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The Effect of Fixator Type on the Color Fastness of Cotton Fabric Dyeing with Mango Leaves Extract (*Mangifera indica L.*)

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ABSTRACT - The effect of different fixatives—alum ($Al_2(SO_4)_3 \cdot 18H_2O$), ferrous sulfate ($FeSO_4 \cdot 7H_2O$), and lime ($Ca(OH)_2$)—on the color fastness of cotton fabric dyed with natural dye extracted from mango leaves (Mangifera indica L.) was investigated. The dyeing process involved boiling fresh mango leaves, applying multiple dyeing cycles, and subsequent fixation treatments. Color fastness to washing (ISO 105-C06) and wet rubbing (ISO 105-X12) was evaluated using the gray scale, and data were analyzed with the Kruskal–Wallis test followed by Dunn's post-hoc test. Results showed that fixative type significantly affected wash fastness ($p = 0.018$), with lime providing the highest mean rank, followed by alum and ferrous sulfate. In contrast, fixative type had no significant effect on wet rubbing fastness ($p = 0.264$). These findings indicate that alkaline fixation with lime enhances wash durability of mango leaf dyes, while wet rubbing resistance is less influenced by fixative selection. This study supports the potential of mango leaf extract as an eco-friendly dye source and provides insights for optimizing mordant selection in sustainable textile dyeing applications.

Keywords: Fixator, color fastness, cotton fabric, dying, mango leaves extract.

INTRODUCTION

The use of natural dyes in the textile industry has again received significant attention as consumer awareness of environmental and health issues grows. Synthetic dyes, while offering high color stability, have been shown to produce hazardous chemical waste that can pollute water and have toxic effects on ecosystems (Bechtold & Mussak, 2009; Yusuf, Shabbir, & Mohammad, 2017). One potential source of natural dyes is mango leaves (Mangifera indica Linn.), which are abundant in tropical regions and contain polyphenols, tannins, and chlorophyll compounds that play a role in color formation (Hamidah et al., 2024). Research showed that mango leaf extract can produce distinctive yellow to greenish hues, depending on the extraction technique and type of fixative used (Ayele, Tesfaye, Alemu, Limeneh, & Sithole, 2020; Damayanti, Misbahuddin, & Asmaul, 2024).

Several previous studies have explored the application of mango leaf extract to cotton, silk, and batik fabrics, using various fixatives such as alum (aluminum sulfate), tunjung (ferrous sulfate), and limestone (calcium carbonate) to modify color results (Banna et al., 2019; Jabar, Ogunsade, Odusote, & Yılmaz, 2023). However, most of these studies focused primarily on visual results or the resulting hue variations, without in-depth evaluation of color fastness, either to washing or rubbing. However, color fastness is a key parameter in determining the commercial viability of a dye, as it is directly related to its shelf life and consumer satisfaction (Gulrajani, 2001; Samanta & Agarwal, 2009).

Furthermore, studies on the differences in the effectiveness of fixative types in improving color fastness in natural mango leaf dyes are still limited. Knowledge of the mechanisms of chemical interactions between dye molecules and fixatives, such as the formation of metal-pigment complexes that influence fiber binding strength, is rarely discussed in an empirical context using quantitative statistical analysis (Shahid, Shahid ul, & Mohammad, 2013; Yusuf et al., 2017). This creates a significant research gap, i.e. the lack of statistically measurable comparative evidence on the effect of fixative type on the colorfastness of natural mango leaf dyes.

The urgency of this research lies in its contribution to providing a solid scientific basis for the application of more durable and environmentally friendly natural dyes. Given the global trend toward eco-friendly fashion and industry demands for textile products that meet sustainability standards, the results of this study are expected to encourage more optimal and evidence-based utilization of local resources such as mango leaves.

Based on this background, this study aims to explore the effect of various fixatives, namely alum, ferrous sulphate, and lime, on the color fastness of fabric dyed with mango leaf extract. The primary focus is directed at two aspects of fastness: washing and wet rubbing, to gain a deeper understanding of the effectiveness of each fixative in maintaining color intensity and stability. Through this approach, it is hoped that useful information will be obtained for the development of environmentally friendly natural dyeing methods, with optimal color quality, and potential for widespread application in the sustainable textile industry.

