

Ethnobotanical valorization of mahogany bark (*Swietenia macrophylla*) as a plant-based natural dye for sustainable batik in Aceh, Indonesia

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Abstract. Novita N, Dahlan D, Iqbar I, Bahi M. 2026. Ethnobotanical valorization of mahogany bark (*Swietenia macrophylla*) as a plant-based natural dye for sustainable batik in Aceh, Indonesia. *Asian J Ethnobiol* 9: y090112. <https://doi.org/10.13057/asianjethnobiol/y090112>. Growing concern about synthetic dye pollution has renewed ethnobiological interest in plant-based colorants as expressions of traditional ecological knowledge and biocultural heritage. In Aceh, Indonesia, bark-derived dyes have long been associated with local textile practices, yet many remain poorly documented and underutilized in contemporary batik production. This study examines the ethnobiological relevance and dyeing performance of mahogany bark (*Swietenia macrophylla*), a culturally familiar tree species and abundant urban pruning residue, as a natural dye for cotton batik. Although this research does not include primary ethnographic fieldwork, it is informed by documented regional knowledge of bark-based dyes and current artisanal batik practices in Aceh. Mahogany bark collected from the Universitas Syiah Kuala (USK) Green Campus, Aceh, was air-dried, milled, and extracted using an energy-efficient aqueous method at 90°C (yield: 18.7±1.2%). Cotton fabrics were dyed under three mordanting conditions (no mordant, alum 10% owf, and iron 5% owf). CIELAB analysis showed consistent chromatic variation, ranging from light yellow-brown (unmordanted) to bright yellowish (alum) and deep brown-gray (iron). Fastness tests (ISO 105) indicated moderate to excellent wash, rub, and light fastness, with iron-mordanted samples performing best. Statistical analysis (ANOVA, $p < 0.05$) confirmed significant treatment effects. By linking material performance with ethnobiological context, this study contributes to ethnobiology by demonstrating how traditional plant knowledge can be revitalized through circular, low-waste dyeing systems, supporting the biocultural sustainability of Acehnese batik.

Keywords: Acehnese batik, CIELAB, mordant, sustainable textile, *Swietenia macrophylla*

INTRODUCTION

Textile dyeing represents a long-standing domain of human–plant interaction in which material practices embody traditional ecological knowledge, cultural values, and artisanal skill. Across Asia, natural dyes derived from leaves, barks, woods, and roots have functioned not only as sources of color but as components of biocultural systems shaped by local environments and intergenerational knowledge transmission. Within this context, batik constitutes a knowledge system in which motifs, materials, and dye plants collectively express cultural identity rather than serving purely technical ends. Natural dyes have received renewed attention not only for their environmental advantages but also for their roles within localized knowledge systems and culturally embedded production strategies (Cardon 2007; Martin 2010).

In Indonesia, batik traditions developed through close engagement with locally available dye plants, including tannin-rich barks valued for their durability and earthy, symbolic tones. The use of natural dyes in Indonesia is closely linked to the transmission of artisanal knowledge and adaptive resource management rather than static or

purely historical traditions (Iskandar and Iskandar 2016; Setyowati and Wardah 2018). However, the widespread adoption of synthetic dyes since the mid-19th century has fragmented ethnobotanical knowledge. While synthetics improved consistency and efficiency, their production and effluents introduced persistent pollutants with documented ecological and health impacts (Alegbe et al. 2024; Periyasamy 2024).

Recent sustainability and circular-economy initiatives have renewed interest in natural dyes as biodegradable alternatives, yet much contemporary research emphasizes material optimization while insufficiently engaging with ethnobiological dimensions such as cultural continuity and biocultural conservation. This gap is particularly evident in Aceh, where batik remains culturally significant but increasingly dependent on imported synthetic dyes. Despite extensive technical research on tannin-rich dye sources, little attention has been given to how urban or managed plant residues enter contemporary craft knowledge systems within Southeast Asian ethnobiological contexts (Gavin et al. 2018).

