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Utilization of Local Natural Dyes and Mordants in Dyeing Polyester Yarn for Timor Woven Fabrics: Characterization and Potential Applications

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Abstract: The objective of this study was to extract natural dyes from plant parts, characterize them, and evaluate their color fastness properties. The yarns were bleached using hydrogen peroxide at a concentration of 10% (based on fiber weight) at 100°C for 30 minutes. Three natural dyes (teak leaves, turmeric, and mango bark) were selected as natural sources for color extraction, which was carried out for 60 minutes at 100°C. Dyeing was performed both with and without the addition of salt, alum, and lime as mordants. The FTIR spectra of fabrics dyed with natural dye extracts showed absorption bands at 2963–2918 cm⁻¹, indicating the presence of C-H stretching from methyl (CH_3) and methylene ($-CH_2-$) groups found in polyester. The band at 1710–1713 cm⁻¹ originated from the carbonyl (C=O) group, which is a main characteristic of polyester. The band around 1504–1577 cm⁻¹ was identified as aromatic C=C bond stretching. The band at 1338–1242 cm⁻¹ indicated C-O stretching, which may be attributed to ester groups in polyester. The band at 1091–1015 cm⁻¹ represented C-H bending, which is also characteristic of polyester molecules. Turmeric and teak leaves demonstrated better color fastness compared to mango bark.

Keywords: Colorfastness; Extract; Mordanting; Natural dye; Teak leaves

Introduction

The development of natural dyes as textile colorants has increased in recent years (Antarsyah et al., 2025). This trend is closely related to environmental sustainability concerns and the implementation of strict environmental regulations, which have led to a resurgence of natural dyes (Lara et al., 2022). Furthermore, natural dyes are considered a primary source of environmentally friendly colorants. Natural dyes are derived from natural sources such as plants, insects, animals, and minerals, either without or with minimal chemical processing (M. M. Islam et al., 2025). Natural dyes possess both advantages and disadvantages. Some natural dyes exhibit limitations in terms of color stability and brightness, which are influenced by exposure to light, temperature, and pH (Xu et al., 2024). Natural dyes typically have poor fastness properties when applied to fibers. To improve fastness, the application of mordants in the natural dyeing process can be employed (Agustarini et al., 2022).

Mordants form complexes with dye molecules, rendering them insoluble in water and thereby enhancing colorfastness (Shahmoradi). Salts of chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), and tin (Sn) are commonly used

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mordants to improve the colourfastness of naturally dyed textiles (Harsito et al., 2021). The Global Organic Textile Standard (GOTS) and the Ecological and Toxicological Association of Dye and Textile Manufacturers (ETAD) advise against the use of toxic metal salts such as Cu, Cr, Mn, and Sn as mordants in textile dyeing; instead, they recommend the use of environmentally friendly metal salts, such as aluminum and iron, as well as bio-mordants (Jabar et al., 2020). Since ancient times, the most widely employed metal mordant in aqueous extraction of natural dyes has been alum, also known as potassium aluminum sulfate (Jabar et al., 2021). Lime, an inorganic substance primarily composed of calcium hydroxide, has also been reported as a metal mordant for dyeing natural fibers. Additionally, sodium chloride has been utilized as a mordants in fiber dyeing (Jabar et al., 2025).

East Nusa Tenggara (NTT) is globally recognized as a tourist destination rich in unique ikat weaving, which is a source of pride for Indonesia. The local communities tend to use synthetic dyes due to their high color brightness; however, these dyes are not environmentally friendly. Conversely, NTT has abundant plant species that produce natural colorants. Therefore, it is necessary to redevelop yarn dyeing techniques using natural dyes that exhibit good color brightness and colorfastness.

