

Color from Nature: Preserving and Promoting Thai Cultural Heritage through Natural Dyeing with Local Plants in Mae Tha District, Lampang Province

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ABSTRACT

This study focused on improving the traditional natural dyeing practices in the Mae Tha community in Thailand. Initial assessments revealed that yarns dyed using traditional techniques with local plant extracts, e.g., lac and sappan wood, often demonstrated inconsistent color quality and low color fastness. Potassium aluminum sulfate (alum) and tin (II) chloride were applied as mordants to improve both color uptake and color durability. The dyed fabrics appeared reddish in all cases. We improved the dyeing practices by carefully controlling the dye extraction processes and adjusting dyeing techniques, as well as using standardized measurement tools to ensure color consistency. Results from color measurements (tested by a modern scientific instrument) confirmed that the dyeing process increased color uniformity and fastness to washing and artificial perspiration. This study demonstrates that traditional practices can be successfully integrated with scientific techniques, thereby preserving cultural heritage while promoting sustainable and eco-friendly methods.

Keywords: Lac dye; Natural dyeing; Promoting Thai wisdom; Sappan wood; Sustainable textile practices

1. Introduction

Mae Tha District is located in Lampang Province, Northern Thailand. It has a rich history in terms of customs and

culture. According to the Archaeological Sites Database of Thailand (2021), the district lies on an ancient volcanic site, where the uppermost bedrock is composed

of basalt formed from lava flows approximately 500,000 to 900,000 years old. The region also features hilly terrain and several flowing streams, which make it geographically unique and have significantly influenced the community's way of life and culture.

The Mae Tha community has a long-standing tradition of dyeing and weaving local textiles, with knowledge passed down through generations. However, such practices have declined due to the changes in both social values and economic priorities. Younger generations have increasingly migrated to urban areas in search of better opportunities, leading to a gradual erosion of traditional wisdom and cultural identity.

However, in recent years, there has been renewed interest in traditional weaving and natural dyeing practices—particularly those using plant-based dyes. Efforts have been made to select the suitable local plants that can produce vivid colors to improve the product appeal. The use of fabrics or yarns made from natural fibers, such as cotton, silk, or hemp, which are hand-woven by local villagers and dyed with natural colors, is regarded as a green product with cultural value. Hand-woven textiles dyed with natural colors are gaining popularity in both domestic and international markets. This not only helps generate income for the community but also preserves cultural heritage for future generations. This revival of traditional weaving and dyeing practices, as seen in Mae Tha, not only strengthens Thailand's cultural identity but also supports environmental sustainability.

A key advantage of natural dyeing over synthetic dyeing lies in its perceived safety for both humans and the environment. As sustainability becomes increasingly important alongside economic and so-

cial development, the environmental impacts of industrial synthetic dyes have come under scrutiny. While synthetic dyes offer convenience, faster processing, and superior colorfastness, they are often non-biodegradable and pose serious environmental risks. In contrast, when properly applied, natural dyes and dyeing processes can be safer for human health and the environment, while also contributing to the conservation of traditional cultural practices. Common natural dye sources include lac, teak leaves, and sappan wood.

Sappan wood (*Caesalpinia sappan*) and lac (*Laccifer lacca*) are well-known natural sources of red dyes. The major colorant in sappan wood is brazilin, which is found in the heartwood [1, 2]. Interestingly, the residue from sappan wood after dye extraction can be further utilized to produce activated carbon, adding value to the process. Lac dye, which is obtained from the secretion of the insect *Laccifer lacca*, contains laccic acids that yield deep reddish hues [3]. When used in conjunction with metal mordants, both dyes exhibit synergistic effects, enhancing the color depth and color fastness.

This research focuses on improving the traditional dye extraction and natural dyeing processes practiced in the Mae Tha community. Scientific measurements and standardized procedures have been applied to the processes to improve product quality, while maintaining cultural significance and promoting environmental sustainability.

