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Original Article

Exploration of natural dyes from local plants in west Sumatera for the development of sustainable environmentally based ecoprint

Exploração de corantes naturais de plantas locais do oeste de Sumatra para o desenvolvimento de ecoprint sustentável e ambientalmente baseado

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Abstract

Sustainability issues and environmental impacts of synthetic dyes have encouraged increased exploration of environmentally friendly natural dye sources. This study aims to identify the potential of local plants from the highlands of West Sumatra as a source of natural dyes, and to analyze the effect of mordant types on color variation and fastness in cotton fabrics. Ten local plant species were used as sources of natural pigments from leaves and bark. Three types of mordants—alum ($KAl(SO_4)_2{\bullet}12H_2O$), calcium carbonate ($CaCO_3$), and tunjung ($FeSO_4{\bullet}7H_2O$)—were applied to produce color variations. Fastness tests were conducted using three types of washing agents (Lerak Extract, Soklin Liquid, and Soklin Bleach) and analyzed quantitatively with a spectrophotometer at a wavelength of 625 nm. The results showed that the use of mordant significantly affected the intensity and color fastness. Tunjung tends to produce darker colors and has the best resistance for guava leaves (Psidium guajava), while alum is more effective for ambacang (Mangifera foetida) skin. Some materials such as pomegranate peel and guava peel show high resistance without the use of mordant due to their strong natural tannin content. Natural detergent Sari Lerak is proven to be the safest for maintaining color stability compared to commercial chemical detergents. These findings confirm that the highlands of West Sumatra have a potential diversity of flora as a source of sustainable natural dyes. This research provides a scientific basis for the development of environmentally friendly ecoprint technology based on local wisdom and supports the transition towards a sustainable textile industry in Indonesia.

Keywords: natural dyes, ecoprint, mordant, colorfastness, ethnobotany.

Resumo

Questões de sustentabilidade e impactos ambientais de corantes sintéticos têm incentivado a crescente exploração de fontes de corantes naturais ecologicamente corretas. Este estudo visa identificar o potencial de plantas locais das terras altas do oeste de Sumatra como fonte de corantes naturais e analisar o efeito de diferentes tipos de mordentes na variação de cor e na solidez da cor em tecidos de algodão. Dez espécies de plantas locais foram utilizadas como fontes de pigmentos naturais extraídos de folhas e cascas. Três tipos de mordentes – alúmen [$KAl(SO_4)_2{\bullet}12H_2O$], carbonato de cálcio ($CaCO_3$) e tunjung ($FeSO_4{\bullet}7H_2O$) – foram aplicados para produzir variações de cor. Testes de solidez da cor foram conduzidos utilizando três tipos de agentes de lavagem (Extrato de Lerak, Líquido Soklin e Alvejante Soklin) e analisados quantitativamente com um espectrofotômetro em um comprimento de onda de 625 nm. Os resultados mostraram que o uso de mordente afetou significativamente a intensidade e a solidez da cor. O Tunjung tende a produzir cores mais escuras e apresenta a melhor resistência para folhas de goiaba (*Psidium guajava*), enquanto o alúmen é mais eficaz para a casca de ambacang (*Mangifera foetida*). Alguns materiais, como casca de romã e casca de goiaba, apresentam alta resistência sem o uso de mordente devido ao seu forte teor de tanino natural. O detergente natural Sari Lerak comprovou ser o mais seguro para manter a estabilidade da cor em comparação com detergentes químicos comerciais. Estas descobertas confirmam que as terras altas de Sumatra Ocidental possuem uma diversidade potencial de flora como fonte de corantes naturais sustentáveis. Esta pesquisa fornece uma base científica para o desenvolvimento de tecnologia de ecoprint ecologicamente correta, baseada no conhecimento local, bem como apoia a transição para uma indústria têxtil sustentável na Indonésia.

Palavras-chave: corantes naturais, ecoprint, mordente, firmeza de cor, etnobotânica.

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1. Introduction

The global textile industry currently faces a major challenge in reducing the environmental impact caused by the use of synthetic chemicals, particularly artificial dyes. Synthetic dyes, while efficient, have proven to be a major source of water and soil pollution due to hazardous waste that is difficult to decompose (Teshayev et al., 2025; Hasanah et al., 2024). Various studies have shown that residues from synthetic dyes contain heavy metals and aromatic compounds that are toxic and carcinogenic to living organisms. This situation is driving a paradigm shift towards the concept of green chemistry and sustainable textile production, which emphasizes the use of natural, environmentally friendly, and renewable materials (Makhmudova et al., 2025; Lawanna et al., 2025).

Indonesia, as a mega-biodiverse country, has extraordinary potential to develop natural dye sources from various tropical flora. One region with outstanding biodiversity is West Sumatra, which boasts a highland landscape with a unique tropical mountain forest ecosystem. The biodiversity in this region not only reflects ecological richness but also holds significant opportunities for the development of environmentally-based creative industries such as ecoprinting—a fabric dyeing technique that utilizes the natural shapes and colors of plants (Pancapalaga et al., 2023; Risnasari et al., 2025).

However, this enormous potential has not been optimally utilized. The use of local plants as a source of natural dyes remains very limited among traditional artisans and textile industry players (Basri, 2023). Lack of knowledge regarding the types of pigment-producing plants, the dye extraction process, and the appropriate use of mordants (color-fixing agents) are major inhibiting factors. As a result, most artisans still rely on imported, environmentally unfriendly synthetic dyes, while the richness of local flora remains scientifically and practically untapped (Hadawi et al., 2025; Babamuratov et al., 2025; Noor, 2025).

