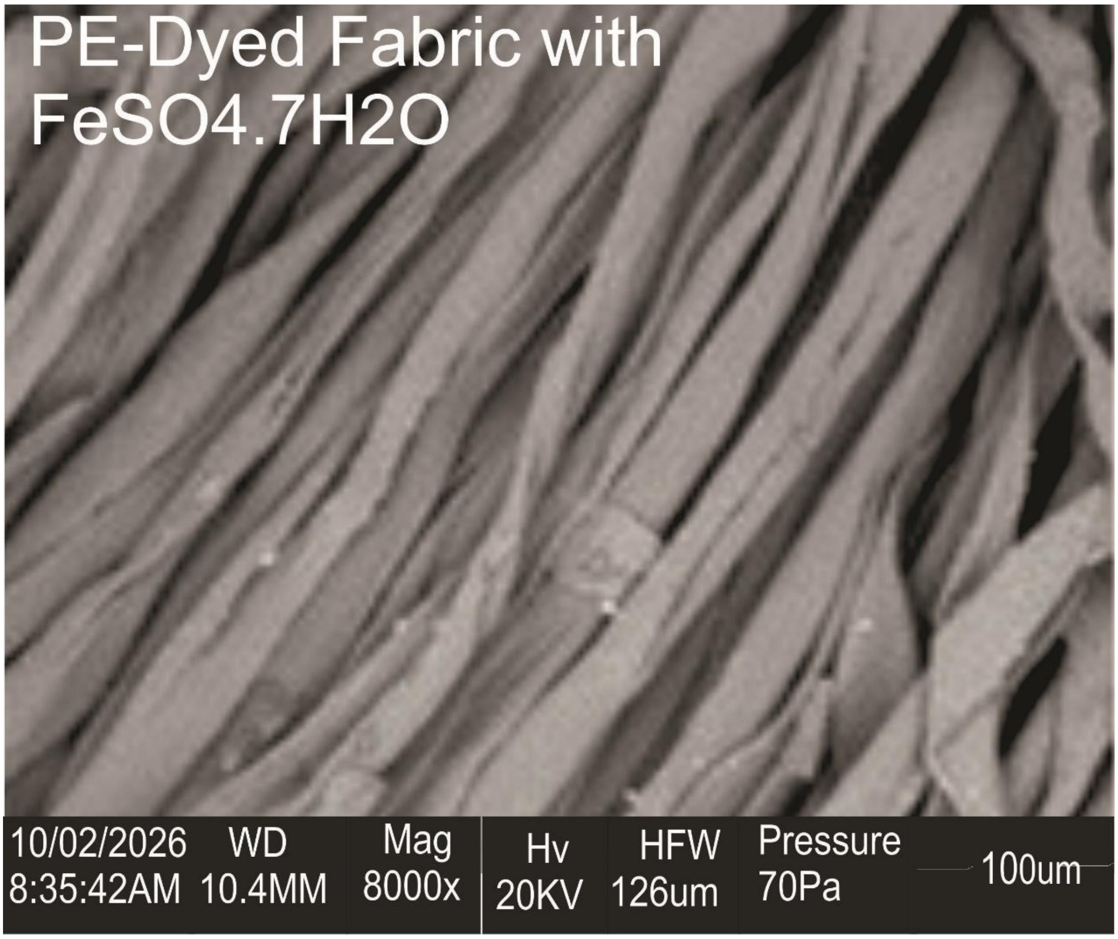

Figure 4: SEM of *Ptericarpus erinaceous* Dyed Cotton Fabric with *$FeSO_4.7H_2O$*

The SEM of iron mordanted dyed fabric in Fig 4 exhibits the most pronounced morphological change. The SEM image likely shows dense and compact dye deposition, increased surface roughness and reduced visibility of native cellulose features. The thicker coating observed is consistent with reports that iron mordanting increases molecular aggregation and surface deposition (Shahid et al., 2013). The enhanced roughness suggests strong anchoring of dye complexes onto the fiber surface. This explains why iron-mordanted fabrics typically demonstrate superior wash fastness but darker shades.