Natural dyes are commonly used on textiles derived from natural fibers, such as cotton, silk, and wool, to enhance their perception as environmentally friendly. The dyeing process typically requires the use of mordants—substances that help fix the dye to the fiber. The application of mordants often alters the shades of the dyed products

and improves color durability. It should be noted that apart from dye and mordant types, their concentrations and application procedure may have a significant influence on the final color outcomes [4-6].

Several studies have investigated the functional potential of natural plant dyes. Brazilin, which is a red homoisoflavonoid found in sappan wood, is able to bind to fibers through hydrogen bonding or the formation of coordination complexes with metallic mordants. Apart from textile dyeing, sappan wood has also been used in Asian folk medicine due to its therapeutic properties. Reference [7] reported that crude ethanolic and methanolic extracts of *C. sappan* contained diverse phytochemicals with excellent antibacterial activity. When applied to nonwoven textiles, the extract achieved up to 99% antibacterial efficacy against *Staphylococcus aureus*, depending on the concentration of the extract [8]. Dyed linen fabrics using sappan wood extract and four metal salt mordants (Fe, Cu, Sn, and Al), resulted in varied color hues and UV protection performance. They found that iron (Fe) yielded the highest color strength and ultraviolet protection factor (UPF). Reference [4] investigated the dyeing of wool yarns with sappan wood extract. Unmordanted samples appeared in many shades ranging from yellowish to red. Light yellow hues and deeper yellow hues were obtained from samples mordanted with aluminum sulfate and ferrous sulfate, respectively [1]. Colorfastness to washing ratings were improved. Reference [9] claimed that wool fabrics dyed with sappan wood extract and mordanted with aluminum, copper, or zinc salts exhibited improved UV protection, mechanical strength, and colorfastness. Reference [10] expanded the color spectrum of cotton fabrics by using a binary sequential dyeing technique.

The technique combined sappan wood (red) and *Galla chinensis* (black), producing 100 distinct colors across 14 color tones, underscoring the industrial potential of natural dyes.

References [11, 16] conducted lac dyeing of cotton using the supercritical CO₂ dyeing technique. They found that the pre-treatment of cotton with polyethylene glycol 400, aluminum acetate, tannic acid, and benzamide before dyeing improved dye uptake. References [12, 15] compared conventional and ultrasonic lac dyeing on cationized cotton fabrics. They claimed that ultrasonic dyeing produced superior color strength and fastness properties. Reference [13] used chitosan as a bio-mordant to improve the microwave-assisted lac dyeing of linen. The resulting fabrics exhibited good colorfastness and UV protection. Reference [14] investigated lac-dyed silk fabrics using different mordants (Al, Fe, Cu, and Sn) and dyeing methods (pad-batch and pad-dry). They found that the mordant type significantly influenced the color shades and fastness. The dyed fabrics displayed red to gray hues.

Collectively, these studies demonstrate that the natural colorants must be used with appropriate mordants and proper dyeing procedures, including dyeing time and temperature. The resulting dyed products could exhibit promising color shade and color fastness. These findings could provide a valuable foundation for improving the quality of the local textile production.

2. Materials and Methods

Following an initial investigation of the traditional dyeing practices of the community, the traditional yarn preparation and dyeing processes were modified to ensure greater consistency and repeatability of the results. Table 1 summarizes the traditional

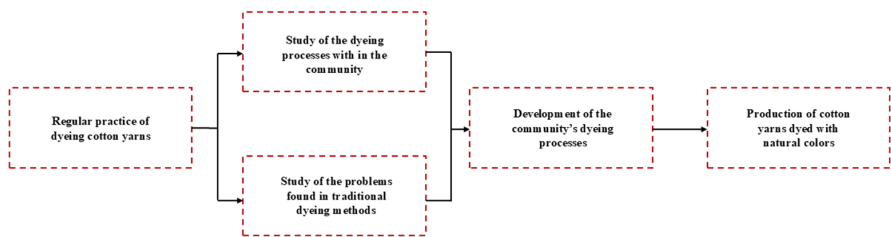


Fig. 1. Conceptual framework illustrating the research process, including the assessment of traditional dyeing practices, implementation of methodological improvements, and evaluation of outcomes.

