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# Research of the Dyeing Properties of Lychee Leaves and Sappan Wood Extract on Silk-Linen Fabric

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**Article**

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**ABSTRACT**

*Synthetic dyes are the primary colouring materials for textile dyeing; however, the residual industrial wastewater from the dyeing process contains complex concentrations of chemical substances, which result in toxicity and environmental pollution with severe negative impacts on ecology and health. This study adopts an eco-friendly perspective, utilizing a mixture of lychee leaves and sappan wood extracts for dyeing silk-linen fabrics. It explores the impacts of dyeing time, mordants, and dyeing methods on the colour quality of the samples. A computer colourimeter was used to compare the colour effects of different dye solution ratios on silk-linen fabrics, and the colour fastness to water, perspiration, and dry rubbing of the dyed fabrics was tested. The results show that the optimized dyeing process for silk-linen fabrics using a mixed solution of lychee leaves and sappan wood includes the following findings: Dyeing time has no significant impact on the CLE L*, a*, and b* values. The highest L* value and colour brightness are achieved under conditions without mordants. By mixing dye solutions in different proportions and treating them with mordants, the colour gamut of silk-linen fabrics has been expanded. The dyed colours are similar to the main popular colours of 2024, making them the trend colours of this year; the samples' fastness performance tests indicate that the colour fastness to water, perspiration, and dry rubbing essentially meets the requirements for textile fabrics. The use of lychee leaves and sappan wood for fabric dyeing is not only environmentally friendly but also possesses significant health-beneficial properties, offering potential commercial value.*

**KEYWORDS**

*lychee leaves, sappan wood, mixed dye liquid, silk-linen*

## INTRODUCTION

The textile industry is considered one of the major sources of environmental pollution, with an estimated 20% of water pollution attributed to textile processing, such as dyeing [1]. A significant amount of metal ions remains unexhausted in the mordant baths used during synthetic dye dyeing production, which are then discharged into wastewater [2]. The wastewater generated from textile processes is characterized by intense colouration and contains complex concentrations of chemicals such as salts, dyes, detergents, peroxides, and heavy metals, raising concerns and negative impacts on ecology and public health [3,4]. The United Nations 2030 Agenda for Sustainable Development proposes a broad and ambitious vision for social, economic, and environmental development [5]. This vision extends to rethinking the sustainable development of the textile industry. Recently, there has been a noticeable shift toward more sustainable and eco-friendly practices across various industries, including textiles and fashion. This shift is driven by the growing environmental consciousness and concerns about the ecological impacts of traditional synthetic dyes and chemical processes.

Natural dyes are recognized for their eco-friendliness, biodegradability, non-toxicity, and the absence of allergic or carcinogenic reactions when in contact with human skin. Entering the 21st century, there is a profound realization that the unique properties and effects of natural dyes and their modified products are fundamental to societal sustainable development [6]. Natural dyes can biodegrade without mixing with any oxidizing or reducing agents, whereas synthetic dyes are degraded by reducing agents, directly or indirectly affecting human health [7]. Natural dyes are more environmentally friendly than synthetic dyes and may possess biological benefits [8]. Plants exhibit a wide range of colours and, compared to synthetic dyes, these natural dyes are environmentally friendly, safe, and have potential bioactive properties such as antimicrobial, antioxidant, antiproliferative, and anti-inflammatory properties [9]. The increasing awareness and sensitivity to the environment have made the reintroduction of natural dyes in the textile industries even more important. To date, natural dyes have been employed in the textile industries for years, and their use is now increasing rapidly [10]. For example, madder extract has been used to dye textiles since ancient times. It has high commercial value as a dye that replaces harmful chemicals in textiles [11]. Acorns act as bio-mordants and natural dyes for textiles and leather, providing an environmentally friendly alternative to synthetic dyes and reducing dependence on chemicals and petrochemicals. The commercial viability of acorns and their export potential make them a valuable resource to support regional trade and boost local economies, with the potential to create new jobs [12].

In recent decades, global scientific interest has been concentrated on sustainable agriculture and the use of agro-byproducts for colouring and functionality, focusing on various natural dyes for finishing. This is because the improper storage and disposal of waste generated during the pruning, collection, management, transportation, and processing of plant leaves and branches can lead to severe environmental pollution due to their high biodegradability associated with high moisture content and microbial load [13]. The sustainable development of dye plants could potentially mitigate some diseases and environmental pollution caused by the use of artificial colourants, enhance the agricultural income of local farmers, create opportunities for businesses and farmers, and provide visibility to the agricultural value of the coloured bio-compounds extracted from selected dye plant varieties [14]. Moreover, it could lead the industry to seek new sources of dyes that are sustainable and less harmful [15]. For these reasons, researchers are motivated to explore new dyeing materials from plant waste for eco-friendly dyeing.