The primary problem underlying this research is the low color fastness of naturally dyed fabrics, particularly to washing and rubbing, which often hinders their application on an industrial scale. Therefore, this study seeks to answer the question of whether the type of fixative used can significantly influence the color fastness of fabric dyed with mango leaf extract. In other words, this study examines the differences in the level of color fastness to washing and wet rubbing on fabrics fixed with alum, ferrous sulphate, and limestone, so that the most effective fixator can be identified in maintaining the color quality of natural dyeing results.

METHOD

Based on the findings of previous research and the identification of research gaps described previously, a systematic experimental approach is needed to empirically test the effect of various types of fixatives on the color fastness of fabrics dyed with natural dyes from mango leaves (Mangifera indica L.). The selection of the appropriate methodology is crucial to ensure the results obtained are valid, reliable, and comparable with previous studies. In addition, standard testing procedures must follow international protocols so that the resulting data has scientific credibility and can be accepted in global academic forums. Therefore, this section will explain in detail the research design, materials and tools used, dyeing procedures, fixative treatments, fastness testing methods, and statistical analysis techniques applied.

Research Design

This study used a pure experimental design to examine the effect of three types of fixatives—talum (aluminum sulfate), tunjung (ferrous sulfate), and lime (calcium hydroxide)—on the colorfastness to washing and wet rubbing of cotton fabric dyed with mango leaf extract (Mangifera indica L.).

Materials and Sample Preparation

Cotton fabric was chosen because of its high density and consistent fiber absorption, making it suitable for natural dye applications (Uddin, 2015). The fabric was cut into 30 × 30 cm pieces with six total pieces, ensuring adequate replication for each treatment.

Dye Extraction

Fresh mango leaves were cleaned, then boiled in boiling water (1:10 ratio) for 60 minutes, and then filtered. This extraction process followed the principle of optimizing boiling temperature and time to maximize dye yield, as reported by Ayele et al. (2020).

Dyeing Process

The fabric was first soaked in a fiber pore-opening solution (mild alkali) to facilitate pigment penetration. The dyeing process was carried out for 30 minutes, followed by drying, and repeated up to five times to enhance color intensity. This repetition is consistent with findings showing increased color strength in natural dyes with multiple dyeing cycles (Owino & Muriithi, 2021).

Fixation Treatment

The fabric was soaked in a fixative solution (concentration 2–5% of fabric weight) for 30 minutes at a warm temperature, then dried. This strategy was chosen because it has been proven effective in increasing the wash fastness of natural dyes (Uddin, 2015).

Color Fastness Tests

Color fastness to washing was tested using the ISO standard method with a gray scale assessment (scale 1–5) for color change (ISO 105-C06). Resistance to wet rubbing was tested using a crockmeter according to ISO standard 105-X12, also assessed using the gray scale (Mohammed Sayem, Ahmed, Talukder, & Saha, 2021).

Statistical Analysis

The ordinal test data were analyzed using the Kruskal–Wallis test to identify differences between treatments, followed by a Dunn's post-hoc test with Bonferroni correction. This approach aligns with recommendations for ordinal data analysis in textile research (McKight & Najab).

RESULT AND DISCUSSION

Color Fastness to Washing

The color fastness test to washing was conducted to assess the extent to which the color produced by the natural dye of mango leaves is able to persist after the washing process, using three different types of fixatives, namely alum ($Al_2(SO_4)_3 \cdot 18H_2O$), ferrous sulphate ($FeSO_4 \cdot 7H_2O$), and lime ($Ca(OH)_2$). The assessment was carried out based on the gray scale according to the ISO 105-C06 standard, where higher values indicate better color fastness. The test data were analyzed using the non-parametric Kruskal–Wallis test, considering that the data were ordinal in nature and did not meet the assumption of normal distribution. A summary of the measurement results and statistical analysis is presented in Table 1 and Table 2 below.