Natural dyes have several significant advantages over synthetic dyes. In addition to producing soft and aesthetically pleasing shades, natural dyes are also skin-safe, environmentally friendly, and can be integrated into products of high cultural value. Natural pigments such as tannins, flavonoids, and anthocyanins, found in the leaves, bark, or fruits of plants, can produce a rich variety of colors and possess strong symbolic value when linked to local cultural motifs and philosophies, such as the deeply entrenched Minangkabau motif. The use of natural dyes in the context of ecoprinting, by embracing local motifs, has the potential to support cultural preservation while strengthening a creative economy based on local wisdom (Khaydarova et al., 2025; Mavlyanova et al., 2024).

However, one of the main technical challenges in the application of natural dyes is their poor colorfastness to washing, light, and friction. This factor is often caused by a limited understanding of the role of mordants as chemical binders between pigments and textile fibers. Various types of mordants, such as alum (alum), calcium carbonate, and ferrous sulfate (tunjung) have different effects on the final color, both in terms of intensity and durability (Abdikarimova et al., 2024; Tran et al., 2025; Chakramurty et al., 2025; Allayarov et al., 2025). Therefore, it is important to conduct systematic research to identify the interactions between mordant types and natural dye sources from local flora in order to determine the most effective and sustainable combination.

From a local perspective, exploring the potential of plants from the West Sumatran highlands is strategically important. In addition to supporting natural resource conservation, the results of this research can also serve as a scientific basis for developing eco-fashion and sustainable crafts that are competitive in the global market. Integrating local wisdom with environmentally friendly technological innovation will strengthen Indonesia's position in the global movement toward a circular economy and sustainable production. Therefore, research on natural dyes based on local flora in West Sumatra is not only ecologically valuable but also has broad socio-economic and cultural dimensions.

Based on these research questions, this study aims to: (1) inventory and explore the potential of local plants from the West Sumatran highlands as a source of natural dyes; (2) analyze the effect of various types of mordants on the variation and intensity of the resulting colors; and (3) test color fastness to various natural and commercial washing agents. Through an experimental approach and quantitative analysis, this research is expected to provide scientific and practical contributions to the development of sustainable natural dye technology, while also supporting the empowerment of the local craft industry based on Minangkabau cultural wisdom.

2. Methods

2.1. Research design

This research used a laboratory experimental approach with a quantitative descriptive-comparative design. The main objective of the study was to identify the potential of local plants from the West Sumatra highlands as natural dye sources and to analyze the effect of mordant types on color variation and fastness in cotton fabrics.

The experiment was conducted in four main stages:
(1) Scouring (fabric pretreatment),
(2) Extraction and Dye Application (extraction and dyeing),
(3) Mordanting and Fixation (mordanting and color fixation), and
(4) Wash Fastness Testing (color fastness testing).

All procedures were carried out in the Textile Technology and Natural Dyeing Laboratory in 2025.

2.2. Materials and equipment

a. Main materials:
    1) Fabric substrate: 100% cotton (plain weave cotton), chosen for its high absorbency and excellent chemical interaction with natural dyes.
    2) Natural dye sources: Leaves and bark from 10 species of local plants native to the West Sumatra highlands, including Psidium guajava, Garcinia mangostana, Mangifera foetida, Persea americana, Mangifera indica, Dimocarpus longan, Archidendron pauciflorum, Pometia pinnata, Punica granatum, and Coffea spp.

3) Mordanting chemicals:

a) Alum (Potassium Aluminum Sulfate / $KAl(SO_4)_2 \cdot 12H_2O$),

b) Calcium Carbonate ($CaCO_3$),

c) Tunjung (Ferrous Sulfate / $FeSO_4 \cdot 7H_2O$).

4) Detergents:

a) Natural detergent (Lerak Extract),

b) Commercial liquid detergent (Soklin Liquid),

c) Bleach detergent (Soklin Pemutih).

b. Main equipment:

Glass beaker, stainless steel dye bath, water bath, magnetic stirrer, UV–Vis spectrophotometer (625 nm wavelength), digital scale, and oven dryer.

2.3. Experimental procedure

a. Fabric Pretreatment (Scouring Process)

The cotton fabric was first washed to remove dirt, wax, and manufacturing residue. The fabric was soaked in a solution of 15 g of soda ash (Na_2CO_3) and 15 g of Turkey Red Oil (TRO) in 400 mL of hot water (~80°C) until the water cooled. Afterward, the fabric was rinsed with clean water and hung to dry. This step aims to increase the fiber's ability to absorb dye.

b. Initial Mordanting Process

Initial mordanting is carried out to open the pores of the fabric fibers and prepare them for stronger binding with the dye molecules. The fabric was soaked for 20 minutes in a solution consisting of:

1) 150 g of alum,
2) 25 g of tunjung (a type of bamboo),
3) 12 g of table vinegar,
4) 50 g of baking soda,
5) and 1.5 L of water.

The fabric is then sun-dried without rinsing to maintain the natural mordanting reaction.

c. Extraction and Dyeing Process

250 g of plant material (leaves or bark) is soaked in 1.5 L of water with 0.5 g of table salt added for 12 hours. The mixture is boiled until the water volume is reduced by one-third, then filtered to obtain a concentrated dye solution.