TGA of *Ptericarpus erinaceous* Unmordanted Dyed Cotton Fabric

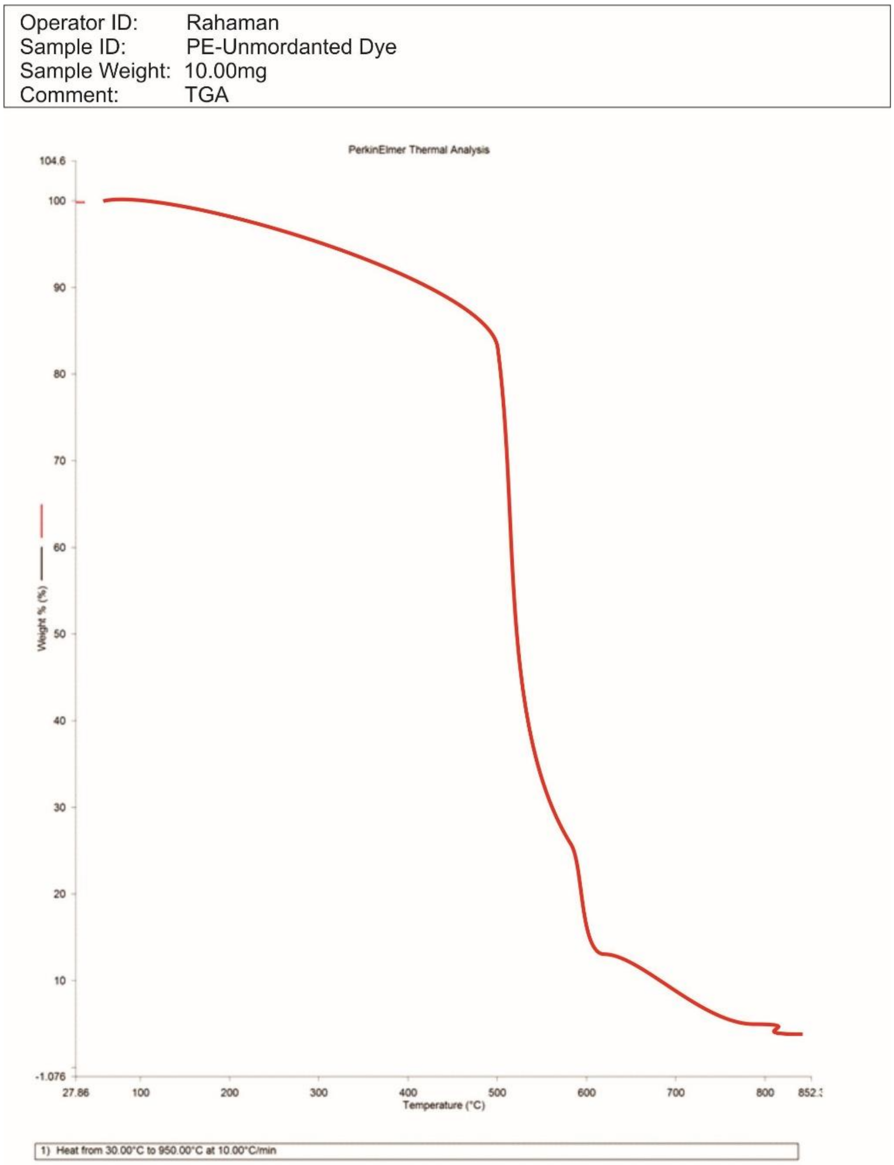

Figure 5: TGA of Ptericarpus erinaceous Unmordanted Dyed Cotton Fabric

The thermal profile of *Ptericarpus erinaceous* unmordanted dyed cotton fabric in Fig 5 shows that at 30 – 150 ºC a minor weight loss from absorbed water. At 270 – 370 ºC a major mass loss similar to untreated cellulose indicating a rapid depolymerization. Above 400 ºC moderate carbonaceous residue formation indicatin a slow mass loss at elevated temperatures. Dyed fabric without metal coordination, show that dye molecules are essentially spectators in the degradation process (Shahid et al., 2013).

