IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.311 ⁒ Peer-reviewed & Refereed journal ⁒ Vol. 12, Issue 7, July 2025

DOI: 10.17148/IARJSET.2025.12750

Utilization of *Pterocarpus marsupium* Sawdust as a Natural Dye Source for Cotton Fabric Dyeing

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Abstract: In the pursuit of sustainable and eco-friendly alternatives to synthetic dyes, this study investigates the viability of *Pterocarpus marsupium* sawdust as a natural dye source for cotton fabric. Natural dyes, being biodegradable and non-toxic, are experiencing renewed interest due to increasing environmental concerns. The dye was extracted from *Pterocarpus marsupium* sawdust using aqueous extraction, and the extraction parameters such as concentration, time, and temperature were optimized for maximum dye yield. The dye was then applied to desized cotton fabric, and dyeing conditions were similarly optimized for time, dye concentration, and material-to-liquor ratio. Mordanting techniques were employed to improve colour fastness, using both alum and bio-mordants. Characterization of the dye was conducted using UV-Visible spectrophotometry, FTIR, phytochemical analysis, and TGA. The dyed fabrics were evaluated for colour strength, fastness to washing, sunlight, crocking, and mechanical properties. The results indicate that *Pterocarpus marsupium* dye provides rich reddish-brown hues with good fastness and antimicrobial properties, making it suitable for applications in apparel and functional textiles. This study demonstrates the potential of utilizing sawdust, a wood industry by-product, as a sustainable dye source, thereby promoting circular economy practices and reducing environmental impact.

I. INTRODUCTION

The textile industry is a significant contributor to global environmental pollution, particularly due to the extensive use of synthetic dyes. These dyes often contain toxic compounds such as azo dyes, heavy metals, and formaldehyde-based resins, which are persistent in the environment and pose health hazards (Saxena et al., 2014). In contrast, natural dyes are renewable, biodegradable, and safer for both human and environmental health, making them attractive alternatives in the shift toward sustainable textile production (Bechtold et al., 2009; Gulrajani, 2010). One promising natural dye source is *Pterocarpus marsupium*, commonly known as Indian Kino. The heartwood and sawdust of this tree are rich in anthraquinones, tannins, and flavonoids—compounds known for their strong dyeing and antimicrobial properties (Siva, 2007; Sharma et al., 2018). The sawdust, often discarded as waste by the wood industry, provides a sustainable raw material that aligns with waste valorisation and circular economy models (Samanta et al., 2011). The use of natural mordants, such as alum and plant-based tannins, enhances the binding of natural dyes to cotton fibers and improves fastness properties without introducing harmful chemicals (Shahid et al., 2012). Despite the challenges related to colour reproducibility and process standardization, innovations in extraction methods—such as aqueous, microwave-assisted, and enzyme-based techniques—have significantly improved the yield and quality of natural dyes (Bechtold et al., 2009; Nayak et al., 2021). This study explores the extraction and application of dye from *Pterocarpus marsupium* sawdust on cotton fabric, optimizing both dye extraction and dyeing conditions. The research further evaluates the dyed fabric for mechanical, aesthetic, and functional properties, including color fastness and absorbency. With global demand for eco-friendly textiles on the rise, this research contributes to sustainable material science and the development of greener dyeing technologies (Atif Hussain et al., 2022; Deo & Desai, 2021).

II. MATERIALS AND METHODS

2.1 Materials

The raw dye source used in this study was sawdust obtained from *Pterocarpus marsupium* (Indian Kino tree), collected from a local wood processing unit. The substrate chosen for dyeing was 100% desized cotton fabric with uniform weave and GSM (grams per square meter). All reagents used for extraction and mordanting—including alum (aluminium potassium sulphate), ferrous sulphate, and citric acid—were of analytical grade and procured from standard chemical suppliers. Mordants used in the study include both metallic and bio-based options to evaluate their influence on dye fixation and fastness.

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

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2.2 Extraction of Dye

The sawdust (Plate 1) was first sieved and dried to eliminate moisture. Aqueous extraction was carried out using a material-to-liquor ratio of 1:20 (w/v). The mixture was heated at 90°C for 60 minutes to allow maximum pigment diffusion. The extract was filtered using muslin cloth to remove particulates. The effect of extraction parameters such as time, temperature, and pH on dye yield was systematically analyzed to optimize conditions (Samanta & Agarwal, 2009).


