FROM FOREST TO FABRIC: NATURAL DYEING WITH TEAK WOOD EXTRACT (*Tectona Grandis*) ON TRADITIONAL YARNS

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ABSTRACT

This study evaluates the potential of teak wood extract (*Tectona grandis*) as a natural dye for traditional woven yarns by comparing the effectiveness of different fixation techniques in enhancing color retention and stability. A spectrophotometric analysis was conducted to measure lightness (*L**), red-green shift (*a**), and yellow-blue shift (b*). Four fixatives - Aluminum Sulphate ($Al_2(SO_4)_3$), Natrium Bicarbonate ($NaHCO_3$), Calcium Carbonate ($CaCO_3$), and Ferro Sulphate ($FeSO_4$)—were tested to assess their impact on color transformation. The results indicate that Ferro Sulphate induced the most intense color transformation, producing deeper and darker hues, while Aluminum Sulphate yielded the most uniform and stable coloration. Calcium Carbonate enhanced lightness, whereas Natrium Bicarbonate resulted in moderate color absorption. These findings confirm the viability of teak wood extract as a sustainable alternative to synthetic dyes, supporting eco-friendly textile dyeing practices. Furthermore, this study provides scientific insights into fixation techniques, offering practical applications for both artisans and the textile industry.

KEYWORDS

Natural dye; Teak wood extract; Color fastness; Sustainability; Fixation techniques.

INTRODUCTION

Natural dyeing is regaining interest due to its sustainability and eco-friendliness. The textile industry significantly contributes to global water pollution, with synthetic dyes harming ecosystems and human health [1-3]. Synthetic dyes contain toxic chemicals that are difficult to degrade, leading to long-term environmental damage. As industries seek greener alternatives, natural dyes present an effective solution. Among them, teak wood extract (Tectona grandis) stands out for its rich color potential and application in traditional yarn dyeing.

Natural dyes have been used for centuries, derived from plant materials such as leaves, bark, flowers, and roots. Unlike synthetic dyes, they offer biodegradable and non-toxic alternatives, making them more suitable for sustainable textile production [4-5]. For instance, mango leaf extract has been explored as a natural dye source, particularly in batik fabric dyeing, using after-mordanting techniques to enhance color absorption and fastness, contributing to the green textile industry [6]. However, challenges remain in achieving color consistency and fastness, which depend on dye sources and fixation techniques. Additionally, the efficiency of natural dyes varies based on fiber type, dyeing conditions, and mordanting agents, making further research essential.

Despite its potential, teak wood extract remains underexplored in the textile industry. Few studies have analyzed its effectiveness, leaving gaps in understanding its dyeing properties and fixation techniques [7-8]. Previous research on plant-based dyes has demonstrated stable and vibrant colors, yet teak wood's full potential remains unexamined [4-5] [9]. Unlike commonly used plant-based dyes such as indigo or madder, teak wood extract contains unique tannins and flavonoids that influence its dyeing behavior.

A critical aspect missing from existing research is the comparison of different fixation methods in maintaining teak wood extract's color stability. Understanding how various fixatives interact with teak dyes can optimize its application in textiles [10]. Fixatives, such as aluminum sulfate and ferrous sulfate, play a crucial role in bonding dye molecules to fibers, influencing shade intensity and longevity. The development of effective fixation techniques could enhance color retention and broaden the commercial use of teak wood extract in textile dyeing.

However, despite the growing interest in natural dyeing techniques, research on the application of teak wood extract remains limited [7]. Prior studies

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have predominantly focused on widely known plant-based dyes such as indigo, madder, and turmeric, leaving the potential of teak wood extract underexplored [11]. Additionally, research on mango seed extract (*Mangifera indica L.*) has demonstrated its viability as a sustainable alternative for batik dyeing [12], further highlighting the importance of exploring underutilized natural dye sources such as teak wood extract. Several studies have explored the potential of plant-based dyes, such as clove leaves (*Syzygium aromaticum L.*), in batik production [13], but the application of teak wood extract remains underexplored. Furthermore, most research in this area lacks comprehensive comparisons of fixation techniques that affect color stability and intensity [14-21]. Recent studies on plant-based dyes, such as mango leaf extract, have shown that after-mordanting can significantly improve color retention in traditional batik fabric, highlighting the importance of selecting appropriate fixatives in natural dye applications [6]. While some studies suggest that certain metal-based mordants enhance dye bonding, there is little consensus on which fixation method provides the most consistent and sustainable results for teak wood extract [22-25]. These gaps indicate the need for a systematic evaluation of teak wood extract dyeing and the impact of different fixatives on its color properties.