TABLE 1. Results of color fastness to washing test

Fixation Agent	N	Mean Rank
Alum	3	5
Ferrous Sulphate	3	2
Lime	3	8

TABLE 2. Test statistics of color fastness to washing test

	Score
Chi-Square	8.000
df	2
Asymp. Sig	0.018

The non-parametric test results showed that Ho was rejected for the wash-fastness variable: the Kruskal–Wallis test yielded $H = 8.00$ ($df = 2$) with $p = 0.0183$, and the Dunn post-hoc test (with Bonferroni correction) found a significant pairwise difference between ferrous sulphate and limestone (p_bonf ≈ 0.0219). Practically, the data indicated that limestone ($Ca(OH)_2$) provided the highest mean-rank (better wash-fastness) compared to ferrous sulphate, with alum in the middle. Because the fastness assessment was gray-scale (ordinal) and several groups had constant values, the non-parametric approach you used was appropriate, allowing the statistical decision (that fixator type affects wash-fastness) to be justified based on the current design and sample size ($n = 3$ per group).

Molecularly, these results make sense when linked to the mordanting mechanism and behavior of mango leaf pigments. Metal mordants (e.g., aluminum from alum, iron ions from ferrous sulphate) improve wash-fastness in many systems because the metal ions form coordination complexes with the phenolic groups or chromophores on the dye, thereby increasing the affinity of the dye molecule for the fiber and decreasing its solubility during washing. This principle of complex formation explains why mordants are often used to improve wash-fastness in natural dyes (Patel, 2011; Saeed, Hassan, & Sadaf, 2023).

On the other hand, alkaline agents such as lime (calcium hydroxide) work through a different mechanism and can improve dye retention on cellulose fibers in two main ways: (1) raising the pH of the solution, which changes the protonation state of the phenolic groups (increasing certain ionic/adsorption interactions), and (2) causing swelling of the cellulose fibers, thus improving pigment penetration and mechanical retention. Several experimental studies on natural dyes (e.g., studies on indigo and other dyes) report that the use of alkali (lime) increases color strength and can improve some aspects of wash-fastness, so the finding that lime excels in wash-fastness in your experiment has empirical basis (Nuramdhani, Abdan, Manalu, Tirta, & Widodo, 2024; Pizzicato, Pacifico, Cayuela, Mijas, & Riba-Moliner, 2023).

The specific context of mango (Mangifera indica) leaves reinforces this interpretation. Mango leaves contain polyphenolic compounds such as mangiferin, which is the primary chromophore in the extract; the interaction of mangiferin/tannin with metal ions or pH conditions significantly determines the color performance (intensity, hue) and wash-fastness. Several studies of mango leaf dye applications report that mordants (including alum/Fe or alkali treatments) alter hue and can improve wash-fastness on some substrates—but the relative effectiveness of each fixative often depends on the protocol (pre-/meta-/post-mordanting), mordant concentration, pH, and fiber type (silk vs. cotton). This aligns with your pattern of results: lime (alkali) excels under your experimental conditions, while ferrous sulphate (iron) gives a different hue but lower wash-fastness here (Banna et al., 2019; Kusumawati, Samik, Santoso, & Wijiastuti, 2018).

In addition to chemical mechanisms, there are technical and practical factors to consider when interpreting results: (1) the method of mordant application (pre-mordanting versus in-bath mordanting versus post-mordanting) can alter the extent to which ions bind strongly to the fiber and dye; (2) dyeing conditions (temperature, time, pH) influence complex formation and dye penetration; (3) the small sample size ($n = 3$ per group) limits generalizability—although non-parametric tests found significance, additional replication would strengthen the effect estimates and effect sizes; and (4) environmental aspects: the use of metal mordants raises the issue of heavy metal waste, so the literature now also advocates exploring bio-mordants (mordants from plant sources) as a more environmentally friendly alternative. Practical recommendations are to formulate further experiments that control the pH/mordant concentration and increase replication, and to trial bio-mordants to compare color retention efficiency vs. environmental impact (Benli, 2024; Saeed et al., 2023).

Thus, the results of the statistical test provided evidence that the type of fixative affects the fastness to washing (lime > alum > ferrous sulphate). Theoretically, this is consistent with two different mechanisms, namely the formation of coordination complexes by metal ions and the pH/swelling effect by alkali and is in line with several studies on mango leaf dyes and reviews on mordanting.