Litchi (*Litchi chinensis*) is one of the world's most precious and economically significant fruit crops. It originated in the provinces of Guangdong and Fujian in China, where it has been cultivated for about four millennia [16]. Litchi has over 2300 years of cultivation history in China and was spread from China to the rest of the world. In 2022, the national planting area of Litchi was approximately 789 thousand acres, with a total production of about 2.531 million tons. Pruning litchi trees can improve their overall health and yield. The leaf waste from pruning litchi trees represents a significant amount of organic material. To fully utilize litchi resources and broaden their application value, this study selected pruned lychee Leaves and the traditional Chinese herb Sappan wood as dye materials for mixed dyeing experiments. The study explored the dyeing effects, tested colour fastness, and extracted optimized processes.

Pharmacological analysis using HPLC and HPTLC on extracts from various parts of litchi varieties, including leaves, roots, seeds, fruits, and pericarps, has revealed a total of 50 bioactive compounds from different parts of the lychee plant. These compounds are categorized into flavonoids, glycosides, phenolic acids, monoterpenes, anthocyanin amino acids, phenolic compounds, and fatty acids [17]. Flavonoids are the "main force" among natural yellow dyes. Flavonoids in some natural dyes have been used to impart functional finishing properties to coloured textiles/fibres, such as deodorizing, antibacterial, antifungal, antioxidative, fluorescent, flame-retardant, and UV-protective properties [18]. The majority of flavonoid compounds exist in plants in the form of glycosides, with the presence of sugar bodies increasing the water solubility of flavonoid compounds. During the dyeing process with flavonoid-rich plants, sugar bodies and glycoside aglycones separate (basic flavonoid skeleton as shown in Figure 1). Natural yellow colours mostly derive from hydroxyl derivatives (i.e., flavonols) and methoxy derivatives of flavonoids and isoflavones [19]. Moreover, the branches and leaves contain petroleum ether extract, which has medicinal effects of anti-inflammatory, and analgesic, relieving heat and stagnation, and reducing moisture and sores [20]. In vitro tests have shown that aqueous extracts of litchi leaves have a significant anti-hepatitis B virus effect [21]. The total flavonoid content in litchi leaves varies significantly with the growth cycle, with the highest contents of 22% ~ 23% found in leaves harvested in December and January, and 16% from May to July. This indicates that the flavonoid content in litchi leaves is higher in December and January [22]. Therefore, litchi leaves not only serve as natural dyes but also have medicinal effects. However, there is still a significant research gap in the field of dyeing with litchi leaves, and current studies on litchi leaves provide a rich basis for this research.

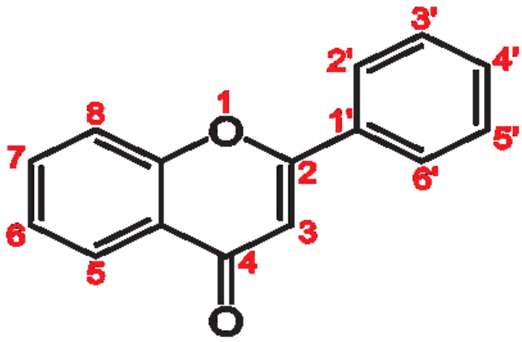



Figure 1. Basic flavonoid skeleton

Sappan wood (scientific name: Biancaea sappan), a plant of the Fabaceae family, is widely distributed in Southeast Asia and the southern regions of China, including Guangdong and Guangxi [23]. The heartwood of Sappan wood contains water-soluble flavonoid compounds, such as brazilin, protosappanin, and sappanin (The chemical composition is shown in Figure 2). Brazilin, the main isoflavonoid component found in the heartwood, is well-known as a natural red dye used for colouring. Extracts from Sappan wood's heartwood, including sappanin and volatile oils, possess antibacterial, anti-inflammatory, and analgesic properties and are utilized in Indian Ayurvedic and traditional Chinese medicine. According to the "Compendium of Materia Medica," Sappan wood can promote blood circulation and break blood stasis. Furthermore, Sappan wood can enhance cardiovascular contraction and has hypnotic and anaesthetic effects on the central nervous system [24]. In Thailand, it is primarily used as a colouring agent in beverages, food, clothing, and cosmetics. Particularly in Chiang Mai, Nan Province, and Nakhon Pathom Province, Sappan wood heartwood decoction is used as an anti-inflammatory agent for treating traumatic diseases and arthritis. In Ayurveda, heartwood is employed to treat Pitta disorders, including rashes, burning sensations, peptic ulcers, high body temperature, heartburn, and indigestion. It can also be used as a blood purifier for treating wounds, diarrhoea, epilepsy, diabetes, etc. [25].