Therefore, this study aims to evaluate the stability and effectiveness of teak wood extract dyeing using different fixatives, comparing their impact on lightness retention and color transformation through spectrophotometric analysis. Unlike prior research on general plant-based dyes, this study specifically examines teak wood extract in combination with multiple fixatives, providing a comparative analysis of their effects on color retention and vibrancy.

By demonstrating the viability of teak wood extract as a natural dye, this study supports the shift toward environmentally friendly textile production [26]. Furthermore, by exploring its application on various textile fibers, this research could open new opportunities for the integration of natural dyes in modern fashion and home textiles.

MATERIALS AND METHOD

This study used an experimental design to evaluate the natural dyeing strength of teak wood extract (Tectona grandis) on traditional woven yarns. The research was carried out in several stages, including material preparation, the coloring process, and color analysis using a spectrophotometer. Each fixation technique was tested to determine its effectiveness in maintaining the resulting color [27-28].

The materials used in this study included teak wood extract (*Tectona grandis*), obtained through an extraction process using water solvents, and traditional woven yarns made from natural fibers such as cotton or silk. The fixation materials consisted of Aluminum Sulphate ($Al_2(SO_4)_3$), Calcium Carbonate ($CaCO_3$), Ferro Sulphate ($FeSO_4$), and Natrium Bicarbonate ($NaHCO_3$). The tools used included a spectrophotometer for color analysis, an analytical scale for material measurement, a stainless-steel dyeing pot, a thermometer for temperature control, and a stirring device to ensure uniform dye distribution.

For the preparation of the teak extract, 2 kg of dried teak wood powder was boiled in 500 ml of water for 2 hours to extract the color compounds. For the preparation of the teak extract, 2 kg of dried teak wood powder was boiled in 500 ml of water for 2 hours to extract the color compounds. Similar to the extraction of clove leaf dye (*Syzygium aromaticum L.*) for batik production [13], this study employed water-based extraction of teak wood powder to obtain natural dye components (see Figure 1). The solution was then filtered to separate the solid residues. The solution was then filtered to separate the solid residues. The woven yarns were pre-washed to remove dirt and oil that might interfere with the dyeing process. Afterward, the yarns were soaked in a fixation solution for 30 minutes to enhance color absorption [29].

The fixation solution was prepared by dissolving 30 g of Aluminum Sulphate ($Al_2(SO_4)_3$), 20 g of Calcium Carbonate ($CaCO_3$), 28–30 g of Ferro Sulphate ($FeSO_4$), or 25 g of Natrium Bicarbonate ($NaHCO_3$) into 2 liters of clean water. These concentrations ensured a standardized comparison of the effectiveness of each fixative.

The dyeing process involved immersing the pre-treated yarns into a teak wood extract solution at 60°C for 60 minutes with constant stirring to ensure even color absorption [30-31]. After the dyeing process, the yarns were rinsed with cold water to remove excess unbound dye.

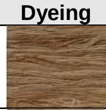
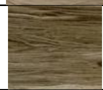
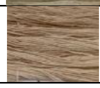
In addition to pre-mordanting, after-mordanting techniques were also considered to improve color fixation and durability, as suggested in previous studies on plant-based dyes such as mango leaf extract [12]. Research has shown that after-mordanting enhances dye-fiber bonding, leading to improved fastness properties [6].

To assess the effectiveness of fixation, the dyed yarns were subjected to spectrophotometric analysis to measure the values of L^* (lightness), a^* (red-green component), and b^* (yellow-blue component). The color difference between undyed and dyed yarns was calculated using the ΔE^*ab formula to determine the effectiveness of dyeing [32].

(a) (b)

Figure 1. Teak wood and its powder; (a) Teak Wood (*Tectona grandis*), (b) Teak wood powder.

Table 1. Visual Results of Yarn Coloring at the Final Fixation Stage.