The mordanted fabric is soaked in the color extract for 12 hours to obtain the basic color. Next, to produce derived shades, the fabric is re-dyed with the addition of one type of mordant (8 g of alum, tunjung, or calcium carbonate in 200 mL of the basic color extract). The 30-minute soaking time is selected based on preliminary test results to ensure optimal pigment absorption.

d. Final Fixation Process

This process aims to lock the color into the fabric fibers to ensure washability. The fixation solution was prepared by mixing 50 g of alum and 50 g of tunjung in 100 mL of water, allowing it to settle for 12 hours, and then using only the supernatant. The fabric was dipped for a maximum of 10 seconds, rinsed, then re-immersed in the fabric softener solution for 10 seconds and dried in the shade.

2.4. Color fastness test (Wash fastness test)

The color fastness test was conducted using three types of washing agents:

(1) Soap Nut Extract (natural),
(2) Soklin Liquid, and
(3) Soklin Bleach (commercial).

A 10x10 cm fabric sample was washed using 500 mL of detergent solution at 40°C for 10 minutes with constant agitation. After drying, the color fastness level was measured quantitatively using a UV–Vis spectrophotometer at a wavelength of 625 nm. The absorbance (A) value of the wash water was used to determine the degree of color fading. Interpretation of the results was based on the principle: the higher the absorbance value, the greater the color fastness (meaning lower color fastness). The procedure of analysis is presented in Figure 1.

2.5. Data analysis

Quantitative data from absorbance measurements were processed descriptively and comparatively to determine differences in colorfastness levels between treatments.

The analysis was conducted on:

a. Variation in plant species (10 species),
b. Type of plant part (leaf vs. bark),
c. Type of mordant (alum, calcium carbonate, tunjung), and
d. Type of washing agent.

The average absorbance values were compared to determine the optimal combination of plant species and mordant that produced the most stable color. Data visualization used diagrams to empirically demonstrate the pattern of differences.

2.6. Validity and replication

Each treatment was performed in triplicate samples to ensure the reliability of the results and reduce experimental bias. The validity of the procedure was tested using a control sample, a mordant- and dye-free fabric, to ensure that the color changes were purely caused by natural plant pigments.

2.7. Research ethics and sustainability

All natural materials are collected sustainably without harming the local ecosystem. Liquid waste from the dyeing process is reprocessed using natural filtration (sand, activated charcoal, and zeolite) to maintain environmental safety, in accordance with the principles of green textile technology and a zero-waste approach.

3. Results

The measurement data are presented in tables and bar charts for each variation of mordant and washing agent. An exploration of 10 plant species from the highlands of West Sumatra reveals that leaves and bark are potential sources of natural dyes, producing a diverse spectrum of colors. Table 1 presents the color palette produced from each plant source, both basic colors and derivative colors after the application of three types of mordants (Calcium Carbonate, Alum, and Tunjung).