Traditionally, rural communities, particularly in Kefamenanu, dye their materials using leaves, roots, and plant bark, mostly by boiling to obtain the desired colors. *Tectona grandis* contains several pigments, notably a high concentration of anthocyanins, which induce red and brown hues that can be utilized as natural dyes (Chauhan et.al, 2023; Kusumawati et al., 2021). The pigments contained in *Tectona grandis* have previously been isolated and identified, with most classified within the anthraquinone group, such as tectoleafquinone (red), anthratectone (orange), and tectoquinone (yellow), as well as within the flavonoid group, including rutin (yellow) and quercetin (brown) (Charoensit et al., 2021). These dyes are environmentally friendly and do not cause skin allergies, unlike synthetic dyes (Tibkawin et al., 2021).

Curcuma longa is an important spice used in cosmetics, and its pigments have also been employed in traditional medicine. Turmeric is particularly valued for its main pigment constituent, curcumin, which imparts a yellow color to textile fibers and food (Zamri et al, 2017). Mango bark (*Mangifera indica*) contains glycosides, tannins, flavonoid, and phenolic compounds that contribute to coloration, with tannins being essential for natural dyeing processes (Benli, 2024). Extracts with a yellowish hue have been used as mordants. In traditional medicine, aqueous extracts from mango bark have been utilized ethnomedically to treat various diseases (Mishra et al., 2020; Teklemedhin, 2018).

The novelty of this research lies in the combined use of three locally abundant natural dye sources—teak leaves (Tectona grandis), turmeric (Curcuma longa), and mango bark (Mangifera indica)—specifically applied to Kefamenanu yarn dyeing, together with a systematic evaluation of different mordanting conditions and their effect on both color brightness and wash fastness. While previous studies have typically focused on single plant sources or on the chemical characterization of pigments, this work integrates multiple underutilized local dyestuffs into a comparative dyeing system and directly links traditional practices with standardized colorfastness testing. In addition, the study explores the use of environmentally acceptable mordants in line with eco-textile standards, thereby addressing the gap between traditional natural dyeing knowledge and modern eco-textile standards. This research is important because Kefamenanu and the wider East Nusa Tenggara region face a tension between preserving the cultural authenticity of ikat weaving and the increasing reliance on synthetic dyes, which pose environmental and health risks. By optimizing natural dyeing techniques using plant resources that are locally available and already familiar to rural communities, the study offers a practical pathway to reduce dependence on synthetic dyes without sacrificing color quality. Moreover, generating quantitative data on color strength and wash fastness supports the development of natural dye protocols that can be scaled for artisan and small-industry use, contributing to sustainable tourism, local economic empowerment, and compliance with international eco-labeling requirements (Negi, 2025).

This study aims to evaluate the dyeing capabilities of three readily available natural dyes in Kefamenanu: teak leaves, turmeric, and mango bark. The research investigates the effect of mordant presence on the dyeing process and the colorfastness after washing.

Method

Materials

The chemicals used in this study included teak leaves, turmeric, and mango bark obtained from Kefamenanu City; cotton thread; 30% hydrogen peroxide (Merck); sodium chloride (Merck); potassium aluminum sulfate dodecahydrate ($KAl(SO_4)_2 \cdot 12H_2O$, Merck); and calcium hydroxide ($Ca(OH)_2$, Merck).

Bleaching of Yarn

Hydrogen peroxide was used as a bleaching and scouring agent. The concentration of hydrogen peroxide applied was 10% (based on fiber weight) with a ratio of

1:100 at 50°C for 30 minutes. After bleaching, the yarn was rinsed with cold water and dried at room temperature.

Extraction of Natural Dyes

Teak leaves were used as the raw material. The leaves were washed and prepared for extraction. Turmeric was washed, peeled, and blended. The filtrate was then ready for extraction. Meanwhile, mango bark was washed, dried to reduce moisture content, and ground into a fine powder. The powdered mango bark was ready for extraction. Teak leaves, turmeric, and mango bark powder were prepared at a concentration of 35% (based on fiber weight) with a ratio of 1:20 for the extraction process. The extraction procedure was carried out for 60 minutes at 100°C. Subsequently, the solution temperature was lowered to 25°C and filtered using filter paper.