TGA of *Ptericarpus erinaceous* Dyed Cotton Fabric with $CuSO_4$ as Mordant

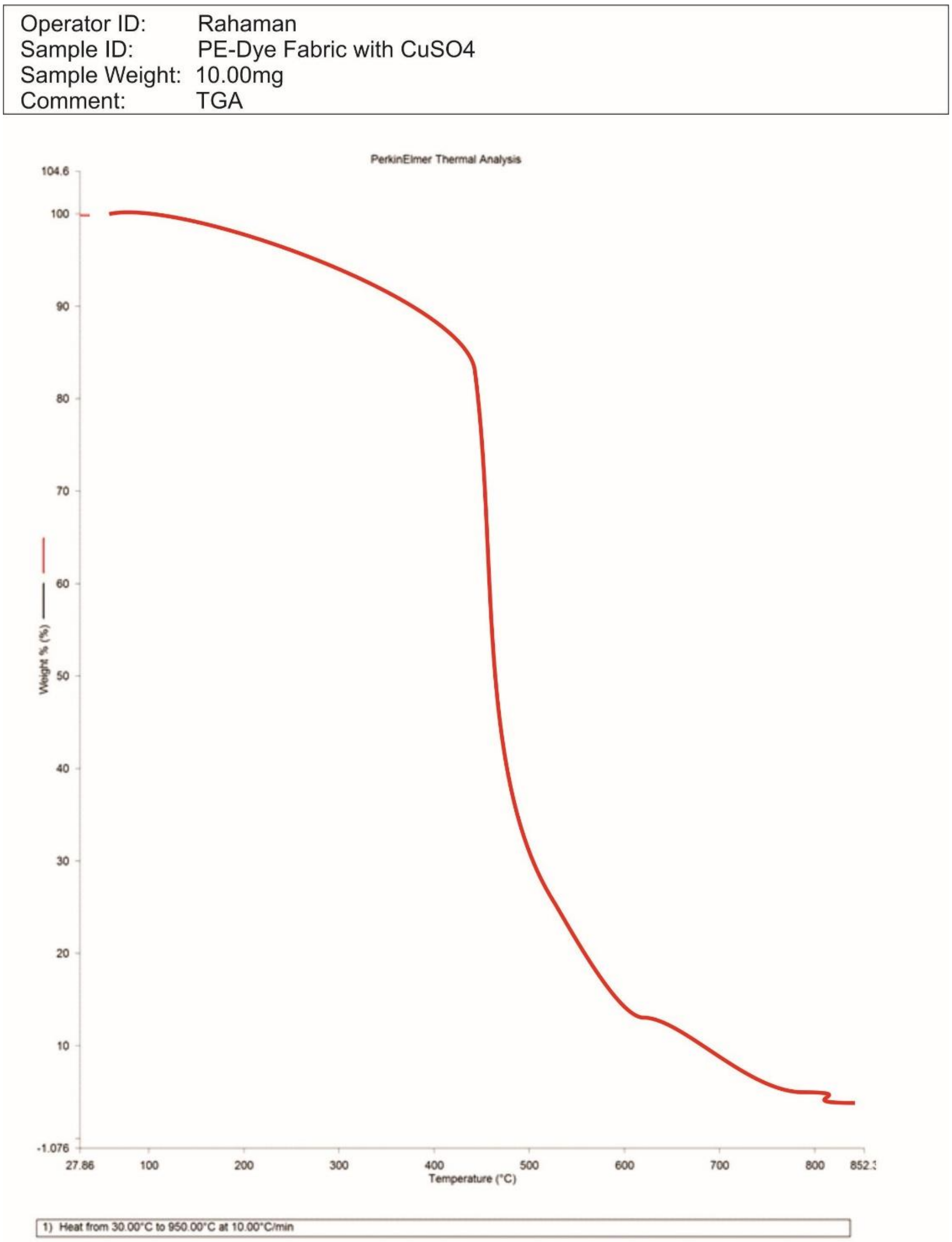

Figure 6: TGA of Ptericarpus erinaceous Dyed Cotton Fabric with $CuSO_4$

The thermal profile in Fig 4.32 shows a minor initial weight loss at 30 – 150 °C Increased onset temperature at 290 – 380 °C which reduced mass loss rate. Higher residual mass compared to unmordanted PE sample above 400 °C Improved carbonaceous layer stability. Copper coordination with flavonoid oxygen donors in *Pterocarpus erinaceus* dyed extracts enhances thermal stability by forming stable dye metal complexes (Bechtold & Mussak, 2009). These complexes restrict polymer mobility by increasing crosslink density and promote char formation, thus delaying mass loss. Copper mordanting enhances thermal stability of *Pterocarpus erinaceus* dyed cotton through similar coordination mechanisms.

TGA of *Ptericarpus erinaceous* Dyed Cotton Fabric with $KAl(SO_4)_2.12H_2O$ as Mordant