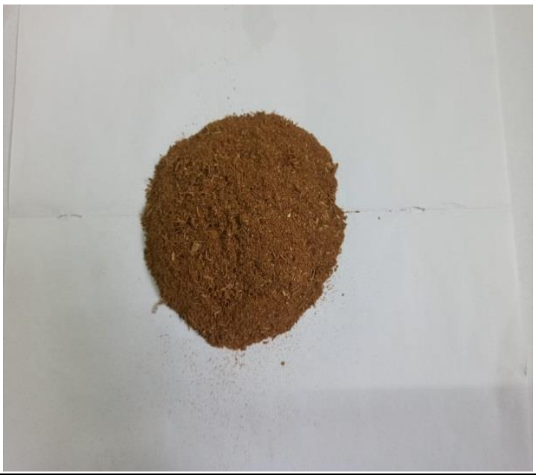

Plate 1. *Pterocarpus marsupium* saw dust

2.3 Mordanting Process

Pre-mordanting was employed to enhance dye uptake and colour fastness. Cotton samples were treated with 10% (owf) alum and 5% (owf) ferrous sulphate. In addition, citric acid was tested as a natural mordant to assess its environmental compatibility. The fabrics were immersed in mordant solution at 60°C for 30 minutes, then air-dried prior to dyeing (Shahid et al., 2013).

2.4 Dyeing Procedure

The dyeing process (Plate 2) was performed in a laboratory dye bath using varying concentrations of dye extract (5%, 10%, 15%, and 20%). The cotton samples were dyed at 80°C for 45 minutes at a constant material-to-liquor ratio of 1:20. post-dyeing, the fabrics were washed with cold water, neutral soap solution, and again rinsed thoroughly to remove unfixed dye molecules (Bechtold et al., 2003). Optimization of dyeing conditions focused on time, temperature, and dye concentration to ensure evenness of shade and colour penetration.


Plate 2. Dyeing Process

DOI: 10.17148/IARJSET.2025.12750

2.5 Characterization of the dye extracts

2.5.1 UV- Visible Analysis

UV-Visible (UV-Vis) analysis is a powerful technique widely used in textile dyeing to evaluate the colour properties of dyed fabrics. The method involves measuring the absorption of ultraviolet (UV) and visible light by the dye, providing insight into the colour strength and quality of the dyeing process. By analysing the absorption spectra, it is possible to determine the concentration and interaction of dyes with fabric fibres, helping optimize dye formulations and processes. (Smith et al., 2020). The colour intensity of *Pterocarpus marsupium* dye extract was analysed using UV-Visible spectrophotometer.

2.5.2 TGA Analysis

Thermogravimetric Analysis (TGA) is a thermal analysis technique used to study the thermal stability and decomposition behaviour of textile fibres and dyes. It measures weight loss as a function of temperature, providing critical information on material composition and degradation (Broadbent, 2001). Thermal stability of the dye extract from *Pterocarpus marsupium* was analysed using TGA.

2.6 Evaluation of dyed fabric

2.6.1 Fabric weight

GSM (ASTM2646) in textiles is a crucial parameter that measures the weight of fabric per unit area. It is an essential indicator of fabric quality, thickness, and durability. Higher GSM values indicate heavier and denser fabrics, which are generally more durable and suitable for applications like winter clothing, upholstery, and industrial textiles. Conversely, lower GSM fabrics are lighter, more breathable, and commonly used for summer wear, curtains, or 35 lightweight garments. GSM can be determined using a GSM cutter and weighing scale or calculated using the formula:

$$GSM = (\text{Fabric weight in grams}*100)$$

GSM cutter is used to cut sample. The weight of the sample is measured electronic weight balance, then the value of the sample is multiplied by 100. Three samples including control and dyed fabrics were weighted and mean value was calculated and recorded.