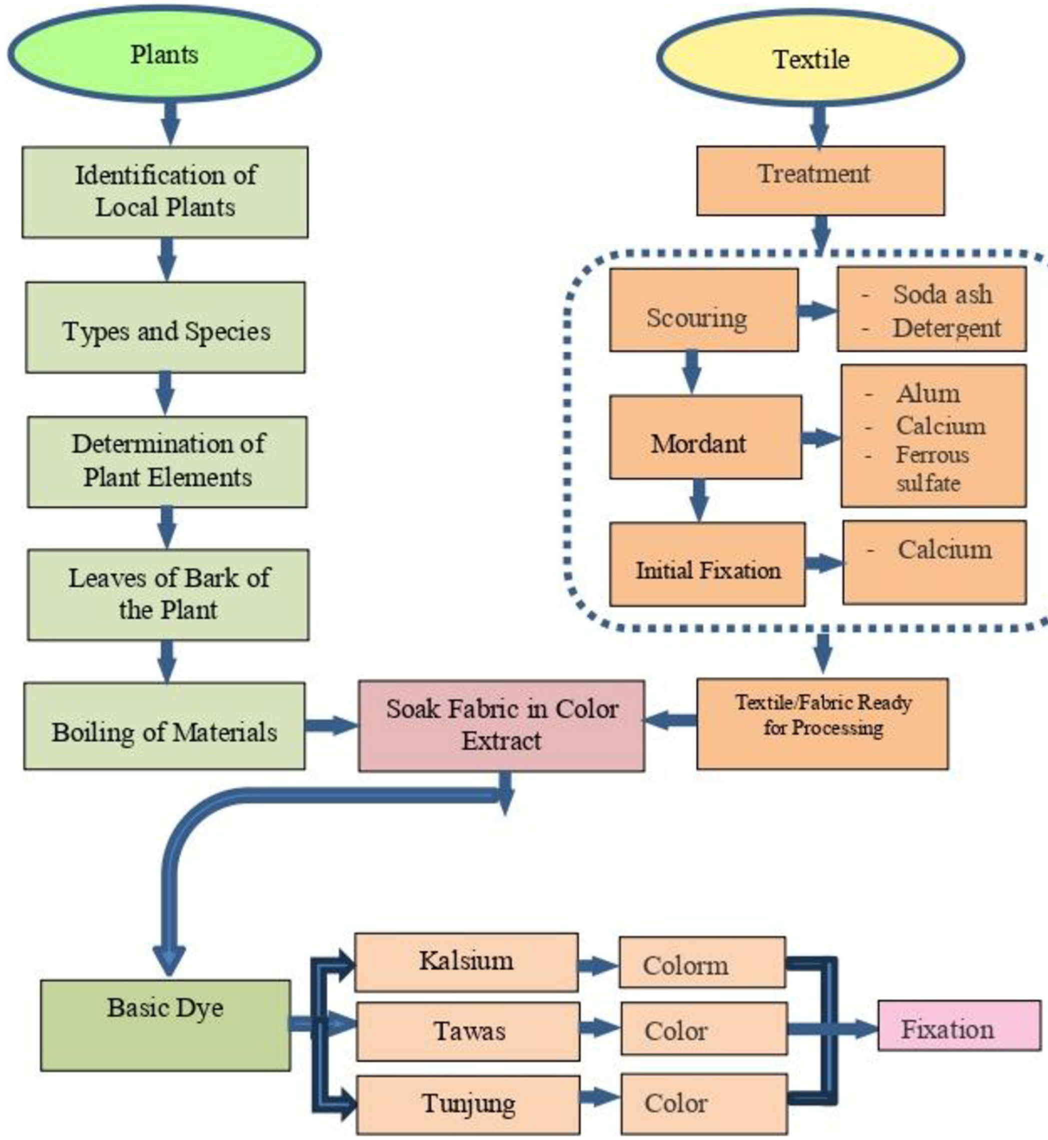


Figure 1. Natural color experiment flow.

The study's results in Table 2 showed that the type of mordant significantly influenced the final color. This is consistent with previous research which stated that mordants function as dye binders to fibers, as well as color generators and modifiers. (Repon et al., 2024). In general, the tunjung mordant ($FeSO_4$) tends to produce darker and more intense colors (for example, on Matoa leaves and Mahogany bark). Alum ($KAl(SO_4)_2$) often produces brighter colors, while calcium carbonate ($CaCO_3$) provides a variety of colors between the two. This difference opens up opportunities for artisans to create a wider color palette from a single dye source.

3.1. Color fastness analysis

To evaluate color durability as see in Table 3, colorfastness tests were conducted on selected samples. The results of the wash water absorbance measurements are presented in the form of a bar chart to visualize the level of colorfastness.

4. Discussion

4.1. Color characteristics of local plant extracts

The extraction process of ten local plant species from the West Sumatra highlands revealed distinct color variations depending on the plant part used (leaves or bark) and their pigment content. In general, leaf extracts produced lighter colors, ranging from yellowish to brownish, while bark extracts tended to produce darker colors, ranging from dark brown, brick red, to blackish gray (Sari et al., 2024; Petrova et al., 2023).

For example, guava leaves (Psidium guajava) and pomegranate peels (Punica granatum) produced a dark brown color due to their high tannin and flavonoid content, which readily bind to cotton fibers. Meanwhile, ambacang (Mangifera foetida) peels produced a strong reddish color due to the presence of anthocyanins and xanthones. These findings align with research by Maharani et al. (2024), which explains that the diversity of chemical compounds in tropical plants influences the intensity and stability of the resulting color.

Table 1. Steps for making natural colors.

Stages	Process	Material	Process
Fabric Treatment	1. Scoring	1. 15 grams of soda ASH	1. Mix the ingredients
		2. 15 gr TRO/Detergent	2. Soak the cloth in cold water
		3. 400 ml hot water	3. Rub then rinse until clean
			4. Dry in the sun until dry
	2. Mordant	1. 150 gr alum	1. mix the ingredients and soak the cloth for 20 minutes
		2. 25 grams of tunjung	2. rub, dry without rinsing
		3. 12 grams of table vinegar	
		4. 50 grams of baking soda	
		5. 1.5 liters of cold water	
	3. Initial Fixation	1. 15 grams of calcium carbonate	1. mix the ingredients
		2. 300 ml cold water	2. Rinse the cloth by dipping it 3-5 times in the initial fixation solution.
			3. rinse with plain water
			4. dry in the sun
Making Basic Natural Dyes		3. 250 gr ingredients (leaves, bark, fruit, etc.)	1. Mix the ingredients then soak overnight
		4. 150 ml water	2. boil until 1/3 of the previous amount of water remains
		5. 0.5 grams of table salt	3. cool then strain and soak the cloth overnight
			4. dry in the sun
Production of Natural Derivative Dyes		1. 200 ml basic natural dye	1. mix the ingredients
		2. 8 grams of alum/calcium carbonate	2. soak the cloth for 30 minutes
			3. dry in the sun
Final fixation		1. 100 ml water	1. Mix and stir the ingredients until dissolved.
		2. 50 grams of alum	2. Let the ingredients dissolve for 12 hours.
		3. 50 grams of tunjung	3. Separate the water from the dregs of the alum and tunjung materials, only take the water from the materials.
		4. Fabric softener	4. Dip the natural dye cloth for a maximum of 10 seconds.
			5. Wash the cloth with plain water
			6. Dip the cloth into the fabric softener liquid for a maximum of 10 seconds.
			7. Dry the cloth in a shady place until dry.

Table 2. Color Variations Produced from Local Plants with Different Mordants (CMYK Color Code).