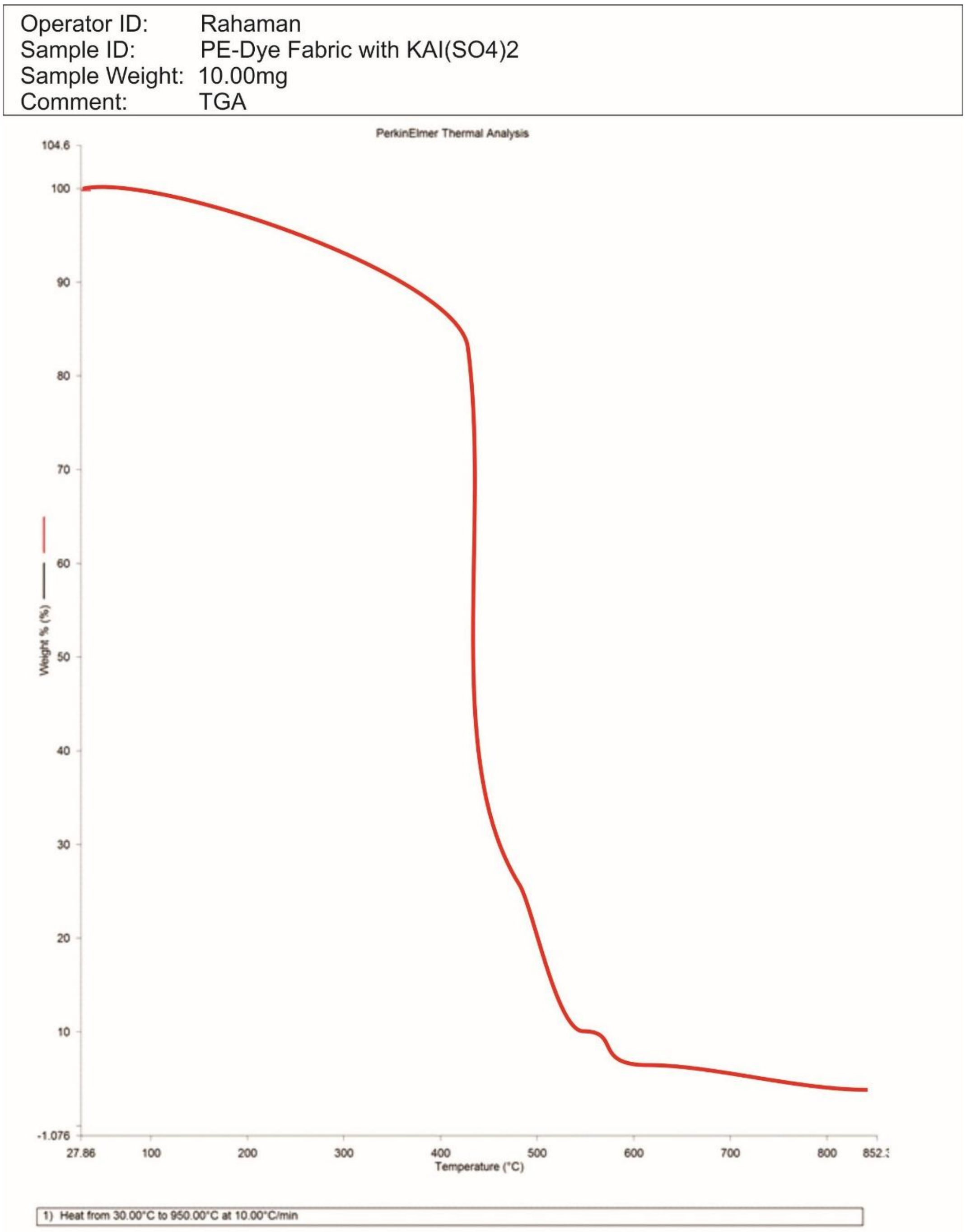

Figure 7: TGA of *Ptericarpus erinaceous* Dyed Cotton Fabric with $KAl(SO_4)_2.12H_2O$

The thermal profilein Fig 7 shows that, at 30−150 ^{o}C minor moisture removal. Slightly delayed degradation onset at 280 – 375 ^{o}C Slight increase in residual mass relative to unmordanted dyed fabric sample above 400 ^{o}C. Alum imparts limited stabilization via weak ionic crosslinking with flavonoid oxygen atoms, improving thermal behavior slightly but not as significantly as transition metal coordination (SenthilKumar et al., 2023). The modest effect is consistent with literature comparing alum vs. transition metal mordants in natural dye systems (Jahan & Zhang, 2022). Alum provides limited thermal stabilization for *Pterocarpus erinaceus* dyed fabrics.

TGA of *Ptericarpus erinaceous* Dyed Cotton Fabric with $FeSO_4.7H_2O$ as Mordant