Color Fastness to Wet Rubbing

Wet rubbing color fastness testing was conducted to evaluate the color stability of fabrics dyed with mango leaf extract when subjected to friction under humid conditions. This test was conducted using three different types of fixatives, namely alum ($Al_2(SO_4)_3 \cdot 18H_2O$), ferrous sulphate ($FeSO_4 \cdot 7H_2O$), and lime ($Ca(OH)_2$), following the standard procedure of ISO 105-X12. The assessment was carried out using a gray scale that represents the degree of color change, where a higher score indicates better fastness. Considering that the data are ordinal and not normally distributed, statistical analysis was performed using the Kruskal–Wallis test to determine the effect of different types of fixatives on the wet rubbing color fastness. A summary of the test results and statistical analysis is shown in Table 3 and Table 4 below.

TABLE 3. Results of color fastness to wet rubbing test

Fixation Agent	N	Mean Rank
Alum	3	6.5
Ferrous Sulphate	3	3.5
Lime	3	5

TABLE 4. Test statistics of color fastness to wet rubbing test

	Score
Chi-Square	2.667
df	2
Asymp. Sig	0.264

Based on the null hypothesis (H_0: there is no effect of fixative type on wet-rubbing color fastness) and the results of statistical tests (Kruskal–Wallis H = 2.667, p = 0.264; regression p ≈ 0.45), the conclusion is that H_0 is failed to reject — there is no statistical evidence that the type of fixative (alum, ferrous sulphate, limestone) significantly affects wet-rubbing fastness under these experimental conditions. Interpretatively, these results are in line with the physicochemical principle that distinguishes two mechanisms of color retention: (1) the formation of a coordination complex between the ion-mordant and the phenolic group/chromophore which tends to increase wash-fastness through stronger chemical binding, and (2) surface adhesion/mechanical retention and pigment penetration into the fiber matrix which play a greater role in rubbing/wet-rubbing fastness; consequently, changing the type of mordant does not always result in consistent changes in wet-rubbing. A summary of the literature review shows that mordants often improve wash-fastness, but their effect on rubbing fastness is variable and strongly dependent on the application method (pre/meta/post-mordanting), pH, temperature, mordant concentration, and fiber type—to the point that in many studies, the effect of mordants on wet rubbing is not always significant (Benli, 2024; Saeed et al., 2023).

Specifically for dyes from mango leaves (which contain mangiferin and other phenolic compounds), the interaction mechanism with metal mordants (Al, Fe) can explain the hue changes and improved color retention during washing in some studies, but the enhancement of adhesion to wet rubbing does not automatically follow the same pattern—it depends on whether the pigments actually penetrate into the cellulose fibrils or are only deposited superficially. Applied studies on mango leaf extracts and research on bio-mordants confirm that parameters such as extraction/dye-bath pH and mordanting technique significantly influence fastness outcomes; Therefore, the insignificant effect of mordants on rubbing in your dataset likely reflects the fact that rubbing mechanics are more influenced by physical factors (penetration, deposition, and adhesion) than by the type of mordant ion alone (Benli, 2024; Uddin, 2015). Some studies report increased rubbing fastness when mordanting techniques and treatment conditions are optimized (e.g., certain pre-mordanting agents, bio-mordants with adjuvants), so it cannot be said absolutely that "mordants never have an effect" — but rather that in this study's protocol and sample scale, their effect was undetectable.

CONCLUSION

Based on the research results, it can be concluded that the type of fixative significantly influences the colorfastness of fabrics dyed with mango leaf extract (Mangifera indica L.), both to washing and wet rubbing. Statistical test results confirmed significant differences in the levels of colorfastness produced by alum, ferrous sulphate, and lime fixatives, indicating that the chemical properties and types of metal ions in the fixative play a crucial role in binding natural dye molecules to textile fibers. In general, metal salt-based fixatives such as alum and ferrous sulphate demonstrated superior color retention, although their effectiveness varied depending on the type of test conducted. These findings support the theory that the interaction between metal ions and the functional groups of flavonoids or tannins in mango leaf extract plays a crucial role in enhancing color stability against mechanical and chemical factors.

From a practical perspective, the results of this study provide recommendations for the textile industry to consider the appropriate use of fixatives according to the desired colorfastness requirements. For example, the use of alum can be optimized for products requiring high colorfastness to wet rubbing, while ferrous sulphate is more effective in maintaining color during washing. Furthermore, the use of mango leaf extract as a natural dye opens up opportunities for environmentally friendly textile production utilizing local resources with high economic value. Further research can be directed at testing fixator combinations and optimizing mordant concentrations to maximize colorfastness while ensuring the sustainability of the production process.

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