Table 1. Traditional dye preparation and dyeing process for cotton yarns using a combination of lac and sappan extracts (pre-improvement method by the local community).

step	Process Demonstration	Process Description
1.		Sappan wood is soaked in an estimated amount, typically one handful of wood per 5 L of tap water, and boiled for approximately 30 min to extract the dye.
2.		The dye solution is separated from the boiled sappan wood in preparation for the dyeing process.
3.		The extracted sappan wood dye is returned to the stove, and two teaspoons of lac dye powder are added to intensify the color
4.		Two handfuls of sodium chloride are added to the mixture before bringing it to a boil.
5.		The cotton yarn is immersed in the dye solution for approximately 1 hour without weighing the yarn beforehand.
6.		After dyeing, the yarn is hung to dry without separating or aligning the strands.
7.		The dyed yarn is dipped in a solution of alum blocks dissolved in tap water at room temperature, then rinsed until clean and hung to dry again.

techniques for cotton yarn preparation and dyeing using colorants from sappan wood and lac (referred to as the improvement method). Table 2 presents the improved process developed by the research team (post-improvement method). The key modifications introduced to enhance the yarn preparation and natural dyeing processes are as follows:

1. Precision in measurement: Thermometers, digital scales, and accurate calculations were used throughout the process to replace estimation-based practices.

2. Standardized material ratios: Fixed dye material to water, yarn, salt, and mordant ratios were established to ensure consistent dyeing outcomes.

3. Revised mordanting sequence: The process was shifted from post-mordanting (application of mordants after dyeing) to pre-mordanting (before dyeing), enhancing dye absorption and improving color fastness.

4. Expanded mordant selection: In addition to the traditional use of potassium aluminum sulfate, tin (II) chloride, which is low-toxic, was introduced to evaluate its effect on dyeing performance.

5. Color evaluation: Color values and fastness properties of the dyed yarn samples were analyzed using standardized testing procedures.

Following an initial investigation of

Table 2. Improved dye preparation and dyeing process for cotton yarns using a combination of lac and sappan wood extracts (post-improvement method by the research.

step	Process Demonstration	Process Description
1.		Preparation of dyeing equipment
2.		Sappan wood is cut into small pieces and soaked in water at a ratio of 1:15 for 24 hours to maximize the extraction of dye.
3.		The cotton yarn is pre-cleaned at 60°C for 30 minutes to remove impurities, followed by rinsing in clean water and air drying.
4.		Mordanting is performed using 3% alum or tin (II) chloride (based on yarn weight), heated to 60°C for 30 minutes. The yarn is turned regularly for even absorption and then dried.
5.		The soaked sappan wood mixture is filtered through a muslin cloth and a strainer to remove wood particles, yielding a clean dye solution.
6.		The pre-mordanted yarn is immersed in the sappan wood extract at a liquor-to-material ratio (L:R) of 1:20 with 2% lac dye powder and 3% sodium chloride. The mixture is heated to 80°C for 1 hour, with gentle stirring. The yarn is then rinsed until the water runs clear and dried in the shade.
7.		The dyed yarn shows consistent coloration and improved quality, indicating the effectiveness of the process.

the traditional dyeing practices of the community, the traditional yarn preparation and dyeing processes were modified to ensure greater consistency and repeatability of the results. Table 1 summarizes the traditional techniques for cotton yarn preparation and

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3. Result and Discussion

As shown in Fig. 2(a), the yarn dyed using the pre-improvement method exhibited poor color uniformity across dyeing batches, including visible inconsistencies within individual strands. This lack of consistency presents challenges for production control and quality assurance. In contrast, the yarn dyed using the post-improvement method displayed significantly improved color uniformity after adopting standardized measuring instruments and refining the

dyeing procedure, as demonstrated in Figs. 2(b)-2(c). Therefore, the post-improvement dyeing method allowed for the prediction of the amount of raw materials required and also enabled the replication of the dyeing results. It was found that the community members were able to repeat the processes and obtained yarns with more consistent color.



Fig. 2. Images of yarn dyed using the (a) pre-improvement method and (b, c) post-improvement method, demonstrating enhanced color uniformity and consistency after process refinement.