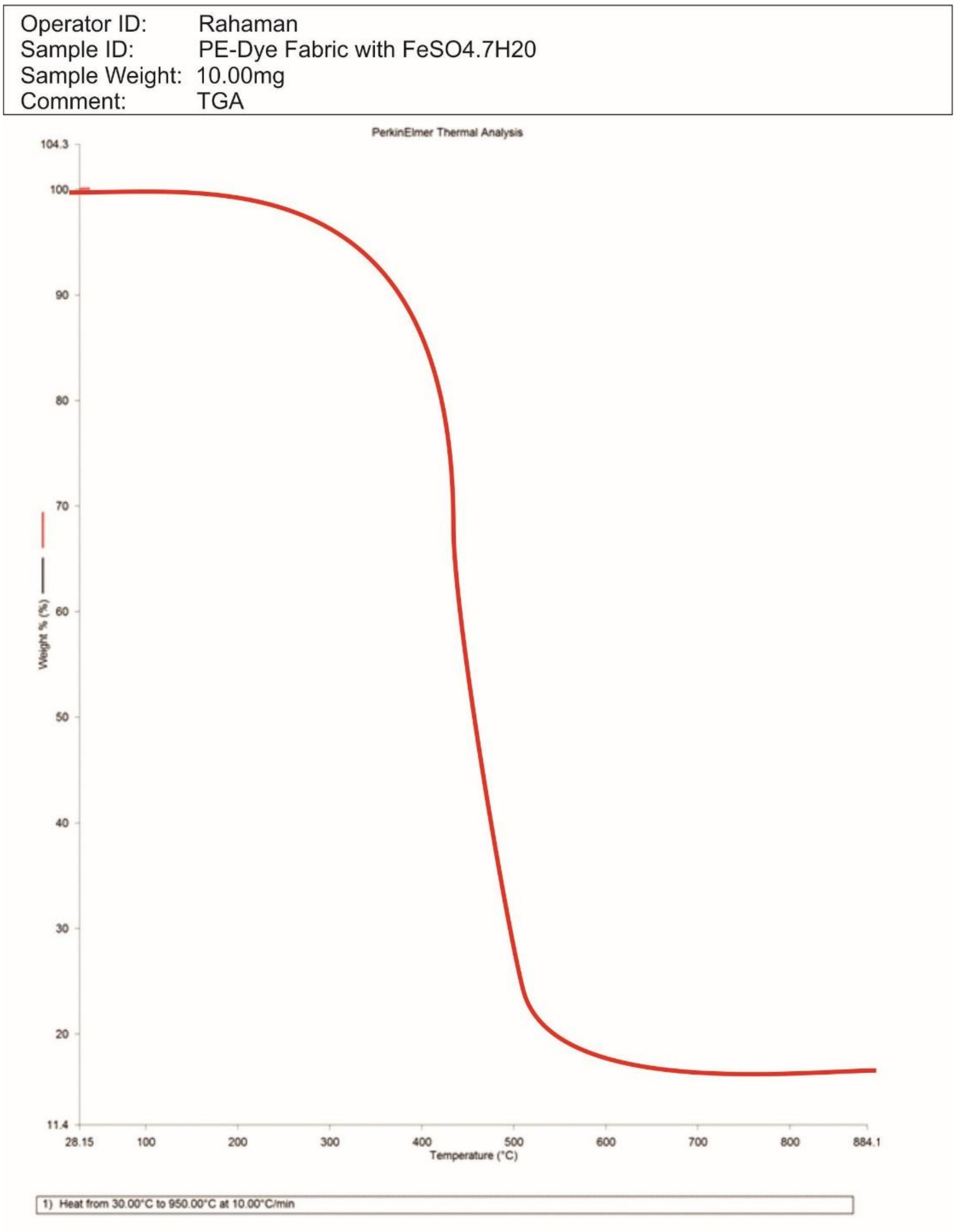

Figure 8: TGA of *Ptericarpus erinaceous* Dyed Cotton Fabric with $FeSO_4.7H_2O$

The thermal profile in Fig 8 shows a minor initial weight loss at 30 – 150 °C. Highest degradation onset among *Pterocarpus erinaceus* dyed fabbric samples at 300 – 395 °C. At above 400 °C highest residual mass because stable iron-induced carbonaceous structure.

Strong iron ion flavonoid coordination complexes form a dense crosslinked network with cellulose, significantly restricting thermal decomposition (Jahan & Zhang, 2022). Iron catalyzes dehydration and aromatization reactions, increasing char and acting as a thermal barrier, consistent with general mechanisms reported in literature for iron mordanted natural dye systems (Shahid et al., 2013). Iron ion mordanted *Pterocarpus erinaceus* fabrics show the greatest thermal enhancement due to multi point metal coordination and catalytic effects.

CONCLUSION

The research concludes that *Pterocarpus erinaceus* is viable, sustainable sources of natural dyes with promising industrial potential. Using maceration method of extraction, dye extracts were successfully obtained from plant species, demonstrating good extraction yields and stability.

The findings of this research demonstrate that dye extract from *Pterocarpus erinaceus* is an effective natural colourants for cotton fabric. The dye exhibited satisfactory dye uptake, produced a range of stable colour shades, and showed good to excellent colour fastness properties when appropriate mordanting techniques were employed. Post-mordanting emerged as the most effective dyeing method, significantly enhancing dye fixation and fastness properties due to the formation of stable dye metal fibre complexes. Copper and iron sulphates were particularly effective mordants, improving colour depth and resistance to washing, rubbing, and light exposure. The combined SEM and TGA results demonstrate a strong correlation between surface morphology and thermal behavior.

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