Coloring Materials	Fixation Materials	Fixation Techniques	Visual Yarn after Dyeing
Teak Wood Extract	Aluminum Sulphate ($Al_2(SO_4)_3$)	End	
	Calcium Carbonate ($CaCO_3$)	End	
	Ferrous Sulphate ($FeSO_4$)	End	
	Natrium Bicarbonate ($NaHCO_3$)	End	

The data obtained from spectrophotometric analysis were statistically analyzed to determine significant differences between the fixation techniques used. This analysis was performed using ANOVA to test hypotheses and draw conclusions regarding the effectiveness of teak wood extract as a natural dye [34] [35].

RESULTS AND DISCUSSION

Result

This section presents the results of the study in a structured manner to ensure clarity and facilitate comparison. The findings are organized into three main parts: (1) Visual analysis of the dyed yarns to provide an initial qualitative assessment of color variations; (2) Spectrophotometric analysis to quantify lightness (L^*), red-green shift (a^*), yellow-blue shift (b^*), and total color difference (ΔE^*ab); and (3) Statistical validation using ANOVA to determine the significance of the observed differences between fixation techniques.

To focus on the most relevant outcomes, this study presents only the final fixation stage (End Stage) while maintaining all four fixation materials: Aluminum Sulphate ($Al_2(SO_4)_3$), Calcium Carbonate ($CaCO_3$), Ferro Sulphate ($FeSO_4$), and Natrium Bicarbonate ($NaHCO_3$). This approach ensures a more precise comparison of each fixative's impact on color stability and intensity.

Table 1 presents the visual appearance of yarns after the final fixation stage for each fixative. This provides an initial observation of how different fixation agents influence color outcomes before moving to quantitative analysis.

These visual results serve as a preliminary comparison before moving to the spectrophotometric and statistical analysis, which will provide deeper insights into color variation and stability.

Spectrophotometry Analysis

Spectrophotometric analysis was conducted to evaluate the color differences at the final stage of fixation. The parameters measured included L^* (lightness), a^* (red-green), b^* (yellow-blue), and ΔE^*ab (total color difference). To quantitatively compare the impact of each fixation technique, Table 2 provides a summary of spectrophotometric measurements, including lightness (L^*), red-green shift (a^*), yellow-blue shift (b^*), and total color difference (ΔE^*ab).

Interpretation of Spectrophotometric Results

Aluminum Sulphate ($Al_2(SO_4)_3$) maintains moderate lightness (L^*), ensuring stable color absorption. The relatively lower ΔE^*ab values indicate higher color uniformity, making it effective for achieving consistent dyeing results.

Calcium Carbonate ($CaCO_3$) retains the highest L^* values, meaning it produces brighter shades.

Table 2. Comparative L*, a*, b*, and ΔE*ab Values for All Fixation Techniques (Final Stage).

Fixation Materials	Fixation Techniques	Test to	Yarn Color Difference Test Value			
			L*	**a***	**b***	**ΔE*ab**
White Thread has not been dyed		0	106.63	1.04	-3.35	0
Aluminum Sulphate ($Al_2(SO_4)_3$)	End	1	46.04	15.57	-3.72	62.31
		2	45.43	4.98	31.72	70.65
		3	45.72	21.63	-9.18	64.56
Calcium Carbonate ($CaCO_3$)	End	1	54.56	9.11	-7.05	52.82
		2	57.04	10.86	-13.45	51.55
		3	56.6	18.67	-23.93	56.9
Ferro Sulphate ($FeSO_4$)	End	1	28.31	-13.09	54.15	98.18
		2	20.82	23.77	-41.64	96.68
		3	16.91	13.43	-26.12	93.39
Natrium Bicarbonate ($NaHCO_3$)	End	1	39.09	20.42	-18.96	71.3
		2	39.24	17.71	-18.28	71
		3	45.14	0.97	13.67	63.8

However, its higher *ΔE*ab* suggests a greater risk of color inconsistency across the fabric.

Ferro Sulphate ($FeSO_4$) causes the most significant reduction in *L** values, leading to darker and deeper color absorption. It also produces the highest ΔE*ab, indicating the most intense transformation among the fixatives.

Natrium Bicarbonate ($NaHCO_3$) exhibits moderate color absorption, with *L** values higher than Ferro Sulphate but lower than Calcium Carbonate. Its *ΔE*ab* values suggest a less dramatic color shift, making it suitable for producing softer, more natural hues.

Comparison of Fixation Techniques at the Final Stage

To evaluate the effectiveness of different fixation techniques, this section compares their impact on lightness retention (*L**) and total color difference (*ΔE*ab*) at the final stage. The analysis provides insight into how each fixative alters the color properties of teak wood extract on yarns.