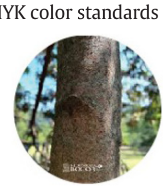
NO	TYPES OF PLANTS	BASIC COLORS	MORDANT		
			CALCIUM CARBONATE	ALUM	TUNJUNG
1.	Guava Leaves (Psidium Guajava) 				
	Color codes according to CMYK color standards	27,38,97,4	16,26,69,0	31,63,100,18	73,69,65,89
	Guava Tree Bark 				
	Color codes according to CMYK color standards	61,65,69,67	64,64,70,70	51,69,77,65	75,68,67,89
2.	Mangosteen Leaves (Garciana Mangostana) 				
	Color codes according to CMYK color standards	36,64,71,24	46,72,72,55	41,76,77,54	67,68,67,82
	Mangosteen Tree Bark 				
	Color codes according to CMYK color standards	45.56.71.29	32,44,66,7	45.61.68.33	52,58,73,43
3.	Ambacang Leaves (Mangifera Foetida) 				
	Color codes according to CMYK color standards	15,41,71,0	2.0,40,0	13,33,68,0	40,59,88,29
	Ambacang Bark (Mangifera Foetida Lour) 				
	Color codes according to CMYK color standards	25,73,62,10	15.58.44.0	18,56,65,2	64,62,68,64
4.	Avocado Leaves 				
	Color codes according to CMYK color standards	42,79,82,61	56,74,71,79	34,73,91,35	58.64,70.63
	Avocado Tree Bark 				
	Color codes according to CMYK color standards	46,50,86,2 9	54.59.76.51	38,47,66,14	64.59,69.57

Table 2. Continued...

NO	TYPES OF PLANTS	BASIC COLORS	MORDANT		
			CALCIUM CARBONATE	ALUM	TUNJUNG
5.	Mango Leaves (Mingifera Indica) 				
	Color codes according to CMYK color standards	47,59,84,42	53,59,82,52	46,63,83,47	74,68,65,87
	Mango Tree Bark 				
	Color codes according to CMYK color standards	56,64,79,68	66,69,67,83	53,53,97,41	75,68,67,90
6.	Longan Leaves (Dimocarpus Longan) 				
	Color codes according to CMYK color standards	48,47,93,26	53,71,68,63	61,54,86,53	71,64,67,76
	Longan Tree Bark 				
	Color codes according to CMYK color standards	48,69,68,52	59,65,74,68	38,63,70,26	74,68,66,88
7.	Jengkol Leaves 				
	Color codes according to CMYK color standards	54,49,76,32	61,58,74,57	55,44,82,28	75,68,66,88
	Jengkol Tree Bark 				
	Color codes according to CMYK color standards	46,59,67,31	55,60,64,42	40,53,65,19	75,68,64,83
8.	Matoa Leaves (Pometia Pinnata) 				
	Color codes according to CMYK color standards	47,64,87,50	50,56,80,39	51,58,92,48	73,69,64,80
	Matoa Tree Bark 				
	Color codes according to CMYK color standards	23,73,71,9	21,81,79,10	25,64,76,11	75,67,65,84

Table 2. Continued...

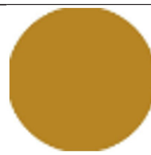
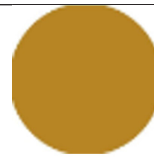
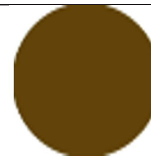
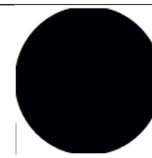
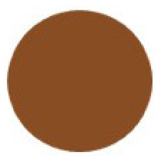
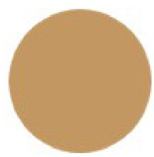
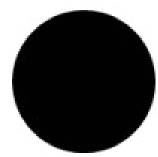
NO	TYPES OF PLANTS		BASIC COLORS	MORDANT		
				CALCIUM CARBONATE	ALUM	TUNJUNG
9.	Pomegranate Leaves					
	Color codes according to CMYK color standards		29,44,100,7	27,46,100,6	44,64,100,44	73,69,64,88
	Pomegranate Peel					
	Color codes according to CMYK color standards		47,69,82,60	59,59,84,61	50,66,81,60	73,69,63,79
10.	Coffee Leaves					
	Color codes according to CMYK color standards		13.49.89.1	18,58,87,3	26,55,84,9	73,64,68,77
	Coffee Tree Bark					
	Color codes according to CMYK color standards		33,71,98,28	24,40,69,2	35,75,87,36	72,68,67,88

Table 3. Results of leaf and back samples.

TREATMENT	ABSORBENT READING				
	SUPER SOAP FRUIT JUICE	SOKLIN LIQUID SOFTENER	SOKLIN WHITENING		
	625 NM	625 NM	625 NM	Amount	Average
Basic Guava Leaves	0.021	0.078	0.084	0.183	0.061
Guava Leaves Calcium Carbonate	0.025	0.040	0.045	0.110	0.037
Guava Leaves Alum	0.012	0.020	0.030	0.062	0.021
Tunjung Guava Leaves	0.006	0.016	0.018	0.040	0.013
Amount	0.064	0.172	0.195		
Average	0.016	0.043	0.049		
Basic Guava Peel	0.023	0.034	0.037	0.094	0.031
Guava Peel Calcium Carbonate	0.059	0.090	0.099	0.248	0.083
Guava Skin Alum	0.018	0.043	0.060	0.121	0.040
Guava Skin	0.038	0.060	0.064	0.162	0.054
Total	0.138	0.252	0.280		

Description: The higher the absorbance value, the higher the light absorbed, the higher the level of dye dissolved in the batik cloth.