Yarn Dyeing

All dyeing processes were conducted using a liquor ratio of 1:20 at 90°C for 60 minutes. Dyeing was performed with a concentration of 35% (based on fiber weight) for each dye extracted by the aforementioned method. Finally, the dyed yarn was removed, rinsed with running water to eliminate unabsorbed dye, and then dried at room temperature. The dyeing conditions are illustrated in Figure 1.

Figure 1. Thread dyeing process diagram

Mordanting

The mordanting process was conducted using the meta-mordanting method. Sodium chloride, aluminum sulfate, and calcium hydroxide at a concentration of 10% (based on the weight of the fiber) were used as mordants. The yarn was immersed in a dye solution containing mordants at a ratio of 1:20 to investigate the effect of mordants on the color properties of yarn dyed with natural dye extracts. The yarn was placed into the mordant and dye solution at 100°C for 30 minutes. After dyeing, the dyed yarn was rinsed with running water and subsequently dried at room temperature.

Characterization

The yarn was then woven into fabric measuring 60 x 40 cm for colorfastness testing and Fourier-transform infrared spectroscopy (FTIR) analysis. The resistance to washing was evaluated according to the ISO 105-C06:2010 standard method. The physicochemical characteristics of the extract, including pH and melting point, were assessed utilizing a pH meter and a melting point apparatus, respectively. In contrast, parameters such as yield and moisture content were quantified employing gravimetric methods.

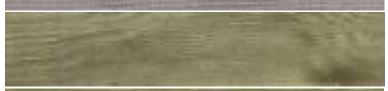
Results and Discussion

Natural colorants predominantly consist of phenolic compounds, which play a crucial role in plant growth and reproduction. Phenolic compounds, based on differences in their chemical structures, are classified into several groups, namely flavonoids, quinones, curcuminoids, and tannins (Wulo & Suparno, 2025).

Colour Characteristics of Woven Fabric

The dyeing and printing processes on fibers, yarns, and fabrics require a bleaching step to remove natural and added impurities, aiming to enhance absorbency and achieve adequate whiteness to accept color effectively (Kurniawidi et al., 2023).

Table 1. Color Characteristics of Woven Fabric

Dye	Mordan	The Resulting Color
Teak leaves	Not	
	NaCl	
	$KAl(SO_4)_2.12H_2O$	
	$Ca(OH)_2$	
Tumeric extract	Not	
	NaCl	
	$KAl(SO_4)_2.12H_2O$	
	$Ca(OH)_2$	
Mango Bark	Not	
	NaCl	
	$KAl(SO_4)_2.12H_2O$	
	$Ca(OH)_2$	

Hydrogen peroxide is an effective oxidizing agent that thoroughly whitens the fabric and is readily removed from the fabric after washing. Dyeing was performed using natural dye extracts derived from turmeric (Curcuma longa), teak leaves (Tectona grandis), and mango bark (Mangifera indica) at concentrations of 35% (based on yarn weight), along with the mordants sodium chloride (NaCl) and potassium aluminum sulfate ($KAl(SO_4)_2 \cdot 12H_2O$), and calcium hydroxide ($Ca(OH)_2$) at concentrations of 10% each (based on yarn weight). The addition of metal mordants can strengthen the interaction between fiber molecules and dye molecules, resulting in higher color intensity compared to treatments without mordants. Dyeing without the use of mordants was employed as a control to compare the resulting color characteristics. The colors produced on each woven fabric are presented in Table 1.

FTIR

FTIR is one of the widely used spectroscopic methods for characterizing functional groups and elucidating molecular interactions. Figures 2, 3, and 4 present the FTIR spectra of fabrics dyed and mordanted in the range of 4000–500 cm^{-1}.

The spectra of fabrics dyed with natural dye extracts exhibit absorption bands at 2963–2918 cm^{-1}, indicating the presence of C–H stretching from methyl (CH_3) and methylene ($-CH_2-$) groups found in polyester. Variations in intensity may be influenced by the type of mordant used. The strong absorption band at 1710–1713 cm^{-1} originates from the carbonyl (C=O) group, which is a primary characteristic of polyester (Kusumawati et al., 2021).