To provide a clearer comparison, Figure 2 and Figure 3 illustrate how each fixation technique influences lightness (*L**) and total color difference (*ΔE*ab*) at the final stage.

- Figure 2 presents the retention (*L**), showing which fixative produces the brightest lightest or darkest results. A higher *L** value corresponds to greater retention lightness, while a lower *L** value reflects deeper color absorption and a darker appearance.
- Figure 3 visualizes the total color difference (*ΔE*ab*), allowing for a clearer comparison of how significantly each fixative alters the original yarn color. A higher *ΔE*ab* value indicates a greater transformation, with Ferro Sulphate exhibiting the most pronounced shifts, while Aluminum Sulphate and Natrium Bicarbonate result in more moderate changes.

The line chart in Figure 2 demonstrates how each fixative affects the lightness or darkness of the dyed yarns. Among the tested fixatives, Calcium Carbonate exhibited the highest *L** values, indicating that it produced the brightest lightest results. In contrast, Ferro Sulphate resulted in the lowest *L** values, meaning it led to darker shades and deeper color absorption. These differences suggest that Calcium Carbonate retains more lightness, while Ferro Sulphate enhances deeper color penetration.

The heatmap in Figure 3 visually represents the degree of color change across different fixatives. A higher *ΔE*ab* value signifies more significant alterations, with Ferro Sulphate producing the most dramatic shifts. This aligns with its role in deepening color intensity. Meanwhile, Aluminum Sulphate and Natrium Bicarbonate result in more moderate *ΔE*ab* values, suggesting that they provide more stable and uniform color retention.

These findings indicate that Ferro Sulphate is most effective for achieving deep and intense hues, whereas Calcium Carbonate is preferable for lighter, brighter tones. Meanwhile, Aluminum Sulphate and Natrium Bicarbonate offer a balance between stability and moderate color changes, making them suitable for applications requiring controlled color variations.

Statistical Analysis (ANOVA Test Results)

To validate whether the observed color differences between fixation techniques are statistically significant, an ANOVA test was conducted on ΔE*ab values. Table 3 summarizes the results, highlighting variations in color transformation caused by different fixatives.

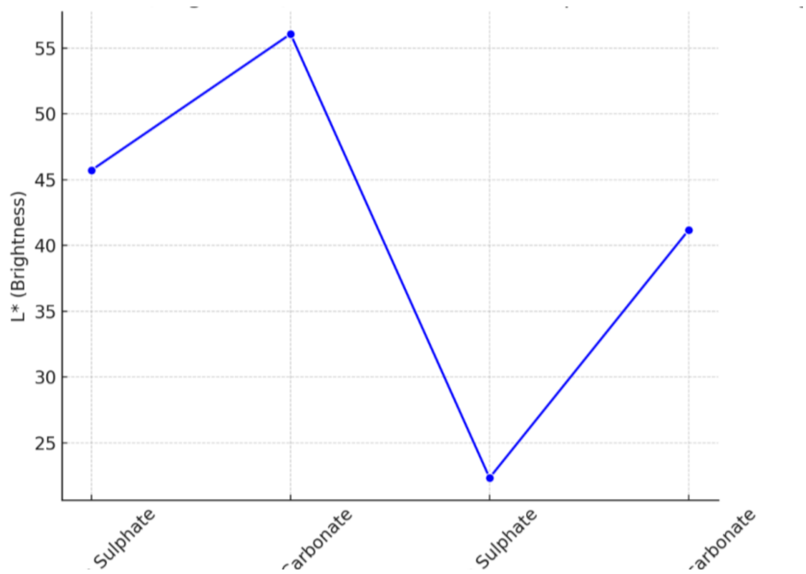


Figure 2. Line Chart of L* (lightness) Across Fixation Techniques at the Final Stage.