Table 3. Continued...

TREATMENT	ABSORBENT READING				
	SUPER SOAP FRUIT JUICE	SOKLIN LIQUID SOFTENER	SOKLIN WHITENING		
Average	0.035	0.063	0.070		
Basic Mangosteen Leaves	0.014	0.064	0.072	0.150	0.050
Mangosteen Leaves Calcium Carbonate	0.018	0.032	0.034	0.084	0.028
Mangosteen Leaves Alum	0.009	0.019	0.028	0.056	0.019
Tunjung Mangosteen Leaves	0.007	0.017	0.019	0.043	0.014
Amount	0.048	0.168	0.182		
Average	0.012	0.042	0.046		
Basic Mangosteen Peel	0.021	0.037	0.040	0.098	0.033
Mangosteen Peel Calcium Carbonate	0.011	0.035	0.045	0.091	0.030
Mangosteen Leaves Alum	0.013	0.048	0.069	0.130	0.043
Tunjung Mangosteen Peel	0.018	0.040	0.047	0.105	0.035
Amount	0.063	0.220	0.249		
Average	0.016	0.055	0.062		
Basic Ambacang Leaves	0.043	0.074	0.082	0.199	0.066
Ambacang Leaves Calcium Carbonate	0.018	0.038	0.040	0.096	0.032
Ambacang Alum Leaves	0.018	0.027	0.028	0.073	0.024
Ambacang Tunjung Leaves	0.021	0.042	0.048	0.111	0.037
Amount	0.100	0.174	0.260		
Average	0.025	0.044	0.065		
Basic Ambacang Leather	0.014	0.027	0.033	0.074	0.025
Ambacang Skin Calcium Carbonate	0.007	0.031	0.034	0.072	0.024
Ambacang Alum Skin	0.007	0.013	0.021	0.041	0.014
Ambacang Tunjung Skin	0.028	0.042	0.051	0.121	0.040
Amount	0.056	0.156	0.181		
Average	0.014	0.039	0.045		
Basic Avocado Leaf	0.012	0.049	0.057	0.118	0.039
Avocado Leaf Calcium Carbonate	0.017	0.035	0.038	0.090	0.030
Avocado Leaf Alum	0.010	0.026	0.035	0.071	0.024
Tunjung Avocado Leaves	0.008	0.015	0.019	0.042	0.014
Amount	0.047	0.150	0.165	0.362	0.121
Average	0.012	0.038	0.041		
Basic Avocado Skin	0.023	0.036	0.038	0.097	0.032
Avocado Skin Calcium Carbonate	0.018	0.053	0.066	0.137	0.046
Avocado Skin Alum	0.010	0.019	0.021	0.050	0.017
Tunjung Avocado Skin	0.022	0.042	0.045	0.109	0.036
Amount	0.073	0.221	0.244		
Average	0.018	0.055	0.061		
Basic Mango Leaves	0.013	0.066	0.070	0.149	0.050
Mango Leaves Calcium Carbonate	0.020	0.037	0.038	0.095	0.032

Description: The higher the absorbance value, the higher the light absorbed, the higher the level of dye dissolved in the batik cloth.

Table 3. Continued...

TREATMENT	ABSORBENT READING				
	SUPER SOAP FRUIT JUICE	SOKLIN LIQUID SOFTENER	SOKLIN WHITENING		
Mango Leaves Alum	0.011	0.024	0.032	0.067	0.022
Tunjung Mango Leaves	0.010	0.020	0.022	0.052	0.017
Amount	0.054	0.153	0.158		
Average	0.014	0.038	0.040		
Basic Mango Skin	0.022	0.031	0.069	0.122	0.041
Mango Peel Calcium Carbonate	0.061	0.090	0.098	0.249	0.083
Mango Peel Alum Seeds	0.014	0.039	0.039	0.092	0.031
Tunjung Mango Skin	0.038	0.063	0.060	0.161	0.054
Amount	0.135	0.251	0.307		
Average	0.034	0.063	0.077		
Basic Longan Leaves	0.016	0.065	0.070	0.151	0.050
Longan Leaves Calcium Carbonate	0.020	0.037	0.063	0.120	0.040
Longan Leaves Alum	0.009	0.020	0.033	0.062	0.021
Longan Leaves	0.006	0.021	0.023	0.050	0.017
Total	0.051	0.158	0.189		
Average	0.013	0.040	0.047		
Basic Longan Skin	0.024	0.033	0.035	0.092	0.031
Longan Skin Calcium Carbonate	0.054	0.083	0.083	0.220	0.073
Longan Skin Alum	0.010	0.035	0.035	0.080	0.027
Tunjung Longan Skin	0.370	0.620	0.059	1,049	0.350
Amount	0.458	0.248	0.260		
Average	0.115	0.062	0.065		
Basic Jengkol Leaves	0.016	0.066	0.079	0.161	0.054
Jengkol Leaves Calcium Carbonate	0.019	0.043	0.051	0.113	0.038
Jengkol Leaves and Alum	0.015	0.029	0.045	0.089	0.030
Jengkol Tunjung Leaves	0.011	0.021	0.032	0.064	0.021
Amount	0.061	0.181	0.210		
Average	0.015	0.045	0.053		
Basic Jengkol Skin	0.023	0.032	0.07	0.125	0.042
Jengkol Skin Calcium Carbonate	0.018	0.047	0.061	0.126	0.042
Jengkol Skin Alum	0.011	0.036	0.059	0.106	0.035
Jengkol Tunjung Skin	0.038	0.063	0.060	0.161	0.054
Amount	0.090	0.129	0.201		
Average	0.023	0.032	0.050		
Basic Matoa Leaves	0.013	0.025	0.035	0.073	0.024
Matoa Leaves Calcium Carbonate	0.02	0.037	0.039	0.096	0.032
Matoa Alum Leaves	0.011	0.020	0.024	0.055	0.018

Description: The higher the absorbance value, the higher the light absorbed, the higher the level of dye dissolved in the batik cloth.