a) b)

Figure 2. a) Sappan Wood bark and dye; b) Chemical structures of colouring components in Sappan Wood [24]

Since the validation of its medicinal properties and its application as a dye, Sappan wood has garnered attention in the dyeing and textile industries both domestically and internationally. Natural pigments extracted from the Sappan wood plant endow wool fabrics with natural colours. Potassium aluminium sulfate ($AlK(SO_4)_2$), copper sulfate ($CuSO_4$), and zinc sulfate ($ZnSO_4$) are used as mordanting materials, facilitating a better fixation of dyes on wool fabric, and exhibiting superior colour performance in terms of the CIE L*a*b* and colour strength (K/S) [26]. Metal salts (referred to as mordants in undyed samples) play a significant role in fixing dye molecules on wool and producing different hues with various shades and tones. The typical colours of fabrics dyed with Sappan wood extract without mordants range from pale yellow to red. A pale yellow hue is obtained with aluminium sulfate as the mordant, while a light yellow hue is achieved with ferrous sulfate. The lightfastness of pre-mordanted samples is relatively superior to that of unmordanted samples. The wash fastness of all mordanted and unmordanted samples displays colour changes from good to excellent levels [27]. Dyes extracted from Sappan wood (*Caesalpinia sappan L.*) naturally colour linen fabrics, producing reddish-brown textiles without the use of mordants; iron-containing mordants produce the highest colour strength, resulting in a dark grey colour very close to black. Deep red and magenta textiles are obtained with $SnCl_2$, while pink textiles are achieved with $AlK(SO_4)_2$. Samples with $CuSO_4$ mordants display a dark purple colour. The colour strength of post-mordanted samples is higher than that of pre-mordanted and simultaneous mordanted samples. Dyeing and mordanting enhance the fabric's ultraviolet protection factor (UPF). Only fabrics mordanted with Fe exhibit good ultraviolet protection capabilities (UPF 15) [28]. Sappan wood and acacia are used for eco-friendly dyeing, with pretreatment involving Turkish red oil (TRO) (for washing) and alum and soda ash (for mordanting). This process yields hues of yellow, brown, red, purple, and black, with the colour fastness fixed at levels 3-4 using ferrous sulfate, alum, and lime [29].

The objective of this study is to investigate the dyeing effects and colour fastness of a mixed dye solution of lychee Leaves and Sappan wood. It explores the impact of dyeing time, mordants, and dyeing methods on the colour appearance and colour fastness of the samples. The study employs a CIE L*a*b* computer colourimeter to compare the colour effects of different proportions of mixed dye solutions on the silk-linen fabric under various dyeing times, mordants, and dyeing processes. It tests the water fastness, perspiration fastness, and dry rubbing fastness of the dyed silk-linen fabric. Currently, research on dyeing silk-linen with lychee Leaves and Sappan wood is still a blank space; this study will help to expand the colour spectrum of silk-linen fabric and the commercial value of lychee leaves.

## EXPERIMENTAL

### Materials and Methods

Fabric: 15% mulberry silk and 85% linen, 16 momme, purchased from Shanxi Jincheng Nancy Silk Linen Weaving Co., Ltd. Fabric specifications are shown in Table 1.

Table 1. Fabric specifications

| Name | silk and linen blend ratio | warp density | | weft thread density | | longitude and latitude density | fabric weave |
|---|---|---|---|---|---|---|---|
| | | tex | count | tex | count | 1 piece/10cm | |
| Silk- Linen | 15/85 | 16.7 | 45 | 16.7 | 45 | 108*58 | plain weave |

Dye materials: lychee leaves (fresh leaves pruned in December), purchased from Lanxi Village, Zhengguo Town, Zengcheng District, Guangzhou City, Guangdong Province; Sappanwood purchased from a pharmacy.