Swietenia macrophylla (mahogany) is a widely planted tree species in Aceh's urban and agroforestry landscapes. Routine pruning and timber processing generate substantial

bark residues that are typically discarded. Ethnobotanically, mahogany and other tannin-rich barks have been used for coloring, tanning, and preservation across cultures, indicating relevance beyond their role as timber resources. Phytochemical studies confirm that *S. macrophylla* bark contains tannins and polyphenols that can bind cellulose fibers and interact with metal salts (Negreros-Castillo and Mize 2014; Benli 2024).

Despite this potential, ethnobiologically informed studies on mahogany bark as a textile dye remain scarce in Indonesia, where research has focused primarily on well-documented species such as *Caesalpinia sappan* and *Terminalia* spp. (Somparsong et al. 2025). Following ethnobiological approaches that recognize adaptive, practice-based knowledge, this study treats artisan observations as contextual insights rather than formal ethnographic data, focusing on material performance while situating results within biocultural use frameworks (Albuquerque et al. 2014; Reyes-García et al. 2019).

This study contributes to Asian ethnobiology by documenting the contemporary potential of a culturally familiar but underutilized plant resource within a traditional textile knowledge system. By framing mahogany bark as part of Aceh's human-plant relationships rather than solely as a technical dye material, the research demonstrates how empirical material analysis can support knowledge revitalization, circular resource use, and biocultural sustainability.

MATERIALS AND METHODS

Study area

This study was conducted at the Universitas Syiah Kuala (USK) Green Campus, Banda Aceh, Aceh Province, Indonesia. Aceh constitutes a meaningful ethnobiological setting due to its long-standing batik traditions, in which plant-based materials historically formed part of localized craft knowledge. The cultural actors relevant to this study are Acehnese batik artisans and small-scale producers operating in urban and peri-urban contexts, where access to locally available dye plants influences sustainable practice.

Mahogany is widely planted in Aceh's urban landscapes and institutional grounds. Although not a primary dye plant in contemporary batik, its bark belongs to a broader ethnobotanical category of tannin-rich barks traditionally associated with coloring and related utilitarian functions in Southeast Asia. Routine pruning on the USK campus generates bark residues that are typically discarded; in this study, such residues were used to reflect a realistic, low-impact resource accessible to urban artisans within a circular-use framework (Figure 1).

Mature trees (12-15 m tall; 25-35 cm diameter) were selected, and bark residues were collected during scheduled campus maintenance without intentional tree felling. The bark was shade-dried (28-32°C) to $\leq 10\%$ moisture content over seven days, milled, and stored before extraction. This study did not involve direct engagement with artisans or Indigenous knowledge holders. Ethnobiological interpretation is based on documented regional knowledge

and publicly available sources, and no ethical clearance for human-subject research was required.

Raw materials and preparation of dye extract

Mahogany bark residues (*S. macrophylla*) were collected during routine pruning at the Universitas Syiah Kuala (USK) Green Campus, Banda Aceh. The bark was shade air-dried (28-32°C) for seven days, then oven-dried at 50°C for 24 h to achieve constant weight. The dried bark was milled and sieved to a 60-mesh particle size.

Aqueous extraction was performed under a single, fixed condition, as reported in the Results. Briefly, 100 g of powdered bark was mixed with 1,000 mL of distilled water (1:10 w/v) and heated at 90°C for 60 min with continuous stirring (250 rpm). After cooling, the extract was filtered through Whatman No. 1 and concentrated to 20% of its original volume using a rotary evaporator at 45°C under reduced pressure.

Extraction yield (%) was calculated as:

$$\text{Yield (\%)} = \frac{\text{weight of concentrated extract}}{\text{weight of dry bark}} \times 100$$

The final extract showed a mean yield of 18.7±1.2% and pH 5.8±0.1. A distilled-water blank was processed in parallel as a procedural control but was not included in dyeing trials.

Fabric selection and pretreatment

Bleached 100% cotton primissima fabric (80 g m⁻²) was used. Samples (10×10 cm; 1.0±0.05 g) were scoured in 2 g L⁻¹ Na₂CO₃ at 100°C for 30 min, thoroughly rinsed with distilled water, and shade-dried. All samples were conditioned at 21°C and 65% relative humidity for 24 h before mordanting and dyeing.