Table 3. Continued...

TREATMENT	ABSORBENT READING				
	SUPER SOAP FRUIT JUICE	SOKLIN LIQUID SOFTENER	SOKLIN WHITENING		
Matoa Tunjung Leaves	0.006	0.031	0.039	0.076	0.025
Amount	0.050	0.116	0.132		
Average	0.013	0.029	0.033		
Basic Matoa Skin	0.013	0.033	0.077	0.123	0.041
Matoa Skin Calcium Carbonate	0.010	0.027	0.062	0.099	0.033
Matoa Skin Alum	0.010	0.042	0.058	0.110	0.037
Tunjung Matoa Skin	0.038	0.040	0.062	0.140	0.047
Amount	0.071	0.182	0.275		
Average	0.018	0.046	0.069		
Basic Pomegranate Leaves	0.016	0.061	0.068	0.145	0.048
Pomegranate Leaves Calcium Carbonate	0.031	0.042	0.044	0.117	0.039
Pomegranate Leaves Alum	0.012	0.021	0.022	0.055	0.018
Tunjung Pomegranate Leaves	0.006	0.031	0.035	0.072	0.024
Amount	0.065	0.173	0.182		
Average	0.016	0.043	0.046		
Basic Pomegranate Peel	0.025	0.036	0.040	0.101	0.034
Calcium Carbonate Fruit Peel	0.060	0.091	0.102	0.253	0.084
Pomegranate Peel Alum	0.018	0.045	0.061	0.124	0.041
Tunjung Pomegranate Skin	0.059	0.080	0.083	0.222	0.074
Amount	0.162	0.243	0.262		
Average	0.041	0.061	0.066		
Basic Coffee Leaves	0.011	0.058	0.060	0.129	0.043
Coffee Leaf Calcium Carbonate	0.029	0.040	0.042	0.111	0.037
Alum Coffee Leaves	0.012	0.022	0.023	0.057	0.019
Tunjung Coffee Leaves	0.007	0.029	0.033	0.069	0.023
Amount	0.059	0.154	0.162		
Average	0.015	0.039	0.041		
Basic Coffee Tree Bark	0.014	0.027	0.029	0.070	0.023
Coffee Tree Bark Calcium Carbonate	0.009	0.021	0.030	0.060	0.020
Alum Coffee Tree Bark	0.010	0.020	0.022	0.052	0.017
Tunjung Coffee Tree Bark	0.060	0.082	0.085	0.227	0.076
Amount	0.093	0.134	0.163		
Average	0.023	0.034	0.041		
	Soaking for 10 Minutes	Soaking for 30 Minutes	Soaking for 15 Minutes		
	25 ml/1000 ml tap water	0.5 ml/1000 ml tap water	12 ml/1000 ml tap water		

Description: The higher the absorbance value, the higher the light absorbed, the higher the level of dye dissolved in the batik cloth.

4.2. Effect of mordant type on color intensity and fastness

The use of mordants significantly influences the brightness and color fastness of dyeing results. The three types of mordants used—alum ($KAl(SO_4)_2 \cdot 12H_2O$), calcium carbonate ($CaCO_3$), and tannin ($FeSO_4 \cdot 7H_2O$)—provide visually and chemically distinct results.

a. Alum produces brighter and more transparent colors, particularly in mango (Mangifera indica) and avocado (Persea americana) leaf extracts. The aluminum ions in alum form strong coordinate bonds with the carbonyl and hydroxyl groups of flavonoid compounds, thereby increasing light reflection and color brightness (Widiana, 2021).
b. Tannin produces darker and more muted colors, such as dark brown or greenish gray. Iron ions act as chromophore enhancers, forming stable iron-tannin complexes, increasing color fastness but decreasing brightness.
c. Calcium carbonate showed moderate color results, but provided even color distribution, especially for anthocyanin-rich extracts such as ambacang skin.

Absorbance measurements at a wavelength of 625 nm showed that fabrics mordanted with tunjung had lower absorbance values after washing, indicating better color fastness. Conversely, fabrics mordanted with alum showed increased absorbance values in the wash water, indicating greater color fading. This confirms the findings of Salma and Eskak (2022) who stated that iron-based mordants are more effective in maintaining natural color stability than aluminum mordants.

4.3. Colorfastness to various detergents

Colorfastness tests showed significant differences between fabrics washed with natural detergents and commercial chemical detergents. Fabrics washed with Soap Nut Extract (a natural detergent derived from the Sapindus rarak fruit) showed the lowest level of colorfastness across all samples. The saponin content in soap nuts acts as a gentle natural surfactant, preventing the bond between the pigment and the fabric fibers.