Mordants: Potassium aluminium sulfate ($KAl(SO_4)_2{\cdot}12H_2O$), ferrous sulfate ($FeSO_4{\cdot}7H_2O$); copper sulfate ($[Cu(H_2O)4]SO_4{\cdot}H_2O$), all laboratory grade, purchased from a pharmacy.

Instruments: DK-S28 electric constant temperature water bath (Shanghai Jinghong Experimental Equipment Co., Ltd.), JP23D-1100 Supor wall breaker, PHB-3 pH meter, NH300 precision computer colourimeter (Shenzhen Sanenshi Technology Co., Ltd.)

*Dye Extraction*

Crush the lychee leaves and soak them in water at a ratio of 1:15 (100 grams of dye material to 1500 millilitres of water) for 24 hours. Then, boil over high heat (2200 W) on an induction cooker for 30 minutes, followed by medium-low heat (800 W) for an additional 30 minutes. Cover the pot during the boiling process to prevent excessive loss of water. After the boiling period, filter the hot dye extract through fine cotton fabric twice while it is still hot. Perform two extractions under the same conditions from an equal weight of dye material to ensure that there are no residues in the dye solution. Store the filtered dye solution in clean containers, label them appropriately, and set them aside for later use. Sappanwood and water were soaked at a ratio of 1:15 (100 grams of dye material to 1500 millilitres of water) for 24 hours at a constant indoor temperature of 25 $^oC$. Then, it was boiled on high heat (2200 W) on an induction stove for 30 minutes, followed by medium-low heat (800 W) for another 30 minutes, covering the pot during the process to prevent excessive evaporation. The boiled dye extract was filtered through fine cotton fabric twice to ensure no residue remained in the dye solution. After the boiling period, the extracted dye residue was further boiled with water at a ratio of 1:10 (100 g of herbal residue to 1000 millilitres of water), brought to a boil, maintained at a boil for 20 minutes, then simmered on medium-low heat for another 20 minutes, and turned off. The hot dye extract was filtered through fine cotton fabric twice to ensure no residue remained. The dye solutions from both extractions were combined, and the filtered dye solution was stored in clean containers, labelled, and set aside for later use.

Dye Solution Mixing Ratios: Two ratios of 2:8 and 4:6 were used for mixing.

*Fabric Pretreatment*

Before dyeing, the silk-linen fabric was soaked and lightly boiled in clear water. After the water started boiling, the fabric was cooked for 10 minutes, then removed, wrung out, and set aside to eliminate the starch on the fabric and improve dye absorption.

*Dyeing Process*

A variety of mordants were used, including no mordant, potassium aluminium sulfate ($KAl(SO_4)2{\cdot}12H_2O$), ferrous sulfate ($FeSO_4{\cdot}7H_2O$); copper sulfate ($[Cu(H_2O)4]SO_4{\cdot}H_2O$), with the mordant to dye solution ratio set at 5 g/L. The dosage of the above mordants complies with NODS (natural organic dye standards) and will not cause any pollution to the environment [10]. The experiment was divided into four dye baths, with the dyeing temperature fixed at 70 °C (control range ±1°C), and the dyeing times set at 15 min, 30 min, and 45 min respectively. The dyeing method was a single bath dye, and the samples obtained from the experiment were rinsed with clean water and dried.

*Testing Methods*

Using the undyed silk-linen fabric as a standard sample, the L*, a*, and b* values were tested with an NH300 precision computer colourimeter (Shenzhen Sanenchi Technology Co., Ltd). The colour brightness values a* and b*, and L* were evaluated based on the CIE L*, a*, and b*. The range of L* goes from L*=0, representing the darkest black, to L*=100, representing the brightest white. The a* coordinate indicates the green-red component, with green in the negative direction (a*<0) and red in the positive direction (a*>0). The b* coordinate indicates the blue-yellow component, with blue in the negative direction (b*<0) and yellow in the positive direction (b*>0) [30]. ΔE*Calculation formula

$$\Delta E^* = [(\Delta L)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5} \tag{1}$$

Random testing was conducted 5 times at different locations on the dyed fabric, and the average value was taken. The colour difference value ΔE* between the undyed and dyed fabric was recorded.

In accordance with the "National General Safety Technical Code for Textile Products GB18401-2010 5.1", the standard for testing, water fastness was determined according to GB/T5713—2010, perspiration fastness according to GB/T3922—2010, dry rubbing fastness according to GB/T3920—2010, and Light fastness according to GB/T8427—2010.