Furthermore, the overall shades of the dyed cotton yarns differed between the pre-improvement and post-improvement processes. These variations are ascribed to improved control over dyeing parameters, i.e., precise measurements of dye, mordant, yarn, water, and salt, strict regulation of temperature and time, and modification of mordanting technique. Following the dyeing process, samples from both methods were evaluated using scientific instruments. Color values were measured using a spectrophotometer according to the CIELab* system (GretagMacbeth LLC, Switzerland).

As shown in Table 3, the pre-improvement dyeing method produced yarns with an L^* value of 54.41, indicating a relatively dark appearance. The a^* value of 24 corresponds to a strong red hue, whereas the b^* value of -0.24 suggests a neutral position between yellow and blue, with negligible influence from either component. A chroma (C^*) value of 24 indicates moderate color saturation, and a

hue angle (h°) of 359.44 aligns with a pure red tone. The color strength, represented by the K/S value, was 8.24, indicating a high degree of dye uptake.

It was found that the yarns dyed using the post-improvement method and alum as a mordant exhibited L^* and K/S values of 55.05 and 8.20, respectively. These values are comparable to those of the pre-improvement samples. The a^* and b^* values increased to 25.57 and 1.75, respectively, indicating a shift toward more reddish and slightly yellowish tones. The chroma increased to 25.63, and the hue angle shifted slightly to 3.91, approaching a reddish-orange tone.

In contrast, the use of tin (II) chloride as a mordant resulted in a substantial increase in L^* to 60.40, indicating a significantly higher brightness. The a^* and b^* values increased to 32.54 and 5.73, respectively, demonstrating an increased contribution of both the red and yellow components. The C^* value reached a peak of 33.04, reflecting the highest color saturation among all methods, while the hue angle (h°) shifted to 9.99, leaning toward a reddish-yellow hue. However, the K/S value decreased to 5.82, indicating a reduced color depth despite the more luminous and vibrant appearance.

The dyeing of cotton yarns with extracts from sappanwood and lac dye was governed by the formation of metal-mediated coordination complexes between cellulose, natural dye molecules, and metal mordants. As shown in Fig. 3, Al^{3+} ions from potassium aluminum sulfate and Sn^{2+} ions from tin (II) chloride acted as bridging agents by coordinating with hydroxyl groups of cellulose and oxygen donor sites of the dyes. Brazilein from sappanwood and laccic acid A from lac dye contained multiple functional groups, such as phe-

nolic hydroxyl, carbonyl, and carboxylate moieties, which exhibited strong affinity toward multivalent metal ions [17-19]. This metal–dye–cellulose coordination reduced dye solubility in the dye bath and enhanced dye fixation on cotton fibers, thereby improving dye uptake and retention.

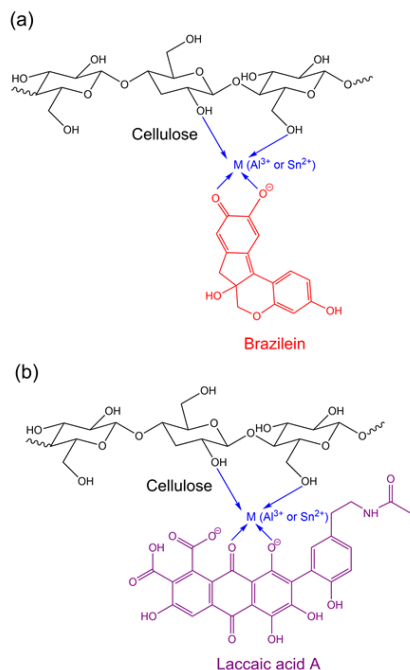


Fig. 3. Proposed coordination complexes between cellulose, metal mordants (Al^{3+} or Sn^{2+}), and (a) brazilein derived from sappanwood, and (b) laccic acid A, a representative dye component of lac dye.

In summary, alum maintained the original color depth while slightly improving the saturation and hue shift. In contrast, tin (II) chloride enhanced lightness and chroma but reduced color strength. Generally, increased L^* and C^* values are desirable for applications requiring bright and vivid textiles, whereas low L^* values with high K/S values are preferred for deeper, more saturated color applications.