Figure 1. Mahogany trees are cultivated at the Universitas Syiah Kuala (USK) Green Campus in Banda Aceh, Indonesia. The bark pruning residues were utilized as a sustainable raw material for natural dye extraction, exemplifying circular resource use by transforming urban tree waste into an eco-friendly dye source for Acehnese batik

Mordanting procedure

Three mordanting treatments were applied, corresponding exactly to those reported in the Results: (1) no mordant (control), (2) alum ($\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$) at 10% owf, and (3) ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) at 5% owf. Mordanting was carried out at a liquor ratio of 1:30 at 60°C for 45 min. Samples were rinsed with distilled water and lightly towel-dried before dyeing.

Dyeing procedure

Dyeing was carried out using the concentrated mahogany bark extract at a liquor ratio of 1:30. Fabric samples were dyed at 80°C for 60 min with constant agitation (200 rpm). The dye bath pH remained stable at 5.9 ± 0.1 . After dyeing, samples were rinsed until the rinse water ran clear and shade-dried at ambient temperature.

Dye exhaustion (%) was calculated as:

$$\text{Exhaustion (\%)} = \frac{A_0 - A_t}{A_0} \times 100$$

The mean dye exhaustion was $72.4 \pm 2.8\%$. Each treatment was conducted in triplicate ($n=3$).

Colorimetric measurement (CIELAB System)

Color measurements were performed using a Datacolor 650 spectrophotometer, calibrated with a white standard under D65 illumination and a 10° observer angle ($d/8^\circ$ geometry; 30 mm aperture). Five measurements were taken at random positions on each sample and averaged. The recorded parameters included L^* , a^* , b^* , chroma (C^*), and hue angle (h°):

$$C^* = \sqrt{a^{*2} + b^{*2}}, h^\circ = \tan^{-1} \left(\frac{b^*}{a^*} \right)$$

Total color difference (ΔE^*) between treatments was calculated using the CIE76 equation:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Fastness testing

Fastness properties were evaluated using internationally standardized ISO methods. Wash fastness: ISO 105-C06 (5 g L^{-1} soap, 40°C, 30 min); rubbing fastness: ISO 105-X12 (dry and wet); light fastness: ISO 105-B02 (xenon arc lamp, 20 h exposure). Fastness ratings were assessed using the standard gray scale (wash and rub) and the blue wool scale (light fastness).

Statistical analysis

All reported experiments were conducted in triplicate ($n=3$). Colorimetric data (L^* , a^* , b^*) were obtained from five readings per sample and expressed as mean \pm standard deviation. Color differences (ΔE^*) among mordant treatments were calculated relative to the unmordanted control. Differences among treatments were evaluated using one-way analysis of variance (ANOVA). When significant effects were detected ($p < 0.05$), Tukey's HSD post hoc test was applied. Fastness ratings were treated as numerical scores and analyzed using the same ANOVA framework. All analyses were performed using IBM SPSS Statistics 25. Graphs were generated using OriginPro 2024.

RESULTS AND DISCUSSION

Dye extraction performance and chemical implications

Aqueous extraction of *S. macrophylla* bark collected during routine urban pruning at the Universitas Syiah Kuala (USK) Green Campus, Banda Aceh, Aceh Province, Indonesia, produced a stable yellow–brown dye liquor at 90°C for 60 min (1:10 w/v), with a mean extraction yield of $18.7 \pm 1.2\%$ and a mildly acidic pH (5.8 ± 0.1). This yield falls within the range reported for tannin-rich barks used historically and contemporarily in natural dyeing, confirming mahogany bark as a chemically competent dye source rather than an incidental waste material (Alegbe and Uthman 2024; Pizzi et al. 2024).

UV-Vis spectra showed absorption maxima between 380 and 430 nm, consistent with hydrolysable tannins and flavonoid-derived chromophores. These compounds are widely documented as key contributors to yellow–brown hues and strong fibre affinity in plant-based dyes (Gao et al. 2024; Pizzi et al. 2024). Comparable spectral features have been reported for bark extracts used in traditional dye systems across tropical regions, including the Amazon Basin and Southeast Asia (Santiago et al. 2023; Araujo et al. 2025).