## RESULTS AND DISCUSSION

### Dyeing effects of lychee leaves and sappanwood 2:8 mixed dye solution

Following the dyeing process outlined in 2.3.3, this section explores the impact of different mordants and dyeing times on the dyeing effects of a 2:8 mixed dye solution of lychee leaves and Sappanwood on silk-linen fabric. The results are shown in Table 2.

Table 2. Dyeing effects of lychee leaves and sappan wood 2:8 mixed

| Sample | Dyeing time, min | Mortand | L* | a* | b* | ΔE | Silk-linen colour |
|---|---|---|---|---|---|---|---|
| S1 | 15 | No mordant | 65.21 | 19.31 | 19.50 | 0.01 |  |
| S2 | 15 | $KAl(SO_4)_2{\cdot}12H_2O$ | 61.35 | 23.24 | 18.81 | 0.01 |  |
| S3 | 15 | $FeSO_4{\cdot}7H_2O$ | 40.44 | 3.41 | 0.35 | 0.10 |  |
| S4 | 15 | $Cu(H_2O)_4]SO_4{\cdot}H_2O$ | 44.87 | 13.45 | 7.00 | 0.02 |  |
| S5 | 30 | No mordant | 64.22 | 18.45 | 18.46 | 0.02 |  |
| S6 | 30 | $KAl(SO_4)_2{\cdot}12H_2O$ | 55.12 | 26.05 | 16.28 | 0.01 |  |
| S7 | 30 | $FeSO_4{\cdot}7H_2O$ | 40.58 | 3.51 | 0.56 | 0.04 |  |
| S8 | 30 | $Cu(H_2O)_4]SO_4{\cdot}H_2O$ | 47.64 | 11.16 | 7.51 | 0.02 |  |
| S9 | 45 | No mordant | 58.59 | 21.19 | 17.22 | 0.09 |  |
| S10 | 45 | $KAl(SO_4)_2{\cdot}12H_2O$ | 50.58 | 25.04 | 13.26 | 0.01 |  |
| S11 | 45 | $FeSO_4{\cdot}7H_2O$ | 38.57 | 3.22 | 1.04 | 0.04 |  |
| S12 | 45 | $Cu(H_2O)_4]SO_4{\cdot}H_2O$ | 46.59 | 10.76 | 9.32 | 0.13 |  |

### Effect of dyeing time on the colouration of silk-linen fabric

According to Table 2, at a dyeing temperature of 70 °C (± 3 °C), the ΔE* value of the silk-linen fabric increases rapidly with the extension of dyeing time, reaching a plateau after 15 minutes. This phenomenon occurs because, at the beginning of the dyeing process, the amount of dye adsorbed by the fibres greatly exceeds desorption. However, as time progresses and the dyeing approaches dynamic equilibrium, the difference between adsorption and desorption narrows, thus, the rate of increase in ΔE* value gradually slows. Extending the time further, between 15 to 45 minutes, the changes in colour characteristic values L*, a*, and b* are not significant. Moreover, overly prolonged dyeing times are impractical for actual production. Therefore, a dyeing time of approximately 15 minutes is considered optimal.

### Effect of mordants on the colouration of silk-linen fabric

The results shown in Table 2 indicate significant colour variation in the L* values (ranging from 58.59 to 65.21) under the same dyeing conditions with different mordants for the 2:8 mixed dye solution of lychee Leaves and Sappanwood. The influence of mordants on the L* values is in the order: of no mordant > alum > copper sulfate > ferrous sulfate (refer to Figure 3). The overall colour tone is in the red spectrum. Samples dyed without a mordant exhibited a* values ranging from 18.45 to 21.19 and b* values from 17.22 to 19.50, resulting in a flesh-pink colour. With alum as the mordant, a* values ranged from 23.24 to 26.05 and b* values from 13.26 to 18.81, yielding an orange-red colour. Ferrous sulfate mordant led to a* values between 23.24 and 26.05 and b* values between 13.26 and 18.81, producing a deep brown-red colour. With copper sulfate as the mordant, a* values ranged from 10.76 to 13.45 and b* values from 7.00 to 9.32, resulting in a brown-red colour.

