

COMPARATIVE MICROWAVE-ASSISTED DYEING OF COTTON WITH CACTUS FRUIT, TURMERIC, AND BASIL: EFFECTS OF ALUM MORDANTING ON RUBBING FASTNESS

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Abstract

The use of synthetic textile dyes is common in the textile industry despite their negative impacts on the environment and potential toxicity, and this has led to a revisit of natural dyes obtained from local plant sources [7], [11]. In this study, the dry and wet rubbing fastness of cotton fabric dyed with microwave extracted natural dyes from three sources available in Pakistan: cactus pear fruit (*Opuntia ficus-indica*), turmeric (*Curcuma longa*), and basil/tulsi leaves (*Ocimum tenuiflorum*) were investigated. The dyes were extracted using a domestic microwave and applied to the cotton fabrics by unmordanting and mordanting with alum by source specific microwave timings. The dry and wet rubbing fastness was tested using the Grey Scale (1-5 GS). The alum-treated cactus sample showed higher dry and wet rubbing-fastness ratings (3-4 GS and 5 GS, respectively) than the unmordanted sample (2-4 GS and 3-4 GS). In the case of turmeric, the dry rubbing fastness increased from 4 GS to 4.5 GS, while the wet rubbing fastness decreased from 3.4 GS to 2 GS. As for basil, dry rubbing fastness increased from 3 GS to 4 GS, while wet rubbing fastness decreased marginally from 4.5 GS to 3.4 GS. In general, the results obtained were source-dependent and did not reveal any combination of source and mordant which would rate the highest in both dry and wet conditions. This leads to an assumption that mordants need to be chosen taking into account their end purpose. However, since replicates and statistics have not been used, these results can only be considered preliminary.

I. INTRODUCTION

The textile industry has made extensive use of synthetic dyes since the mid-nineteenth century mainly due to their affordability, reliable shade replication, and extensive colour range. However, synthetic dyes have often been found to be non-biodegradable, and their manufacture and disposal have always been associated with the pollution of water, skin irritation, and even carcinogenic effects [7], [11]. These growing

environmental concerns, along with increasing consumer demands for sustainable textiles, have renewed scientific interest in natural dyes from various plant sources such as plants, fruits, roots, and leaves, many of which are biodegradable and comparatively less toxic and available locally and economically in various parts of the world including Pakistan [8].

Natural dyes, however, are often applied to fibres with a mordant because many natural colourants exhibit relatively low substantivity toward cellulose

fibres [11], [19]. Alum was the most common mordant in natural dyeing due to relatively low toxicity, accessibility, and a wide range of compatibility with natural colourants. Other mordants include iron and copper salts, tannic acid, and various biomordants such as citrus juice, chitosan, and tannin-rich plant extracts [10], [16], [18]. Mordant type, mordanting technique (pre-, meta-, or post-mordanting), and mordant amount each played a significant role in colouration results in terms of shade, colour depth, and fastness properties, but the effects were highly source- and fibre-specific [9], [16], [19]. Therefore, fastness properties obtained for one natural dye could hardly be generalised to another one without proper testing.

Among individual dyes, turmeric had long been known to be used for coloring fabrics in South and Southeast Asia and continued to be among the most available and well-researched sources of yellow dye, due to its curcumin composition and ease of acquisition as a food-grade powder [3], [10], [15], [16], [19], [20]. The leaves of basil (tulsi) were traditionally associated with religious and medicinal purposes in South Asia, and dyeing textiles became a secondary purpose for it in regional studies [4], [5]. By comparison, cactus pear fruit was under-represented as a source for dyeing fabrics; available research literature about *Opuntia* species paid far more attention to their juice, food colouring, and antioxidant properties than to their use in fabric dyeing, and, in the case of fabric dyeing, wool but not cotton served as a substrate [2], [13].

The technique used for extraction also hindered the comparative analysis between these sources. The traditional aqueous extraction technique involved long durations of boiling that could range from thirty minutes to several hours, along with larger amounts of water, translating into greater energy consumption. On the other hand, microwave-assisted extraction (MAE) has proven to be effective in reducing the duration of extraction and amount of solvent used while increasing the yield since microwave energy allowed heating of material from inside as compared to only heating at the surface [1], [3],

[14]. The use of MAE in dyeing fabrics using natural dyes rather than their extraction for food and pharmaceutical use has not received much attention yet [6], [12], [13].