The moderately acidic extract favoured cellulose fibre swelling and dye penetration, supporting effective dye–fibre interactions without alkaline degradation. Importantly, extraction relied solely on water and moderate heating, aligning with low-energy, craft-compatible practices described in sustainable natural dye frameworks (Pizzicato et al. 2023; Ivanovic 2025). From an ethnobiological perspective, the simplicity of this extraction pathway enhances its potential transferability to artisanal batik workshops in Banda Aceh and the surrounding Aceh Besar districts, where access to advanced chemical inputs is limited.

Visual shade development and reproducibility

Distinct, reproducible shades emerged across mordanting treatments (Figure 2). Unmordanted cotton produced light golden–tan hues, alum yielded brighter yellow–brown tones, and iron generated dark olive–brown to grey–brown shades. These chromatic shifts align closely with documented tannin–metal complexation behaviour in both historical and contemporary dyeing traditions (Hynes and Coinceanainn 2001; Hosseinnezhad et al. 2020; Benli 2024).

Such shade modulation is widely recognised in ethnographic dye literature, where iron mordants are used to achieve darker, more subdued tones and alum to enhance brightness and warmth (Alegbe and Uthman 2024; Quispe-Quispe et al. 2025). The reproducibility observed across replicates indicates that mahogany bark dyeing can achieve the consistency required for batik production, which is essential for artisans working in cooperative workshops in urban Banda Aceh and peri-urban Aceh Besar.

Culturally, these warm, earthy shades resonate with Acehnese batik aesthetics, which often emphasise vegetal motifs and subdued natural palettes rather than highly saturated colours. The ability to obtain multiple tones from

a single plant resource mirrors adaptive knowledge practices documented in other ethnobiological contexts, where dye plants are valued for versatility as much as for colour intensity (Santiago et al. 2023; Brlek et al. 2025).

Colorimetric properties and mordant effects

CIELAB measurements quantitatively confirmed visual trends. Lightness (L^*) decreased markedly from the unmordanted to the iron-mordanted samples, while alum increased yellowness (b^*), producing brighter hues. Iron treatment produced lower L^* and b^* values, reflecting the formation of iron–tannin complexes that absorb across a broader visible spectrum (Trejo-Huizar et al. 2020; Wen et al. 2023).

These outcomes align with dyeing studies using bark, peel, and nutshell wastes, which show that metal mordants strongly influence chroma and darkness (Dulo et al. 2022; Islam et al. 2024). For artisans, this confirms that mordant choice—rather than increased dye concentration—offers an efficient pathway to colour diversification, reducing raw material demand and supporting resource-efficient craft production.

Fastness performance and practical suitability

Fastness ratings ranged from moderate to excellent. Iron-mordanted samples showed the highest wash (4-5) and light fastness (5-6), while alum produced intermediate improvements. These results align with the established behaviour of tannin-based dyes, in which metal coordination enhances dye–fiber bonding and photostability (Hynes and Coinceanainn 2001; Brlek et al. 2025).

Comparable fastness values have been reported for other bark- and waste-derived natural dyes intended for functional textiles (Quispe-Quispe et al. 2025; Somparsong et al. 2025). In practical terms, the performance achieved meets basic durability expectations for batik garments used in daily life in tropical urban environments such as Banda Aceh, particularly in indoor or low-UV exposure contexts.

Environmental performance and urban biomass valorisation

Based on observed pH behaviour and published evidence on tannin-rich dyes, the dyeing process exhibited characteristics associated with lower environmental risk than synthetic dyes, which are widely reported to generate

persistent toxicity and high pollutant loads (Berradi et al. 2019; Ardila-Leal et al. 2021; Periyasamy 2024). Although biodegradability was inferred from tannin chemistry rather than directly measured, existing reviews consistently report reduced ecological impacts for tannin-based dye effluents (Pizzicato et al. 2023; Alegbe and Uthman 2024).

The use of urban mahogany pruning residues situates this study within broader bioeconomy and waste-valorisation frameworks documented for forestry by-products in tropical regions (Guo et al. 2024; Araujo et al. 2025). In Banda Aceh, where mahogany is widely planted as a shade and ornamental tree, such residues represent a predictable, low-cost dye resource that does not compete with food or timber uses.