2.6.2 Fabric thickness

Fabric thickness (ASTM D1777) testing is an essential process in the textile industry to assess the dimensional properties of fabrics, which directly impact their performance, durability, and application. Thickness is measured as the perpendicular distance between the two surfaces of a fabric under a specified pressure. Various factors such as fibre composition, weave structure, and finishing processes influence fabric thickness. This parameter is critical in applications like garment manufacturing, upholstery, and industrial textiles, where properties such as insulation, comfort, and mechanical strength are crucial. (Smith et al., 2018). Loading weight is placed on the weight pan. Specified pressure foot is fitted on mounting rod, lifting lever is pressed and presser foot top is lifted. The sample is placed on the anvil and lifting level is released gently. The downward presser is applied on the presser foot on the sample. The readings of thickness are in mm. The same procedure was repeated for all the samples and recorded.

2.6.3 Fabric stiffness

Fabric stiffness (ASTM D1388) is a key mechanical property that determines a fabric's ability to resist bending or draping. It is an essential parameter in textile applications such as apparel, upholstery, and industrial fabrics, influencing comfort, durability, and performance. The stiffness of a fabric depends on factors such as fibre type, yarn structure, weave, finishing processes, and fabric thickness. Measuring fabric stiffness helps manufacturers optimize material selection for specific end uses. (Sharma et al., 2019).The instrument is placed on the table so that horizontal platform .the side is held in horizontal plane and pushed along with the fabric sample slowly .The fabric leading edges project beyond the platforms .the part of the sample will hand over and start bending under its own weight. The pushing of the sample is stopped when its tip reaches the level of inclined plane. The reference point at the center of leading edge is considered. The length of 36 overhanging is recorded for warp and weft separately .Four readings for each specimen are taken from each side up .First at one end and then at the other. Then the mean value is calculated and recorded.

2.6.4 Tensile strength and elongation

The tensile testing (ASTM D5034) of fabric strength and elongation is an essential portion of evaluating the strength and performance of fabric products when subjected to tensile forces. Fabric strength testing determines how much forces applied on the fabric until the breaking point is reached, while elongation shows how much the fabric is stretchable or extendable under the tensile force applied.

The even weight of fabrics used in garment, upholstery, industrial textile, and technical fabrics all need properties offered by fire retardant chemicals, catering to safety and quality. (Patel et al., 2020). Within the tensile testing machine is two clamps that hold the sample. Two clamps separated by distance of 200 mm were used in the tests, with the longer side of the fabric being aligned parallel to the load as it was applied with equal length of fabric extending beyond the jaws of the clamp at each side. The jaws of the clamps hold the sample in place. Silk or nylon is tensioned across the jaws. On operating the machine ruptured at the center when the jaws moves. At this point the reading from the dial is noted in kilograms or pounds as strength of the fabric .The elongation readings is noted from the scale. This is done for the warp and weft direction.

2.6.5 Absorbency Test

2.6.5.1 Sinking

It is usually used for a preliminary test for the dyed behaviour of textile fibres when they are immersed in the dye bath. This test assesses how well the fibre takes up a particular dye and ensures even penetration and absorption of the dye throughout the fibre. An experiment that consists of putting a fabric or yarn sample in a dye solution to measure how long it take for the fabric or yarn to sink. Quick sinking means a good affinity for the dye, while delayed sinking 37 means poor wetting properties requiring pre-treatment procedures (scouring or mercerization) for better dye absorption. (Gupta 2019). A sample of size 25 mm*25mm was cut and dipped on the surface of distilled water. As soon as the stop clock is started the time taken for the sample to sink in water is recorded in seconds, if the sample does not sink within one minute it is considered floating .then mean value is calculated.

2.6.5.2 Wicking

The wicking test (AATCC TM -197) in dyeing is a crucial evaluation method used to assess the capillary action of liquids within a textile material. This test measures how effectively a fabric can transport moisture along its surface or through its structure, which is essential for applications such as sportswear, medical textiles, and functional fabrics. The wicking property of a fabric is influenced by factors such as fibre type, yarn structure, fabric weave, and surface treatments. A higher wicking rate generally enhances comfort by promoting quick moisture absorption and evaporation. Various methods, including vertical wicking, horizontal wicking, and gravimetric techniques, are employed to analyse the wicking behaviour of dyed fabrics. These methods help determine the impact of different dyeing processes and finishes on moisture management properties. Understanding the wicking characteristics of textiles is vital for optimizing fabric performance in various end-use applications (Das et al., 2007). The test sample is suspended such that 20mm is immersed in the dye solution after making 20mm with incredible ink. This suspended fabric depending on its absorbency property exhibits the rise of liquid. The stop watch is used to check the time. The time is kept constant which is one minute. The level of the sample is noted in mm or cm, then mean value was calculated.