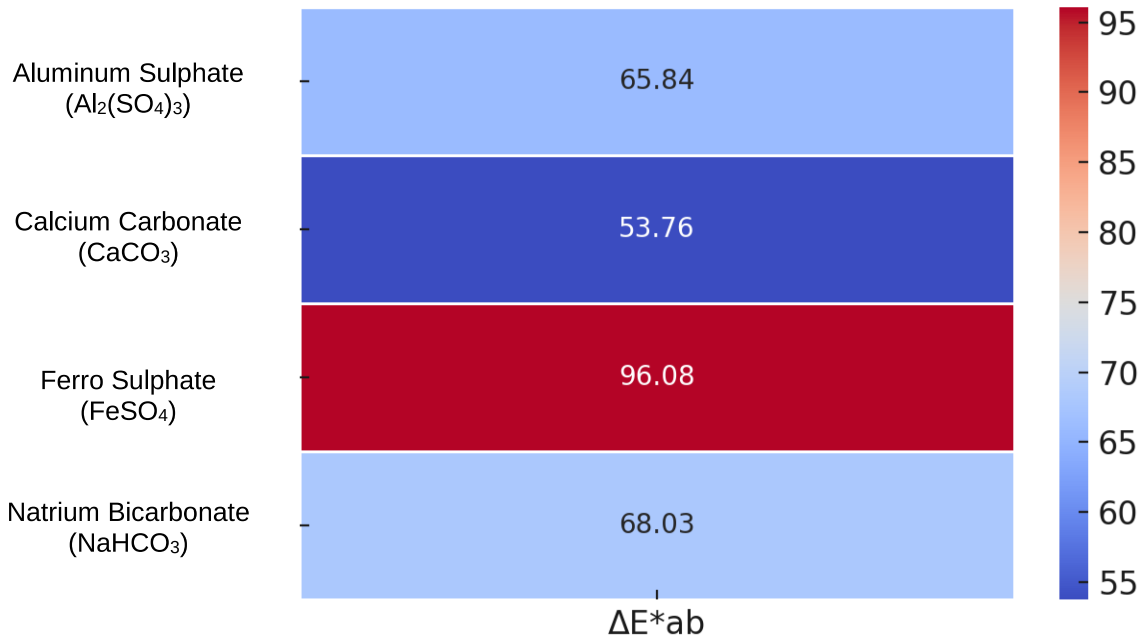


Figure 3. Heatmap of ΔE*ab (Color Difference) Across Fixation Techniques at the Final Stage.

Table 3. ANOVA Test Results for *ΔE*ab* Across Fixation Techniques.

Source of Variation	Sum of Squares (SS)	Degree of Freedom (df)	Mean Square (MS)	F-value
Between Groups	0.00	3	0.00	75.97
Within Groups	100.93	8	12.62	-
Total	100.93	11	-	-

The results indicate a significant difference in color transformation among fixation techniques ($F = 75.97$, $p < 0.05$), confirming that the choice of fixative substantially affects the final color outcome. Post-hoc analysis suggests that Ferro Sulphate differs significantly from the other fixatives, reinforcing its strong impact on color transformation.

<u>Implications for Thread Dyeing Instruction in Craft Education</u>

The findings of this study hold strong relevance for teaching thread dyeing in Craft Education, particularly in courses related to textile dyeing techniques, textile crafts, and sustainability in crafts. Utilizing teak wood extract as a natural dye not only enriches color exploration in textile crafts but also provides scientific insights into the interaction between fixative agents and textile fibers.

In textile craft courses, students can study how fixatives such as Aluminum Sulphate, Calcium Carbonate, Ferro Sulphate, and Natrium Bicarbonate influence lightness levels (L^*), red-green shifts (a^*), yellow-blue shifts (b^*), and total color difference (ΔE^*ab). Through laboratory-based or studio-based experiments, they can evaluate how specific fixatives produce more stable or intense colors, offering valuable insights for future artisans and textile designers.

In the context of batik and traditional woven fabric dyeing, understanding fixation techniques is highly beneficial for students looking to develop textile works using natural dyes. Many batik and weaving artisans still rely on trial-and-error approaches to determine the best fixative, making this study a scientific reference for students interested in applying natural dyeing methods more precisely. By understanding the varying effects of fixatives, they can confidently choose the appropriate techniques to achieve durable and uniform colors.

Beyond technical aspects, this research also has implications for craft education focused on sustainability. With growing awareness of environmentally friendly craft practices, the use of natural dyes such as teak wood extract serves as an alternative to synthetic dyes, which have negative environmental impacts. In craft courses emphasizing innovation and ecology, students can develop dyeing approaches that utilize local resources more sustainably while preserving traditional values in textile craft practices.

Integrating these research findings into the Craft Education curriculum can provide students with a deeper learning experience in natural dyeing exploration. By combining scientific, technical, and sustainability aspects, students not only gain theoretical knowledge of the dyeing process but also develop the ability to apply it in innovative craft practices relevant to today's creative industries.