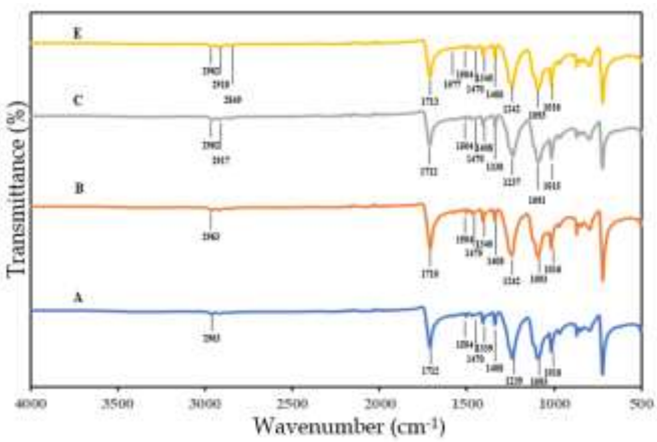


Figure 2. FTIR spectra of fabric dyed with teak leaf extract

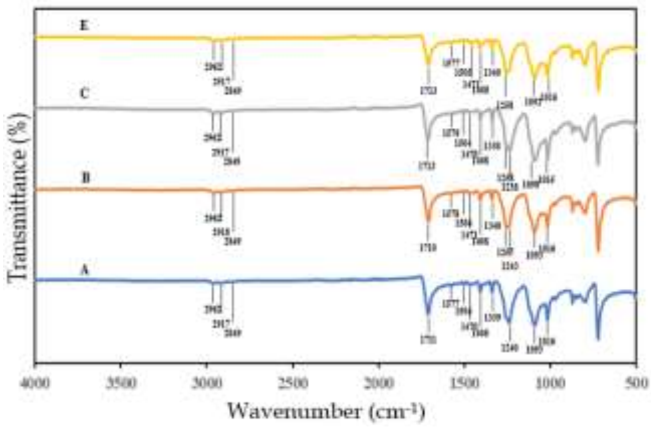


Figure 3. FTIR spectra of fabric dyed with turmeric extract

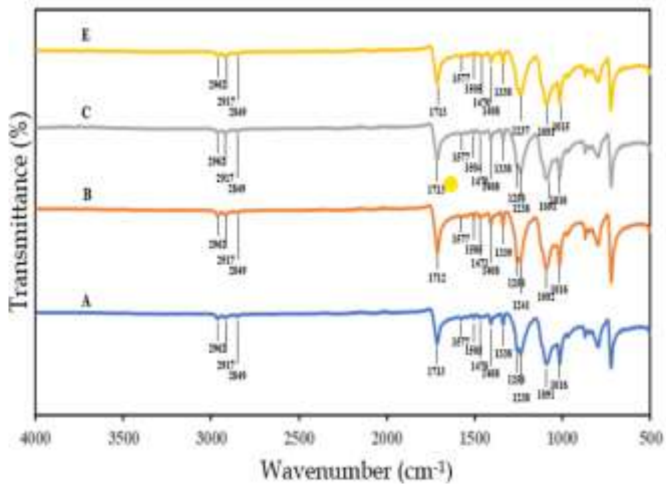


Figure 4. FTIR spectra of fabric dyed with mango bark extract

Color Fastness Against Washing Test

The ranking of wash fastness on cotton and polyester fabrics dyed with jati leaf, curcumin, and mango bark dyes, with or without a mordant, is presented in Table 2. The results indicate that the color fastness ranking of cotton and polyester fabrics dyed using jati leaf and turmeric exhibits good to very good wash fastness. In contrast, fabrics dyed with mango bark dye show lower fastness (Rahman et al., 2025). The fundamental interaction between the dye and the fiber involves hydrogen bonding and physical bonding. With the use of mordant, dye molecules form complexes with the fabric, enhancing wash fastness (Islam et al., 2024; Zheng et al., 2023). These complexes are formed through metal ion coordination with specific groups in the dye, such as two adjacent hydroxyl groups or a hydroxyl and a carbonyl group.