Contextual ethnobiological insights

Informal observations drawn from publicly documented artisan demonstrations and secondary sources indicate a strong interest in mahogany bark dye for its tonal flexibility and perceived environmental safety. These sources indicate that producing multiple shades from a single locally available plant aligns with adaptive strategies within Acehnese textile knowledge systems. These observations are presented as contextual insights rather than formal ethnographic data, consistent with the guidance on transparently delineating the knowledge scope. Nevertheless, they illustrate how chemical performance intersects with cultural valuation, a core concern of ethnobiology (Alegbe and Uthman 2024).

Synthesis and ethnobiological relevance

Taken together, the results demonstrate that *S. macrophylla* bark from Banda Aceh, Indonesia, functions as a reliable tannin-based dye that produces culturally valued hues with acceptable durability and a relatively low environmental impact. By linking dye chemistry, urban biomass reuse, and artisan practice, this study contributes to ethnobiology by documenting how non-traditional plant materials can be integrated into living craft knowledge systems. The findings support broader arguments that sustainable textile futures depend not only on material performance but also on culturally embedded practices and locally grounded resource use (Ivanovic 2025; Li et al. 2025).

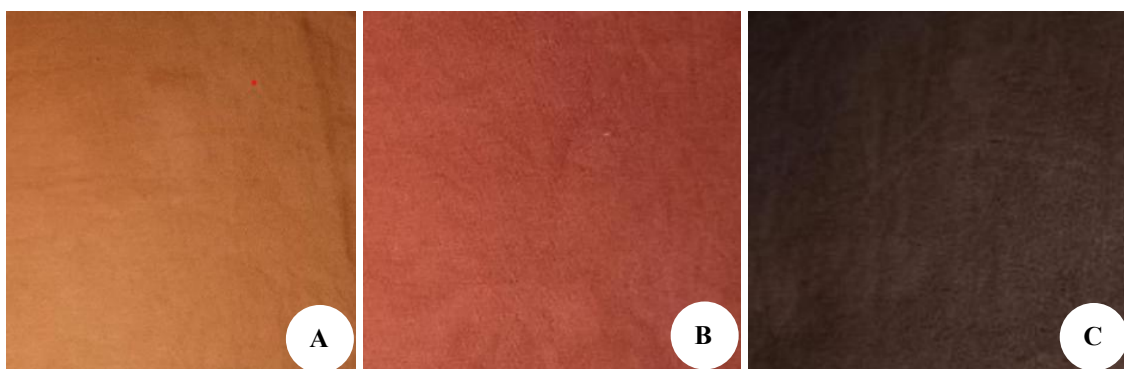


Figure 2. Representative color bars of mahogany-dyed cotton under three mordant conditions. A. No mordant, B. Alum, C. Iron



Figure 3. Acehnese batik product featuring motifs inspired by local flora and dyed with natural extracts from mahogany bark. The reddish-brown to deep brown hues were obtained through aqueous extraction and mordanting with alum ($\text{Al}_2(\text{SO}_4)_3$) and ferrous sulfate (FeSO_4), which enhanced both brightness and color fastness. The integration of ethnobotanical resources with traditional batik techniques demonstrates the potential of natural dye innovation to produce textiles with high artistic value and eco-friendly attributes. This approach highlights the role of sustainable dyeing practices in reducing reliance on synthetic chemicals, valorizing pruning residues, and strengthening the cultural identity of Acehnese batik in the context of contemporary sustainable fashion

Ethnobiological significance

This study documents the adaptive use of urban mahogany bark in Acehnese batik production in Banda Aceh, demonstrating how locally available plant residues can be integrated into culturally meaningful dyeing practices (Figure 3). It highlights the role of plant-based knowledge in sustaining environmentally responsible livelihoods within contemporary urban settings.

In conclusion, mahogany bark from urban pruning can serve as a reliable natural dye for cotton batik, yielding reproducible earth tones with acceptable fastness when mordanted with alum or iron. Ethnobiologically, this study documents the contemporary integration of an underutilised local plant resource into Acehnese craft practice, illustrating adaptive plant use rather than inherited tradition. The findings contribute applied evidence to ethnobiology while remaining limited to material and practice-based analysis.

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