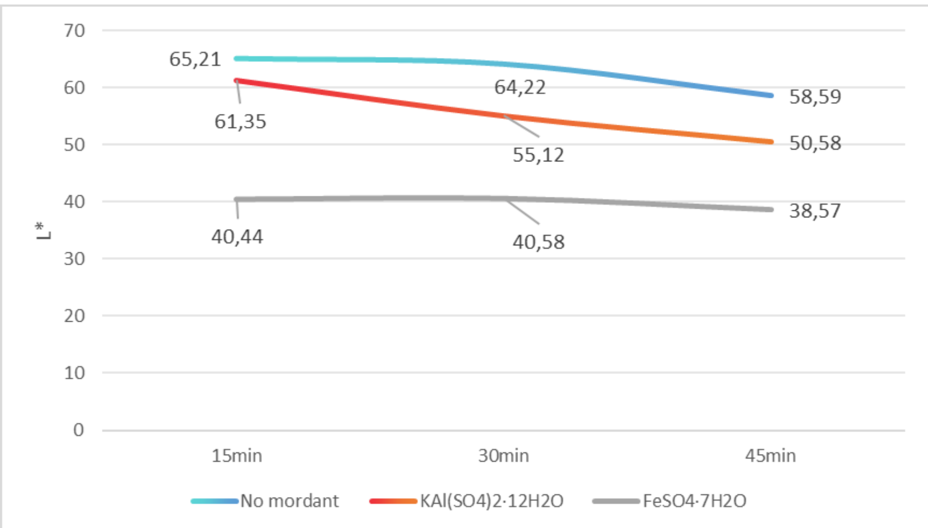
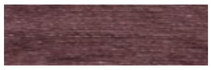



Figure 3. Effect of dyeing time on colour L* of 2:8 mixed dyeing of lychee leaves and sappan wood

### Dyeing effects of lychee leaves and sappanwood 4:6 mixed dye solution

Following the dyeing process, this section examines the effects of different mordants and dyeing times on the dyeing outcomes of a 4:6 mixed dye solution of lychee Leaves and Sappanwood on silk-linen fabric. The results are summarized in Table 3.

Table 3. Dyeing effects of lychee leaves and sappan wood 4:6 mixed

| Sample | Dyeing time, min | Mortand | L* | a* | b* | ΔE | Silk-linen colour |
|---|---|---|---|---|---|---|---|
| S13 | 15 | No mordant | 66.22 | 16.77 | 27.91 | 0.13 |  |
| S14 | 15 | $KAl(SO_4)_2{\cdot}12H_2O$ | 57.12 | 29.73 | 19.64 | 0.17 |  |
| S15 | 15 | $FeSO_4{\cdot}7H_2O$ | 36.80 | 4.98 | -0.40 | 0.02 |  |
| S16 | 15 | $Cu(H_2O)_4]SO_4{\cdot}H_2O$ | 54.91 | 14.84 | 12.83 | 0.18 |  |
| S17 | 30 | No mordant | 63.98 | 21.38 | 28.59 | 0.03 |  |
| S18 | 30 | $KAl(SO_4)_2{\cdot}12H_2O$ | 55.07 | 29.80 | 18.52 | 0.04 |  |
| S19 | 30 | $FeSO_4{\cdot}7H_2O$ | 31.93 | 4.29 | -0.16 | 0.01 |  |
| S20 | 30 | $Cu(H_2O)_4]SO_4{\cdot}H_2O$ | 47.20 | 14.95 | 10.74 | 0.09 |  |
| S21 | 45 | No mordant | 63.20 | 20.82 | 25.86 | 0.10 |  |
| S22 | 45 | $KAl(SO_4)_2{\cdot}12H_2O$ | 50.66 | 31.50 | 20.75 | 0.11 |  |
| S23 | 45 | $FeSO_4{\cdot}7H_2O$ | 32.14 | 3.54 | 0.06 | 0.09 |  |
| S24 | 45 | $Cu(H_2O)_4]SO_4{\cdot}H_2O$ | 44.33 | 14.20 | 12.35 | 0.04 |  |

### Impact of Dyeing Time on the Colouration of Silk-Linen Fabric

As indicated in Table 3, at a dyeing temperature of 70 °C (± 3 °C), the ΔE* value of silk-linen fabric increases rapidly with the extension of dyeing time, plateauing after 15 minutes as the rate of increase in ΔE* value gradually slows down. Compared to the 2:8 mixed dye solution, the L* values are brighter for the 4:6 mixed dye solution. Within the 15 to 45 minute dyeing range, the changes in colour characteristic values a* and b* are in the order of 30min>45min>15min, indicating that overly prolonged dyeing times are impractical for actual production. Therefore, a dyeing time of approximately 30 minutes is deemed suitable.

