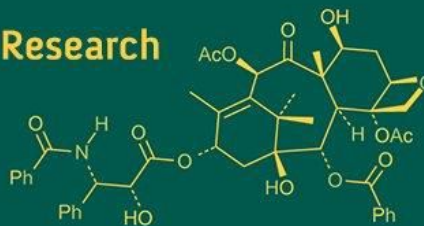


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
 ISSN Online: 2617-4707
 NAAS Rating: 5.29
 IJABR 2025; 9(4): 1181-1185
www.biochemjournal.com
 Received: 26-01-2025
 Accepted: 27-02-2025

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Sustainable shades: Unlocking the dyeing potential of teak leaves

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DOI: <https://www.doi.org/10.33545/26174693.2025.v9.i4n.4266>

Abstract

The use of dyes has been imperative to mankind from the time immemorial but the development of synthetic dyes has become a major concern due to its toxicity and poor biodegradability these environmental concerns have fuelled interest in natural dyes as sustainable alternatives. Existing evidences show the use of natural and chemical mordants blending it with the natural dyes. The results of these studies have been impeccable but there has been research gap in the use of stages of leaves to produce varied colour and strength of the dyes. This study investigates the use of teak leaves (*Tectona grandis*), a by-product of the timber industry, as a natural dye source and the objectives of the study were to quantify the dye yield from young, mature and old leaves with ethanol solvent by Soxhlet extraction method, extraction of dye from high dye yielding teak leaves to dye the natural fabric using different mordants and to observe the extent of dye absorption by the fabric during pre, simultaneous and post mordanting treatments. Dye quantification was performed on young, mature and old leaves using Soxhlet extraction, with young leaves yielding the highest dye. Cotton fabrics were dyed using natural (areca nut, betel leaves, amla) and chemical mordants (copper sulphate, vinegar) by all the three mordanting techniques. Pre-mordanting resulted in the darkest shades for natural mordants, while chemical mordants demonstrated superior colour fixation. The study highlights teak leaves as a viable and eco-friendly dye source for sustainable textile applications.

Keywords: Biodegradable, soxhlet extraction, quantification, dye, mordant, fibres, teak

1. Introduction

Natural dyes have been an integral part of human civilization for centuries, offering vibrant hues derived from plants, animals, and minerals. These dyes were traditionally used for colouring textiles, leather and other materials before the advent of synthetic dyes in 1856. Despite their historical significance, natural dyes lost their prominence due to the superior fastness properties and affordability of synthetic dyes. However, growing concerns over the environmental and health hazards posed by synthetic dyes have led to a resurgence of interest in natural colourants (Lellis *et al.*, 2019) ^[10]. Synthetic dyes contribute significantly to industrial waste and pollution, often releasing toxic chemicals that disrupt ecosystems and pose serious health risks. In contrast, natural dyes are biodegradable, non-carcinogenic, and environmentally sustainable, making them a viable alternative in textile industries (Takker *et al.*, 2021) ^[23]. Among the diverse sources of natural dyes, plant-based dyes have garnered attention due to their widespread availability and bioactive properties. Leaves, seeds, roots, flowers, bark, and fruits have all been explored for their dyeing potential. One particularly promising source is the leaves of Teak (*Tectona grandis* Linn. f.), a valuable tropical timber species known for its rich phytochemical composition. Teak leaves contain flavonoids, alkaloids, tannins, anthraquinones, naphthoquinones, anthocyanins, and cyanidins, many of which exhibit antimicrobial, antioxidant, and dyeing properties (Centeno, 1997) ^[5]. The extraction of dye from teak leaves represents an innovative approach to utilizing a timber industry byproduct, reducing waste, and promoting sustainable dyeing practices.