Discussion

The results of this study indicate that different fixation techniques significantly influence the final color outcomes of teak wood-dyed yarns. The spectrophotometric analysis shows that Ferro Sulphate leads to the most pronounced color transformation, producing the deepest and darkest shades, while Calcium Carbonate results in higher lightness retention. The statistical analysis further supports these findings, confirming that the differences observed among fixation techniques are significant ($F = 75.97$, $p < 0.05$).

These findings align with previous studies on natural dyeing processes, which suggest that different fixatives interact uniquely with tannins and other color compounds in natural dyes. For instance, research by [36] also found that metal-based fixatives, such as Ferro Sulphate, intensify color depth by enhancing mordant-dye interactions. Similarly, studies by [15], [37] and [38] demonstrated that iron-based fixatives produce darker and richer hues due to their strong affinity with tannin-rich natural dyes. Previous studies on clove leaf dye (*Syzygium aromaticum L.*) suggested its potential for batik production due to its stable color properties [13]. In contrast, teak wood extract exhibited different characteristics, particularly in its reaction with fixation agents such as Ferro Sulphate and Calcium Carbonate. In contrast, alkaline fixatives like Calcium Carbonate tend to produce lighter hues by shifting the pH balance of the dyeing solution, as reported by [39-41].

A similar trend has been observed in natural dyeing using mango leaf extract, where after-mordanting techniques were reported to improve color fastness by enhancing the dye-fiber interaction [6]. Studies on mango leaf extract indicate that applying mordants after the dyeing process allows for better absorption and fixation of tannin-rich compounds, resulting in enhanced dye stability and resistance to fading. However, our findings show that teak wood extract exhibits stronger pre-mordanting effects, particularly when combined with Ferro Sulphate, which produces deeper and more intense hues. The comparison suggests that while after-mordanting techniques may improve color longevity, pre-mordanting with specific fixatives can enhance color intensity and shade depth in tannin-based dyes. This distinction highlights the importance of selecting appropriate mordanting methods depending on the desired color outcome and durability.

However, differences were observed when compared with the findings of: [17] [40] [42] [43], who noted that aluminum-based fixatives often lead to brighter yet more stable colors. In our study, Aluminum Sulphate showed moderate lightness retention but did not enhance color vibrancy as much as Calcium Carbonate. This variation may be attributed to differences in dye composition and fiber characteristics. Additionally, research by [44] and [45] suggested that Sodium Bicarbonate can create a more uniform color distribution, yet our findings indicate that it resulted in moderate color absorption with less dramatic color shifts.

Moreover, the results indicate that Aluminum Sulphate and Natrium Bicarbonate offer moderate color retention, making them viable options for achieving balanced color intensity. These findings are valuable for textile artisans and industries seeking sustainable dyeing techniques, as they provide insights into how fixative selection can optimize both color vibrancy and stability. Previous research on mango seed extract (*Mangifera indica L.*) has highlighted its effectiveness as an eco-friendly dye for batik, particularly in improving color retention and fastness [12]. Compared to mango seed extract, teak wood extract interacts differently with fixation agents such as Ferro Sulphate and Aluminum Sulphate, leading to variations in color intensity and lightness retention.

Theoretical, Pedagogical, and Curriculum Implications

These findings have significant implications for both the textile industry and traditional dyeing practices. The strong effect of Ferro Sulphate in deepening color saturation confirms its potential for applications requiring rich, dark tones, making it particularly relevant for artisans producing handcrafted textiles with long-lasting, intense hues. Conversely, Calcium Carbonate's ability to retain lightness offers an alternative for industries aiming to achieve lighter, more uniform hues, particularly in eco-friendly fabric production [46]. These findings reinforce the importance of natural dyeing techniques in reducing dependence on synthetic chemicals while maintaining high-quality color results.

From a theoretical perspective, this study deepens the understanding of color fixation by demonstrating the varying effects of different fixatives on dye stability and transformation. The strong affinity of Ferro Sulphate with tannin-based dyes aligns with existing theories on metal-based mordants, which enhance dye-fiber interactions and darken color tones. Meanwhile, the brightening effect of Calcium Carbonate supports the principle that alkaline conditions shift color balance by altering dye solubility and fiber binding [38] [47-50]. These findings reinforce established models of natural dye chemistry while expanding knowledge on the role of fixatives in color uniformity and longevity.