Table 2. Color Fastness of Fabrics Dyed Using Extracts of Teak Leaves, Turmeric, and Mango Bark

Dye	Mordan	Color Fastness Value		Colorfastness Evaluation	
		Poliester	Cotton	Poliester	Cotton
Teak Leaves	Not	4/5	5	Good	Very good
	NaCl	4/5	5	Good	Very good
	$KAl(SO_4)_2.12\ H_2O$	4	5	Good	Very good
	$Ca(OH)_2$	4/5	5	Good	Very good
Tumeric extract	not	4	5	Good	Very good
	NaCl	4/5	5	Good	Very good
	$KAl(SO_4)_2.12\ H_2O$	4/5	5	Good	Very good
	$Ca(OH)_2$	4	5	Good	Very good
Mango Bark	Not	4	¾	Good	Quite good
	NaCl	3/4	¾	Quite good	Quite good
	$KAl(SO_4)_2.12\ H_2O$	3	3	Enough	enough
	$Ca(OH)_2$	4/5	4/5	Good	good

Role of Dyeing Time

Dyeing time is a critical economic factor that must be considered for sustainable yarn production; the shorter the dyeing time, the lower the energy and labor costs. The color strength (K/S) of yarns dyed with extracts from teak leaves, turmeric, and mango bark increased significantly within the first 30 minutes, followed by a slight increase up to 50 minutes, before experiencing a marginal decrease until the dyeing time reached 90 minutes (Figure 5).

This behaviour is attributed to the availability of active sites on the yarn matrix for absorbing molecules from each natural extract. The initial increase in color strength (K/S) during the first 30 minutes and the subsequent gradual rise until 50 minutes indicate the attainment of an optimal dyeing equilibrium time for the yarn (Alegbe et al., 2024). The marginal reduction in color strength (K/S) observed beyond 50 minutes may be due to the accumulation of extract molecules on the surface of the yarn fabric. These results are consistent with the conclusions reported by Rasool et al. concerning the eco-friendly dyeing processes of silk and cotton employing natural dyes (Rasool et al., 2023).

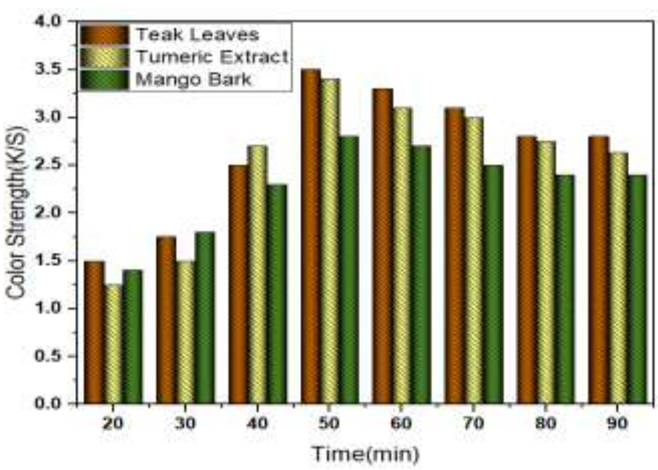


Figure 5. Effects of dyeing time

Role of pH

The role of the dye solution's pH cannot be overlooked when aiming for optimal dyeing performance.