Table 4 presents the results of the wash fastness test for yarns dyed with a

mixture of lac and sappan wood, evaluated in accordance with ISO 105-C06:2010. In the gray scale assessment for color change, yarns dyed using the pre-improvement method received a rating of 1, indicating poor wash fastness with significant color fading. After the introduction of potassium alum and tin (II) chloride, the ratings improved slightly to 1–2 (poor to fair), suggesting enhanced dye fixation and a modest improvement in washing resistance.

In contrast, the gray scale assessment for staining on adjacent fabrics showed more distinct differences between the two methods. Yarns dyed using the pre-improvement method exhibited poor (Grade 1) to moderate (Grade 3) staining resistance.

However, those using the post-improvement method achieved significantly higher fastness levels, with most samples rated from good (Grade 3) to very good or excellent (Grades 4–5). The only exception was acetate fabrics, for which both methods yielded similarly high ratings (Grades 3 to 4–5). The relatively low staining observed on acetate is attributed to its chemical structure and interaction with the dye mixture. This outcome can be explained by the polar characteristics of the primary dye compounds—brazilein from sappan wood and anthraquinone derivatives from lac dye—which contain multiple hydroxyl groups and exhibit strong hydrophilicity. In contrast, acetate fibers are relatively hydrophobic due to the acetylation of hydroxyl groups in cellulose, which reduces their affinity for dyes. Consequently, minimal dye transfer occurs, leading to low staining levels on adjacent acetate fabrics.

Significant improvements in staining resistance were also observed on protein-based and amine-containing fibers, such

Table 3. Colorimetric parameters of dyed yarns measured using spectrophotometry (CIELAB Color Space).

Dyeing Process	L*	a*	b*	C*	h°	K/S
Pre-Improvement	54.41	24.00	-0.24	24.00	359.44	8.24
Post-Improvement Using Alum as a Mordant	55.05	25.57	1.75	25.63	3.91	8.20
Post-Improvement Using Tin as a Mordant	60.40	32.54	5.73	33.04	9.99	5.82

as wool and nylon. For wool, the fastness ratings improved from very poor to fair (Grades 1–2) in the pre-improvement method to good (Grade 3) in the post-improvement method. Nylon followed a similar trend, improving from fair (Grade 2) to good or very good (Grades 3–4). These findings suggest that both alum and tin (II) chloride mordants play a crucial role in improving the wash fastness of natural dyes when applied to various textile substrates.

Table 5 presents the results of the color fastness test to acidic artificial sweat, conducted in accordance with ISO 105-E04:2013. This assessment simulates real-life scenarios in which dyed textiles come into contact with perspiration, potentially causing color fading or dye transfer.

Gray Scale evaluations for color change indicate that yarns dyed using both the pre-improvement and post-improvement methods achieved similarly high ratings (Grades 4–5) when mordanted with alum, reflecting very good to excellent color fastness. In contrast, the post-improvement yarn mordanted with tin (II) chloride received a lower rating (Grade 3), suggesting only moderate fastness. This reduction may be attributed to the relative instability of dye-mordant complexes formed between tin (II) ions and the dye compounds in sappan wood and lac under acidic conditions, resulting in greater susceptibility to color change.

The Gray Scale for staining shows

that resistance to dye transfer is generally comparable across all yarns, regardless of mordant type or dyeing method, indicating that these variables had minimal effect on staining behavior under acidic conditions. However, yarns dyed using the post-improvement method and mordanted with alum demonstrated slightly improved staining resistance on wool and nylon fibers. Consistent with previous results on wash fastness, acetate fibers exhibited the highest staining resistance.

Table 6 summarizes the color fastness test results for yarns exposed to alkaline artificial sweat, as evaluated using the Gray Scale. For color change, minimal differences were observed between the pre-improvement and post-improvement samples. The pre-improvement yarns achieved Grades 3–4, indicating good to very good fastness—comparable to the post-improvement yarns mordanted with tin (II) chloride. Notably, the post-improvement yarns mordanted with alum exhibited slightly superior fastness, receiving Grade 4 (very good), outperforming the other samples. Overall, yarns dyed with the combination of lac dye and sappan wood extracts demonstrated acceptable resistance to color change under alkaline perspiration.