### Impact of mordants on the colouration of silk-linen fabric

The results from Table 3 show that, under the same dyeing conditions, the L* values exhibit significant colour variation due to different mordants for the 4:6 mixed dye solution of lychee Leaves and Sappanwood. Without a mordant, the dyed silk-linen fabric displays a brighter red (a* values range from 16.77 to 21.38) with more yellow tones (b* values range from 25.86 to 28.59), where a* < b*, resulting in an orange hue. Under the influence of alum as a mordant, the fabric achieves a brighter red (a* values range from 29.73 to 31.50, b* values range from 18.52 to 20.75), with a* > b*, producing an orange-red colour. With ferrous sulfate as the mordant, the L* values range from 31.93 to 36.80, noticeably lower compared to other mordant conditions, resulting in a black-purple colour. Copper sulfate as a mordant results in a purplish-red colour (refer to Figure 4).

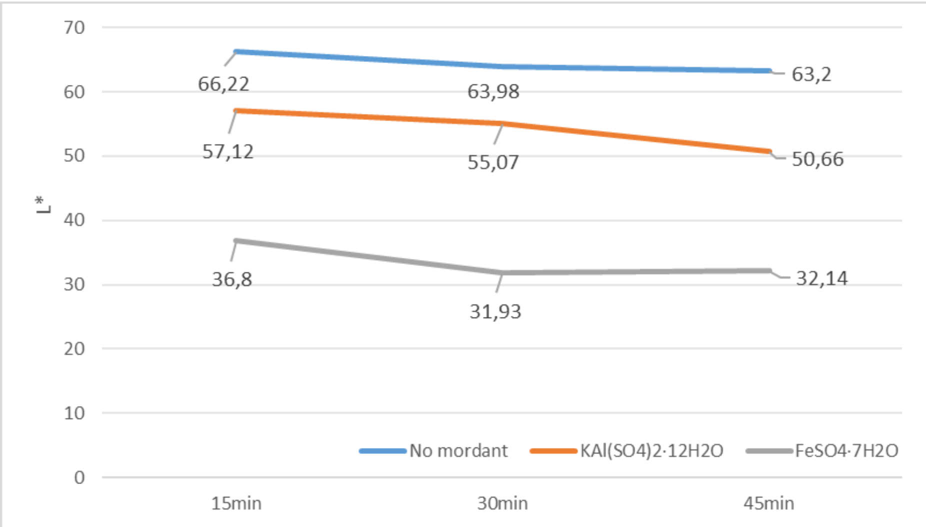



Figure 4. Effect of dyeing time on colour L* of 4:6 mixed dyeing of lychee leaves and sappan wood

### Colour fastness

This study adheres to the "National General Safety Technical Code for Textile Products GB18401-2010 5.1" standard to evaluate the colour fastness of both mordanted and unmordanted silk-linen fabric samples. The assessment of the fabric's resistance to water, perspiration, and dry rubbing was conducted using the respective standards: GB/T5713—2010 for water fastness, GB/T3922—2010 for perspiration fastness, GB/T8427—2010 for Light fastness, and GB/T3920—2010 for dry rubbing fastness.

Table 4. Colour fastness test results of silk-linen fabric dyed with lychee leaves and Sappan wood 2:8 and 4:6 mixed dye solutions under un-mordanted conditions

| Sample | PH | Colour Fastness | | | |
|---|---|---|---|---|---|
| | | Lightfastness | Water Fastness | Perspiration Fastness | Dry rubbing Fastness |
| S1 | 7 | 3~4 | 3 | 2~3 | 3 |
| S4 | 7 | 3~4 | 3 | 3 | 4 |
| S7 | 7 | 3~4 | 3 | 3 | 4 |
| S10 | 7 | 3~4 | 3 | 2~3 | 3 |
| S13 | 7 | 3~4 | 3 | 4 | 4 |
| S16 | 7 | 3~4 | 3 | 3 | 4 |

Table 5. Colour fastness test results of silk-linen fabric dyed with lychee leaves and Sappan wood 2:8 and 4:6 mixed dye solutions under conditions using potassium aluminium sulfate ($KAl(SO_4)_2 \cdot 12H_2O$) as a mordant

| Sample | PH | Colour Fastness | | | |
|---|---|---|---|---|---|
| | | Lightfastness | Water fastness | Perspiration fastness | Dry rubbing fastness |
| S2 | 7 | 3~4 | 3 | 2~3 | 3 |
| S5 | 7 | 3~4 | 3 | 2~3 | 4 |
| S8 | 7 | 3~4 | 3 | 3 | 4 |
| S11 | 7 | 3~4 | 3 | 2~3 | 3 |
| S14 | 7 | 3~4 | 3 | 4 | 4 |
| S17 | 7 | 3~4 | 3 | 3 | 4 |