In the context of textile dyeing education, these findings serve as valuable instructional resources, particularly in laboratory-based learning, where students can directly observe the impact of different fixatives on color outcomes. By integrating these results into practical coursework, students gain hands-on experience in natural dyeing processes, enabling them to analyze spectrophotometric data and refine their dyeing techniques based on scientific principles. This approach enhances problem-based learning (PBL) by encouraging experimentation with different mordants and critical evaluation of dye-fiber interactions [51-55]. Furthermore, integrating sustainability-focused dyeing techniques in craft education fosters an awareness of eco-friendly material applications, preparing students for responsible design practices.

With the growing emphasis on sustainability in the craft and textile industries, this study underscores the importance of integrating natural dyeing methods into the curriculum of Craft Education programs. Incorporating spectrophotometric analysis into coursework bridges the gap between traditional craftsmanship and scientific methodologies, providing students with both artistic and technical expertise [56] [57]. Courses such as Natural Dyeing Techniques, Textile Sustainability, and Applied Color Chemistry can offer a balanced perspective between creative expression and environmental responsibility. This integration ensures that graduates not only understand historical and contemporary natural dyeing methods but also develop the skills necessary to innovate within the textile industry using sustainable materials and processes.

Strengths and Limitations of the Study

This study provides a comprehensive evaluation of teak wood extract as a natural dye in combination with different fixatives, offering valuable insights into color development and stability. The integration of spectrophotometric analysis and statistical validation strengthens the reliability of the findings, making them applicable to both academic research and industrial applications. Additionally, this study aligns with the global movement toward sustainable textile production by promoting the use of natural dyes as eco-friendly alternatives to synthetic colorants [7], [58-60].

However, several limitations must be acknowledged. Since the experiments were conducted under controlled laboratory conditions, the findings may not fully capture real-world textile dyeing challenges, where variables such as temperature, humidity, and water pH can significantly impact color retention [61-64]. Furthermore, the study did not assess the long-term durability of the dyed yarns, particularly in terms of color fastness to washing, light, and rubbing, which are crucial for textile industry applications [14], [17] [37], [65]. Additionally, this research focused exclusively on teak wood extract; future studies should investigate other plant-based dye sources to determine whether similar fixation trends apply across different natural dyes.

Future research could build on these findings by exploring the molecular interactions between teak wood extract and fixatives using advanced spectroscopic techniques [66-68]. Such investigations would provide a deeper understanding of the chemical bonding mechanisms involved in natural dye fixation, enhancing the practical applications of these techniques in commercial textile production.

By advancing knowledge on fixation techniques and their impact on color stability, this study contributes to the development of eco-friendly dyeing methods, paving the way for more sustainable and scientifically informed textile practices.

CONCLUSION

This study examined the effects of different fixation materials on the final color outcomes of teak wood-dyed yarns. The results indicate that Ferro Sulphate produced the most intense color transformation, yielding darker and richer hues due to its strong interaction with tannin-based dye compounds. In contrast, Calcium Carbonate resulted in higher lightness retention, making it a suitable fixative for achieving lighter shades. Aluminum Sulphate and Natrium Bicarbonate demonstrated moderate effects, balancing color retention and absorption, thus providing stable but less dramatic color variations.

The statistical analysis ($F = 75.97$, $p < 0.05$) confirmed significant differences among the fixation techniques, reinforcing the critical role of fixatives in determining final color properties. These findings align with previous research on natural dye fixation while also expanding the understanding of teak wood extract as a dye source, particularly in relation to its interaction with different mordants.

From a practical perspective, these results offer valuable insights for textile artisans, natural dye researchers, and eco-friendly dyeing industries in selecting optimal fixation methods to achieve specific color effects. Additionally, the study highlights the potential of natural dyes as sustainable alternatives to synthetic dyes, supporting global initiatives for environmentally responsible textile production.

For future research, long-term durability tests on color fastness to washing, light exposure, and rubbing should be conducted to evaluate the practicality of teak wood extract in commercial applications. Additionally, expanding the study to other natural dye sources and fiber types could further validate the findings. Advanced spectroscopic analysis of molecular interactions in natural dye fixation would also enhance the scientific understanding and industrial applicability of this process.

Overall, this study contributes to the growing body of knowledge on natural dyeing techniques, providing a scientific foundation for optimizing the use of teak wood extract in sustainable textile production.

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