2.6.6 Colour Fastness

Colour fastness in textile dyeing refers to the resistance of dyed or printed fabrics to fading or bleeding under various external influences such as washing, light exposure, perspiration, and rubbing. It is a critical quality parameter that determines the durability and appearance retention of textiles over time. The colour fastness of a fabric depends on several factors, including the type of dye, fibre composition, dyeing method, and post-dyeing treatments (Shenai 1995).

2.6.6.1 Colour Fastness to Washing Colour fastness to washing is a critical property of dyed and printed textiles, reflecting their resistance to fading or running when subjected to laundering processes. It is an essential quality parameter for consumer satisfaction, affecting the aesthetic and functional value of textile products. Poor colour fastness can lead to issues such as staining of other garments, loss of vibrancy, and overall degradation of fabric appearance. The assessment of washing fastness typically involves standardized tests, such as those specified by the International Organization for Standardization (ISO 105-C06) and the American Association of Textile Chemists and Colourists (AATCC TM61), which simulate domestic laundering conditions. Various factors, including dye type, fibre composition, and washing conditions (temperature, detergent, mechanical action), influence the colour fastness of a fabric. A thorough understanding of these factors helps manufacturers develop products that meet quality standards and consumer expectations (Gulrajani, 2010).

2.6.6.2 Colour Fastness to Sunlight

Colour fastness to sunlight is a crucial property in textile dyeing that determines the resistance of dyed or printed fabrics to fading when exposed to ultraviolet (UV) radiation and other environmental factors such as temperature and humidity. This property is particularly important for outdoor textiles, automotive fabrics, and apparel subjected to prolonged sunlight exposure. The degree of light fastness depends on the chemical structure of the dye, the fibre type, and the presence of UV absorbers or stabilizers. (Christie 2007). The test is based on conditions of the fabric of the exposed to sunlight for several hour. A sample 16 cm *15mm was taken from the coloured material, the entire sample

DOI: 10.17148/IARJSET.2025.12750

is covered with paper to prevent from direct sunlight for 8 hours. the change in the colour of the fabric was compared with the original and was noted with the grey scale.

2.6.6.2 Colour Fastness to Crocking

The crocking test in textile dyeing is a method used to evaluate the resistance of dyed or printed fabrics to colour transfer when rubbed against another surface. This test is essential for determining the durability of textile coloration and preventing staining on other fabrics or surfaces during use. Crocking can occur in both dry and wet conditions, with wet crocking generally leading to higher colour transfer due to moisture weakening dye-fibre bonds. During rubbing it consist of two metal 39 blocks it stationary while the upper blocks has an arrangement to move and for the base by means of rotating handle. The colour transfer from the dyed fabric to which the material is assessed with AATCC grey scale. The colour fastness of the dyed fabric is recorded.

III. RESULTS AND DISCUSSIONS

3.1 Fabric weight

The weight of the fabric (GSM) of undyed fabric, and mordant dyed fabric samples were analyzed and the values are presented in Table I.

Table I Fabric weight

Samples	Fabric weight	Average
UDF	92.4	92.4
	92.2	
	92.6	
AMF	94.3	94.2
	94.0	
	94.4	
MMF	94.3	94.3
	94.1	
	94.3	

From the Table it clear that, the fabric weight of the dyed samples increased when compared over the original fabric. This increase might be due to the uptake of dye. The maximum was noticed is MMF.

3.2 Fabric thickness

The thickness of the undyed, and mordant dyed samples is analysed and presented in Table 2.

Table 13 Fabric Thickness

Samples	Average
UDF	0.21
AMF	0.23
MMF	0.26

From the Table II, it is observed that, the fabric thickness of the dyed samples increased. When compared to undyed fabric. Maximum thickness (0.26mm) noticed in myrobalan was increased mordanted fabric. The increase in thickness might be attributed to the dye uptake.