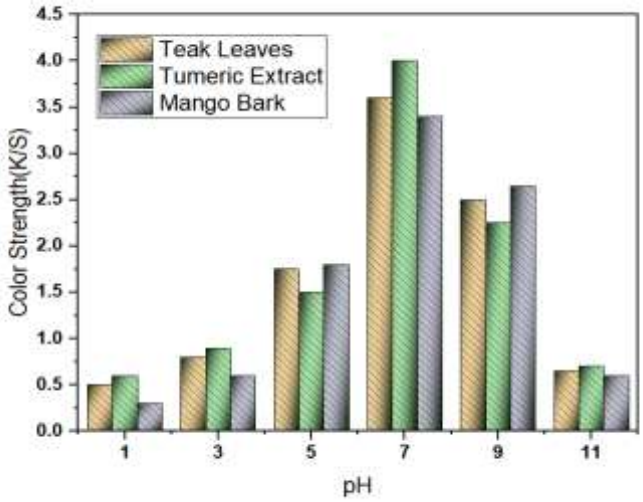


Figure 6. Effects of dyeing pH

The color strength and dye uptake of yarns dyed with extracts from teak leaves, turmeric, and mango bark increased as the dye bath pH increased from 1 to 7, after which a decline was observed (Figure 6). Haque et al. suggest that the observed increase in K/S values as the dye bath pH rises from 1 to 7 can be explained by a reduction in competitive interactions within the acidic environment between the protonated yarn and phenolic-based dye compounds (Hong, 2022). The likely electrostatic repulsion between deprotonated yarns and phenolic dye molecules could explain the reduced $K/SK/S$ values observed at higher pH levels (Reda et al., 2025).

Role of Temperature

The kinetic energy within the dye bath, which governs the diffusion rate of dye molecules from the liquid phase to the solid fiber phase, is intrinsically influenced by the temperature of the reactor.

As the temperature of the dyeing medium increases from 40 to 60 °C, the color strength also increases; however, the color strength decreases when the temperature exceeds 60 °C (Figure 7). This indicates that temperatures below 60 °C are insufficient to transfer an adequate amount of dye molecules to the fibers to achieve optimal color strength. Above this optimal temperature, the natural dyes from each extract gain additional energy, which facilitates the release of some molecules from the fiber surface (Khan et al., 2025; Razak, 2011). Zia et al. reported comparable findings regarding cotton fabrics dyed with natural colorants (Zia et al., 2019).

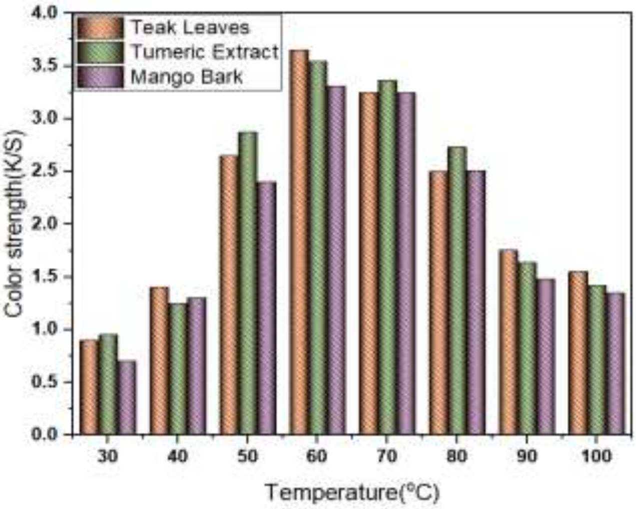


Figure 7. Effects of dyeing temperature

Conclusion

The experimental results demonstrate that phenolic-based natural dyes extracted from teak leaves, turmeric, and mango bark can be successfully applied to cotton and polyester fabrics, especially when combined with appropriate bleaching and mordanting treatments. FTIR analysis confirms the interaction between dye molecules, mordants, and polyester functional groups without altering the fundamental polymer structure. Dyeing with teak leaf and turmeric extracts exhibits good to very good wash fastness on both fabrics, whereas mango bark provides comparatively lower, though still acceptable, fastness, which can be improved by suitable mordant selection. Process optimization shows that maximum color strength is achieved at a dyeing time of about 50 minutes, a near-neutral pH of around 7, and a temperature of approximately 60 °C, beyond which color strength declines due to the desorption of dye molecules. Overall, these findings highlight the potential of locally sourced natural dyes as eco-friendly alternatives for textile coloration, provided that key process parameters and mordant systems are carefully controlled.

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Author Contributions
Writing-Original, Validation, M.T.D.T.; Methodology, E.K; Editing, Investigation, Y.I.K.; Writing-Reviewing, Conceptualization, F.K.; Editing, Conceptualization, E.W; Investigation, F.R.B; Preparation, A.M; Supervision, J.K.M; Editing, G.D.G.

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Conflicts of Interest
There are no conflicts to declare.

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