Table 6. Colour fastness test results of silk-linen fabric dyed with lychee leaves and Sappan wood 2:8 and 4:6 mixed dye solutions under conditions using ferrous sulfate (Fe) as a mordant

| Sample | PH | Colour Fastness | | | |
|---|---|---|---|---|---|
| | | Lightfastness | Water fastness | Perspiration fastness | Dry rubbing fastness |
| S3 | 7 | 3~4 | 3 | 2~3 | 4 |
| S6 | 7 | 3~4 | 3 | 2~3 | 5 |
| S9 | 7 | 3~4 | 3 | 3 | 4 |
| S12 | 7 | 3~4 | 3 | 2~3 | 4 |
| S15 | 7 | 3~4 | 3 | 4 | 5 |
| S17 | 7 | 3~4 | 3 | 3 | 4 |

The colour fastness test results of samples with and without mordants were compared. The outcomes indicate that samples treated with mordants exhibit higher fastness values compared to those untreated. It is observed that mordanting enhances the fastness properties of silk-linen fabrics. Dyeing duration also significantly impacts the fabric's fastness performance. The findings suggest that the use of mordants positively affects the colour fastness properties of silk-linen fabrics, with dyeing time also playing a significant role. The mordanting process aids in the absorption of dyes and strengthens the bond between dye and fabric. Post-mordanting, silk-linen fabrics achieve improved fastness properties, as the mordanting process establishes a strong bond between dye molecules and fibre molecules, aiding in the retention of fabric colour fastness when exposed to various physical or chemical forces. The colour fastness indices generally meet the requirements for textile fabrics. However, the perspiration fastness is only rated at levels 2 to 3, attributed to the Sappanwood dye's extreme sensitivity to pH. It is anticipated that improvements could be made through alterations in dyeing methodology or modifications to the dye structure. Further research in subsequent work will explore these potential enhancements.

## CONCLUSION

The fabric is stiff, light, breathable and comfortable. It is a natural fibre material suitable for summer clothes. It is dyed with mixed extracts of lychee leaves and hematoxylin, which is not only breathable and cool but also environmentally friendly and healthy. However, because the dyed fabrics in this study have low colour fastness to perspiration, avoid using alkaline laundry detergents during the washing process, and avoid sunlight exposure after washing to better protect the colour of the fabrics. In summary, using a silk/linen blended fabric along with multiple plant-based dyes in a study offers a platform for exploring the complexities of dye-fibre interactions, achieving diverse colour outcomes, and advancing sustainable and innovative textile development practices.

Natural production and sustainability are crucial for the textile industry to create eco-friendly and healthy products. The reuse of tree trimmings and other arboreal waste has garnered attention in the textile dyeing sector, with recent years witnessing a trend towards investigating the dyeing properties of plant waste materials based on regional characteristic resources as a direction for the development of natural dyes.

Litchi tree leaf waste, as a potential natural dye source, holds significant research value. Studies on the variation of total flavonoid content in lychee Leaves provide a scientific basis for exploring the use of litchi waste in dyeing and its impact on colour factors. Lychee leaves and Sappan wood are not only natural dyes but also possess medicinal properties. The chemical components of the pigments contained in these plants directly influence the final experimental colour values. The current study, by exploring the colour characteristics and colour fastness of a mix of lychee Leaves and Sappan wood applied to silk-linen fabric, expands the traditional colour spectrum to align with the popular colours forecasted for 2024. The colours produced in this study are similar to the main trend colours of 2024, which not only benefit sustainable ecological development and human safety and health but also meet the public's aesthetic in adapting to fashion trends.

*Author Contributions*

Conceptualization – Daoruang K, Sankaburanurak A and Apiwathnasorn C; methodology – Luy Q, Daoruang K, Sankaburanurak A and Apiwathnasorn C; formal analysis – Luy Q; investigation – Luy Q; resources – Luy Q; writing-original draft preparation – Luy Q and Sankaburanurak A; writing-review and editing – Luy Q and Sankaburanurak A. All authors have read and agreed to the published version of the manuscript

*Conflicts of Interest*

The authors declare no conflict of interest.

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