However, both color change and staining grades were slightly lower under alkaline conditions than under acidic sweat conditions (Table 5). In the staining evaluation, the results ranged from good to excellent for most adjacent fabrics, except for

Table 4. Color fastness to washing ratings of dyed yarns assessed according to ISO 105-C06:2010.

Yarn Sample	Color Change	Color Staining					
		Wool	Acrylic	Polyester	Nylon	Cotton	Acetate
Pre-Improvement	1	1-2	2	2-3	2	1	4-5
Post-Improvement Using Alum as a Mordant	1-2	3	3-4	4	3-4	3-4	4-5
Post-Improvement Using Tin as a Mordant	1-2	3	4	4	3-4	3	4

Table 5. Color fastness ratings of yarns dyed to acidic artificial sweat, assessed according to ISO 105-E04:2013.

Yarn Sample	Color Change	Color Staining					
		Wool	Acrylic	Polyester	Nylon	Cotton	Acetate
Pre-Improvement	4-5	3-4	4-5	4	3-4	3	4
Post-Improvement Using Alum as a Mordant	4-5	2-3	4-5	4	2-3	2	2-3
Post-Improvement, Using Tin as a Mordant	3	3-4	4-5	4	3-4	3	4

cotton, which consistently showed lower resistance to staining. Particularly in yarns subjected to the post-mordanting method, staining on cotton was poor, with grades of 1 to 1–2.

The persistently low staining resistance of cotton under both acidic and alkaline conditions is attributed to the composition of artificial sweat, which contains high concentrations of salts such as sodium chloride and ammonium chloride. These salts increase the ionic strength of the solution and destabilize dye–mordant complexes by enhancing their ionization and solubility, thereby promoting dye migration. This effect is more pronounced under alkaline conditions, leading to the re-binding of dissociated dye molecules to the abundant hydroxyl groups of cotton through hydrogen bonding and ionic interactions.

These observations align with the consistently lower staining grades recorded for cotton in both Tables 5 and 6 compared to other fiber types. In contrast, the synthetic and protein-based fibers exhibited more moderate staining.

The slightly diminished fastness under alkaline conditions may also be attributed to the greater susceptibility of the dye–mordant complexes to hydrolysis or

dissociation. Alkaline environments, particularly those containing hydroxyl groups, enhance the ionization of dyes, thereby increasing solubility and mobility. In contrast, acidic conditions exert a weaker destabilizing effect, contributing to improved color retention and reduced staining.

4. Conclusion

This study successfully supported the Mae Tha Community's weaving group in refining traditional cotton yarn dyeing practices using locally sourced natural dyes, namely lac dye and sappanwood extract. Although the improved dyeing method involved additional preparatory steps and standardized measurement procedures, it effectively reduced overall processing time and material consumption on a per-batch basis by enabling predictable dye uptake and reproducible color quality within a single dyeing cycle. Compared with conventional practices, which often suffered from inconsistent dyeing and required repeated dyeing or re-mordanting, the refined approach minimized material waste, labor, and reprocessing time. The adoption of scientifically guided dye formulation and revised mordanting procedures resulted in improved color uniformity and,

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Yarn Sample	Color Change	Color Staining					
		Wool	Acrylic	Polyester	Nylon	Cotton	Acetate
Pre-Improvement	3-4	4	4-5	4	4	2-3	3
Post- Improvement Using Alum as a Mordant	4	3	4	3-4	3	1	1-2
Post-Improvement Using Tin as a Mordant	3-4	4	4	3-4	3-4	1-2	2-3

in some cases, enhanced color fastness to washing and artificial perspiration. Beyond technical improvements, this work contributed to the preservation of Thai cultural heritage, fostered local employment, and promoted environmentally responsible, sustainable natural-dye products that reflect Thai identity.

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