In contrast, fabrics washed with Soklin Liquid and Soklin Bleach experienced greater colorfastness, especially in samples using alum mordant. The alkaline chemicals and bleaching agents in commercial detergents weaken hydrogen bonds and disrupt the dye-mordant complex.

Quantitatively, the absorbance of the wash water for samples with alum mordant increased by an average of 0.020–0.030, while for samples with tunjung (a type of bamboo) only increased by 0.008–0.012. This indicates that the combination of tunjung mordant and natural detergents produces the highest colorfastness. These results are consistent with research by Nofita and Dewangga (2021), which confirmed that washing using natural ingredients can maintain the color intensity of natural dyes because they do not contain bleaching agents and are gentle on the fibers.

4.4. Comparison of color fastness between leaf and bark extracts

A comparative analysis of leaf-based and bark-based dyes shows that bark extract has higher color fastness. This is due to the higher content of tannins and polyphenolic compounds in the bark tissue, which form stronger metal-organic complexes during the mordanting process.

Pomegranate (Punica granatum) peel, for example, exhibits excellent color fastness even without additional mordant. The high tannin content acts as a natural binding agent (self-fixative), able to bond directly with the cellulose fibers in fabric. Therefore, selecting the right plant part (leaf or bark) is a crucial factor in determining the intensity, durability, and efficiency of the natural dyeing process.

4.5. Environmental and sociocultural implications

The use of local plants as a source of natural dyes not only contributes to sustainable textile production but also preserves Minangkabau cultural identity through environmentally friendly craft practices. The ecoprint technique, which combines local motifs and natural colors, creates aesthetic, economic, and ecological value simultaneously.

This approach also supports the achievement of Sustainable Development Goal (SDG 12), namely responsible production and consumption, by reducing dependence on synthetic chemicals and encouraging the use of renewable natural resources (Firoiu et al., 2025). The integration of traditional knowledge with modern scientific approaches reflects a transdisciplinary approach towards sustainable craft innovation that aligns with green economy principles (see Table 4).

Overall, the results of this study indicate that the flora of the West Sumatran highlands has great potential as a source of sustainable natural dyes. The combination of tannin-rich plant extracts, the use of iron-based mordants, and washing with natural detergents yields the most stable and environmentally friendly color results.

This research makes an important contribution to the development of green textile technology by strengthening the link between:

Table 4. Summary of Main Findings.

Parameters	Yield Trends	The Best Combination
Color Intensity	Higher with alum	Mangifera indica + alum
Color Fastness	Better with tunjung and bark extract	Punica granatum + tunjung
Detergent Type	Most stable with natural detergent (Lerak Extract)	Psidium guajava + tunjung + Soap Nut Extract
Environmental Impact	Lowest with natural ingredients without bleach	All natural treatment

1. Exploration of local natural resources (ethnobotany),
2. Craft technology innovation (ecoprint), and
3. Preservation of Minangkabau cultural values.

These findings confirm that the integration of local wisdom and global sustainability principles can form the basis for the development of ecoprint as a craft innovation model that is not only aesthetic, but also ethical and ecological.

5. Conclusion

The results of this comprehensive study demonstrate that local plants from the West Sumatran highlands have enormous potential as natural dye sources for developing environmentally sustainable ecoprinting. Experiments on ten plant species demonstrated that color variation and fastness are significantly influenced by the plant part, the chemical composition of the pigment, the type of mordant used, and the characteristics of the washing agent.

In general, bark extracts performed better than leaf extracts in terms of both color intensity and durability, due to their high tannin and polyphenol content acting as natural mordants. Pomegranate (Punica granatum) peels and guava (Psidium guajava) leaves were shown to produce stable colors, even without the addition of synthetic mordants, demonstrating the significant potential of these plants as sustainable dyes based on local resources.

The use of an iron-based mordant ($FeSO_4$) yields the highest level of colorfastness, forming a strong metal-organic complex with the natural pigment and cotton fiber. In contrast, alum mordants tend to produce brighter colors but have lower washfastness. Calcium carbonate ($CaCO_3$) produces more neutral and even color results, but is not as strong as tunjung in maintaining color stability. This emphasizes that the effectiveness of a mordant is determined not only by the type of metal but also by its chemical compatibility with the pigment structure of each plant species.

Furthermore, fastness tests indicate that the use of Sari Lerak natural detergent is much more effective in maintaining color stability than commercial chemical detergents. The saponin content in lerak acts as a gentle and environmentally friendly natural surfactant, does not damage the dye-fiber bond, and supports the concept of sustainable textile production. Thus, the combination of local natural dyes, environmentally friendly metal-based mordants, and natural washing agents is an ideal strategy for producing ecological and durable ecoprint products.

From a theoretical perspective, this research enriches the scientific literature in the field of natural textile technology and sustainable craft technology by providing empirical evidence regarding the influence of chemical interactions between tropical plant pigments and various types of mordants on color stability. Practically, the results provide a scientific basis for the development of environmentally friendly textile craft products, while strengthening the integration of Minangkabau local wisdom with the principles of a circular economy and the green creative industry.

This research also has strategic implications in the context of the Sustainable Development Goals (SDGs), particularly Goal 12 on "responsible production and consumption." Through exploring the potential of local flora and applying zero-waste principles, this study demonstrates that natural dyeing practices are not only an ecological alternative but also an innovation model that empowers local communities, increases economic value, and strengthens regional cultural identity.

Data Availability Statement

Data will be available based on the reasonable request.

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