Teak is a deciduous tree belonging to the family Verbenaceae, predominantly found in tropical and subtropical regions. It is extensively distributed across India, with natural populations occurring in states such as Karnataka, Kerala, Madhya Pradesh, Maharashtra, and Odisha. Teak thrives in well-drained alluvial soils with a pH range of 6.5 to 7.5 and an annual rainfall of 800-2500 mm. It flourishes in warm climates with temperatures ranging from 13 °C to 43 °C and is well adapted to diverse environmental conditions, making it an

ideal resource for large-scale dye production (Ball *et al.*, 2000) [4]. Teak leaves undergo seasonal shedding, typically from November to January in dry regions and in March in wet areas, with leaf renewal occurring in May. These naturally shed leaves, often considered waste, can be repurposed for dye extraction, providing an eco-friendly alternative to synthetic dyes. The primary colourant compounds in teak leaves vary with leaf age and extraction conditions, making it essential to quantify dye yield from different stages of leaf development.

Numerous studies have explored the optimal extraction and dyeing conditions for teak leaf dyes. Qadariyah *et al.* (2018) [17] examined Soxhlet extraction and Ultrasound-Assisted Extraction (UAE), concluding that the highest dye yield (42.79%) was obtained at pH 3 with an extraction time of 20 minutes at 60°C. The application of mordants significantly altered the final colour, with fixatives such as ferrous sulfate yielding darker shades. Agarwal *et al.* (2020) [1] standardized dyeing conditions using various natural and chemical mordants, demonstrating that wool exhibited dark reddish-brown hues, whereas nylon displayed light pink tones. Vankar *et al.* (2003) [25] reported successful dyeing of cotton and silk fabrics using methanolic teak leaf extract, with alum and stannic chloride producing light brown shades. Similarly, Khanpetch *et al.* (2005) [8] explored the effects of different mordants, noting that ferrous sulfate imparted greenish-yellow hues while alum resulted in reddish-purple shades. Further, Rosyida *et al.* (2018) [19] highlighted the role of anthocyanins in teak leaves, showing that pH variations influenced colour expression. At pH 5, unmodified extract produced purple-red hues, while alum and ferrous sulfate mordants shifted colours to reddish-purple and black, respectively. Mohammad *et al.* (2016) [12] demonstrated the potential of teak leaf anthraquinones in wool dyeing, developing 36 distinct shades using combinations of metal mordants. Khorana *et al.* (2021) [9] identified ethyl acetate extracts as yielding the most intense reddish-brown pigments, with aluminium hydroxide enhancing colour intensity by adsorbing flavonoids and anthraquinones.

While significant progress has been made in understanding the dyeing potential of teak leaves, limited studies have focused on quantifying dye yield from leaves at different developmental stages. Additionally, the absorption efficiency of natural fabrics using pre, simultaneous, and post-mordanting treatments requires further evaluation. This study aims to address these gaps by assessing the dye yield from young, mature, and old teak leaves extracted using ethanol in a Soxhlet apparatus. Furthermore, it seeks to optimize the dyeing process by testing different mordants and mordanting techniques to enhance colour fastness and absorption efficiency.

By leveraging the untapped potential of teak leaves for natural dye production, this research contributes to sustainable textile practices and the reduction of environmental pollution associated with synthetic dyes. The integration of teak leaf dyes into mainstream textile industries could provide an eco-friendly, economically viable, and aesthetically diverse alternative to synthetic colourants.

2. Materials and Methodology

The materials utilized during this study were organized based on the different stages of dye extraction and fabric dyeing. These included:

- 1. For preparation of teak leaf powder:** Fresh teak leaves, weighing scales, measuring jugs, grinders, scissors, sieves and labelled containers.
- 2. For Soxhlet extraction:** A Soxhlet extractor, ethanol (99.9% purity), teak leaf powder, glass beakers, petri dishes, spatulas, measuring cylinders, funnels, filter paper and cotton thread.
- 3. For preparation of mordants:** Areca nut (*Areca catechu*), betel leaves (*Piper betle*), amla (*Phyllanthus emblica*), copper sulfate and vinegar.
- 4. For preparation of dye bath:** Distilled water, teak leaf powder (young leaves) and induction stoves.
- 5. For fabric dyeing:** Cotton fabric (dimensions: 30 cm × 30 cm, 12.49 gm), mordants, dye bath solutions and temperature monitoring equipment.