3.3 Fabric thickness

The stiffness of the samples in warp direction is analysed and the results are presented in Table III.

Table 1II Fabric stiffness along warp and Weft direction

Samples	Average	
	Warp	Weft
UDF	2.13	1.87
AMF	2.12	1.71
MMF	2.14	1.94

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

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From the Table it absorbs that, the fabric stiffness has increased in myrobalan mordanted fabric, whereas decreased in alum mordanted fabric. When compared to undyed fabric in both warp and weft direction. The increase stiffness in myrobalan mordanted fabrics might be due to the increased deposition of dye molecules.

3.4 Tensile Strength and elongation
The strength and elongation of the samples in warp direction are analysed and the results are presented in Table IV.

Table IV Strength and Elongation along Warp and Weft direction

Samples	**Average**	
	Warp	**Weft**
UDF	16.33	21.33
AMF	16.66	21.61
MMF	18.2	24.12

From the Table it is absorbed that, the strength of mordanted dyed samples was found to increase when compared to the undyed fabric. Maximum increase was found in myrobalan mordanted fabric in both warp and weft direction. The fabric elongation (%) was found to be decreased in both mordanted samples, compared to undyed samples in both warp and direction. In weft direction elongation (%) of the mordanted sample was found to be increased when compared to the un mordanted sample. To conclude the result revealed that the myrobalan mordanted fabric exhibited better tensile strength and flexibility when compared to alum mordanted dyed sample.

3.5 Absorbency Test
3.5.1 Sinking Test
The water absorbency of fabric samples was evaluated using a sinking test, and the results are summarized for dry and wet condition in Table V.

Table V Absorbency in Sinking

Samples	**Average**	
	Dry	**Wet**
UDF	-	0.7
AMF	**0.7**	**0.4**
MMF	**0.6**	**0.3**

From the Table V, it is absorbed that the dyed fabric samples showed increased absorbency when compared to undyed fabric samples. Among the mordanted sample, MMF exhibited increased absorbency when compared to AMF in both wet and dry conditions.

3.5.2 Wicking Test
The water absorbency of fabric samples was evaluated using a wicking test, and the results are summarized for dry and wet conditions in the Table VI.

Table VI Absorbency in wicking

Samples	**Average**	
	Dry	**Wet**
UDF	2.5	2.7
AMF	5.6	5.9
MMF	6.2	6.4

From the Table VI, it is absorbed that, the absorbency of the dyed fabric samples showed increased absorbency when compared to undyed fabric sample. Among all the mordanted sample, MMF exhibited increased absorbency when compared to AMF in both dry and wet conditions.

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3.6 Colour Fastness Test

3.6.1 Colour Fastness to Washing, Sunlight and Crocking

Table VI Colour Fastness Test

Sample	Washing	Sunlight	Crocking	
			Dry	Wet
DF	3	3	4	3
AMF	4	4	4	4
MMF	5	4	5	4

5-Excellent, 4-Good,3- Moderate,2-poor,1-Very poor

From the Table VII, it is clear that, with regarding to washing alum mordanted sample exhibited a good fastness to washing and myrobalan mordanted sample shows excellent. When compared to un-mordanted dyed fabric. With regarding to sunlight, a good fatness in both AMF and MMF samples. And fatness to crocking exhibited good in alum and excellent in myrobalan mordanted sample in dry condition, when the sample in wet condition AMF and MMF both showed good in colour fastness.

IV. CONCLUSION

The present study results revealed that, "*Pterocarpus marsupium*" could be a prospective dye source for dyeing cotton fabric. The process of extraction and dyeing colorants and mordants used are environmental friendly which cause maximum environmental pollution. The findings revealed that the optimal dyeing condition – concentration 100%, time 90 minutes with MLR of1:20. Resulted in cotton fabric with high color strength. Overall, this study highlights the importance of optimizing dye extraction and dyeing conditions. This work clearly indicates that the extract from "Pterocarpus marsupium "saw dust extract could be used as a source for natural dyes and dyeing cotton fabric

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IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588
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Impact Factor 8.311 ⁑ Peer-reviewed & Refereed journal ⁑ Vol. 12, Issue 7, July 2025
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