Teak leaves were collected from the Kajuru teak plantation in Somwarpet, Kodagu on March 2023. Both tree canopy leaves and those from regenerating plants were harvested manually. A total of 1.42 kg of leaves, including young, mature and old leaves, were collected for the study. The collected leaves were categorized into three stages—young, mature and old based on their position on the node. Young leaves were purplish and smaller, mature leaves were green and medium-sized, and old leaves were larger with a brownish-green colour. The leaves were separated, midribs removed (for mature and old leaves, table 1) and shade-dried for 10 days. Once dried, the leaves were pulverized into powder (table 2), sieved and stored in labelled containers. The cotton fabric which were to be used for dyeing was scoured to remove impurities and enhance dye absorption. This process involved soaking the fabric in hot water (60°C) containing 50 ml/L of a non-ionic detergent for 10 minutes. The fabric was then rinsed thoroughly under running water and sun dried before dyeing.

Table 1: Weight of leaves at different stages of the tree

Sl. No.	Stage of the leaves	Initial weight (g)		Dry weight (g)
		With midrib	Without midrib	
1	Young	630	--	251.05
2	Mature	465	305	177.5
3	Old	330	285	190.78

Table 2: Weight of powdered leaves

Sl. No.	Stage	Weight of the powder (g)
1	Young leaves	171.90
2	Mature leaves	123.64
3	Old leaves	119.57

Two types of mordants were used in the study

- 1. Natural mordants:** Areca-nut, beetle leaves and amla were made into smaller pieces and then sun dried for a day. Each of these were taken in powdered form (200 gm each) and made into 1liter decoction by boiling it in 1.5 liters distilled water for 20-25 minutes.

- 2. Chemical mordants:** Copper sulfate and vinegar solutions (5%) were prepared by dissolving 5 g of the solute in 95 ml of water.

Quantification of dye using soxhlet extraction and preparation of dye bath

To determine the stage of teak leaves with the highest dye yield, Soxhlet extraction was performed using ethanol as a solvent. Five grams of teak leaf powder (from each leaf stage) was packed into thimbles and extracted with 300 ml ethanol at 60°C. The process was repeated until the solution

turned colourless. The ethanol-dye mixture was then evaporated at 80°C to obtain the solid dye. Observations revealed that young leaves yielded the highest dye content (5.16 g), followed by mature (4.69 g) and old leaves (2.83 g, table 3). Based on the Soxhlet results, only the young leaves were used for dye bath preparation. A total of 161 g of young teak leaf powder was boiled in six litres of water for 3.5 hours. The mixture was continuously stirred until a thick consistency was achieved, after which it was cooled, filtered, and stored in bottles. The dye extract was deep maroon in colour.

Table 3: Observations of soxhlet extraction

Stage of the leaf	Total no. of cycles the (until the extract turned colourless)	Time taken to complete the extraction process (min)	Weight of the dye content (g)
Young	8	245	5.16
Mature	6	175	4.69
Old	5	140	2.83

Dyeing of the fabric

The cotton fabric was dyed using three mordanting techniques:

- **Pre-mordanting:** In this method, the fabric is first treated with the mordant and then put into the dye bath. Initially the fabric was boiled with 250 ml natural mordant or 5% chemical mordant at a temperature between 40-60°C for 45 minutes. It was then sundried for 10 min. The dried fabric was then put into 250 ml dye bath and boiled at the same temperature and time as mentioned above.
- **Simultaneous mordanting:** In this method, the mordant is added to the dye bath itself. Dye bath 250 ml of along with 250 ml of natural mordant or 5% chemical mordant was mixed together and boiled along with the fabric at a temperature between 40-60°C for 45 minutes. The fabric was then sun dried for 10 min.
- **Post-mordanting:** In this method the dyed fabric is treated with the mordant. The fabric was put into 250 ml dye bath and boiled at a temperature between 40-60°C for 45 minutes. It is then sun dried for 10 min. The dried fabric was then put into 250 ml natural mordant or 5% chemical mordant at a temperature between 40-60°C for 45 minutes.

After dyeing, the fabrics were rinsed under running water to remove excess dye and sundried for uniform colour fixation. The dyed fabrics were observed for colour intensity and uniformity.

3. Results and Discussion

The dye yield was quantified using the Soxhlet extraction method with ethanol solvent. The results indicated that yielded the highest dye content in young leaves (5.16 g per 5 g of powder), followed by mature leaves (4.69 g), and old leaves (2.83 g). This higher yield can be attributed to the higher concentration of secondary metabolites like anthocyanins, tannins, and flavonoids in young leaves. These compounds are known to degrade as leaves age. Qadaryyah *et al.* (2018) ^[17] also reported optimized dye yields of 42.79% at pH 3, emphasizing the impact of

extraction parameters on dye yield. Similarly, Amogne *et al.* (2020) ^[3] found that younger plant parts generally exhibit higher dye content due to better metabolite availability.

The colours obtained on cotton fabrics varied significantly with the mordant used:

1. Natural Mordants

- Areca nut imparted a brick-red colour.
- Betel leaves gave a purplish-brown hue.
- Amla provided a light brown with a yellowish tinge.

2. Chemical Mordants

- Vinegar resulted in a light brown with purplish undertones.
- Copper sulfate produced the darkest shade, ranging from blackish to dark olive green.

The pre-mordanting method generally produced the darkest shades, whereas post-mordanting led to moderate hues. Mordanted fabrics displayed significantly better colour retention compared to non-mordanted fabrics. Colour loss stabilized after 10 washes for mordanted fabrics but persisted in non-mordanted ones. Studies by Khanpetch *et al.* (2005) ^[8] and Rosyida *et al.* (2018) ^[19] corroborate the role of mordants in achieving a broader spectrum of colours and enhancing colour fastness. The study also evaluated pre-mordanting, simultaneous mordanting, and post-mordanting techniques. Pre-mordanting consistently provided darker and more uniform shades, particularly with chemical mordants. The enhanced colour uptake during pre-mordanting aligns with findings by Agarwal *et al.* (2020) ^[11], who observed better dye absorption when mordants were applied prior to dyeing.

Teak leaves, a by-product of the timber industry, present an eco-friendly alternative to synthetic dyes. The dye extraction process (using ethanol) and the use of natural mordants align with sustainability goals. Moreover, teak dyes can replace hazardous synthetic dyes, which are associated with pollution and health risk.

Table 4: Colour imparted on the fabric during different stages of natural mordanting

Sl. No.	Mordant	Stage of mordanting		
		Pre	Simultaneous	Post
1	Areca-nut (Brick red)			
2	Beetle leaves (Purplish brown)			
3	Amla (Light brown having a yellow tinge)			

Table 5: Colour imparted on the fabric during different stages of chemical mordanting

Sl. No.	Mordant	Stage of mordanting		
		Pre	Simultaneous	Post
1	Vinegar (Light brown having purplish tinge)			
2	Copper sulphate (Blackish to dark olive green)			

4. Conclusion

The conventional method for dye extraction involved scouring, quantification using a Soxhlet apparatus and dye extraction through boiling. The use of different mordants resulted in a variety of colours, with the non-mordanted fabric displaying a brown colour, evenly distributed across the fabric. In contrast, the colours on mordanted fabrics were uneven, possibly due to the limited quantity of dye bath used. The darkness of the colours varied, following this order: Copper sulphate > Areca-nut > Vinegar > Amla > Betel leaves. Chemical mordants, applied at a 5% concentration, imparted more colour compared to the 250ml of natural mordants. Teak leaves were found to produce a range of shades from light to dark brown, with tones varying from yellowish to black. Given their abundance, teak leaves present a promising and eco-friendly source of natural colourants for textile dyeing on a commercial scale. Further studies could explore the optimization of mordant concentrations and dye bath quantities, as well as the environmental impacts of using natural versus synthetic mordants. Research on the sustainability and scalability of natural colourants, especially from plants like teak, would be valuable for promoting eco-friendly practices in the textile industry. Additionally, exploring alternative natural mordants and their effects on colour yield and fabric

properties would expand the scope for eco-conscious textile dyeing.

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