Considering such a fragmented scenario, individual dye sources, inconsistencies in reporting the fastness properties, and variations in the extraction procedures employed among the studies conducted, in this study, dye extraction was performed separately from the fruits of cactus, turmeric, and basil leaves using a domestic microwave oven. Each dye was separately applied on cotton fabric with and without an alum mordant and subjected to dry and wet rub tests under the same test conditions.

II. Problem Statement

Microwave-assisted dyeing on each of these three sources had been researched individually; however, the literature available was highly disjointed in nature, rendering it less practically useful in the case of a dyer deciding which source to choose. The existing research on *Opuntia ficus-indica* dyeing generally centred around wool fabrics, characterisation of the betalain pigment, or bio-mordants such as ascorbic acid, but not the cotton dyeing using a traditional mordant under a standardised procedure [2], [13]. The research on the turmeric dyeing was quite extensive but spread between food chemistry (yield optimization of curcumin instead of fastness), mixed-dye microwave protocols with the use of pomegranate rind instead of cactus or basil [12], tie-dyeing [15], knitted cotton with biomordants [17], [18], and cotton dyeing with various metallic and biomordant combinations providing different values of the fastness metric [10], [16], [19], [20]. The basil (tulsi) leaf dyeing on cotton was extensively covered in the literature, although never with the microwave-assisted extraction technique and the measurement of rubbing fastness [4], [5].

Further review of studies on the process of natural dye extraction and mordanting revealed the high variability of results, depending on the particular combination of source, extraction process, and mordant chosen, and that these results could not

be generalised between any sources or fibres studied [7], [8], [9], [11], [21]. For this reason, there have been no studies found employing the same microwave extraction and dyeing process for all three of the above sources of natural dyes and measuring dry and wet rubbing fastness. Without this comparison performed, it was hard to determine which of the three sources would be the most appropriate in applications when rubbing fastness was the key characteristic to consider.

III. Research Questions

1. How did alum mordanting affect the dry and wet rubbing fastness of cotton dyed with microwave-extracted cactus fruit, turmeric, and basil leaf dyes, respectively?
2. Which source-mordant combination showed the highest observed dry and wet rubbing-fastness ratings under the experimental conditions used?

IV. Research Contributions

This study added to the literature on natural dyes in the following ways. Firstly, this study used the same technique of microwave extraction, mordanting and dyeing for three different natural dye sources, namely a fruit, a rhizome/root and a leaf, thereby enabling a more systematic comparison than comparisons drawn across separate studies employing different methodologies [1], [2], [3]. Secondly, it focused on rubbing/crocking resistance of these natural dyes both dry and wet, which has been largely understudied in the context of other dye properties such as washing, light and colour strength [4], [5], [6], [21]. Thirdly, the study reported the exact process parameters used, namely the amounts of extraction, volume of water, temperature and time of microwave treatment, and concentration of mordants, making it possible for a low-cost and low-equipment method of dyeing which can be useful in situations where these materials are readily available in Pakistan [8].

V. Literature Review

Paper [1]: "Microwave Assisted Natural Dye Extraction from Amaltas (*Cassia fistula*) for Cotton Dyeing: Process Optimization Using Modern Statistical and Machine Learning Algorithms," by M. Aftab, T. Ahmad, S. Adeel, and M. Javed. Microwave-assisted extraction was used by the authors to extract tannins from amaltas pods for dyeing cotton fabric. Response surface design and machine learning were employed to optimise the process based on extraction time, temperature, and dye concentration, with the resulting colour strength and fastness on the cotton fabric as the criteria. The use of machine learning and statistical analysis to identify the optimum process conditions ensured a high degree of confidence in the results, and the study demonstrated the efficacy of MAE for dyeing cotton fabric specifically, rather than reporting only general extraction yields. It also considered interactions among process variables, which is rarely addressed in natural-dye MAE studies. However, the single source of dye was a limitation of this study, and it did not consider rubbing fastness, which limits its direct comparison with the results of the current study.

Paper [2]: "Dyeing of wool yarn with aqueous extract of *Opuntia ficus-indica* fruit using ascorbic acid as a bio-mordant," by H. Barani and F. Rahmani. In this study, wool yarn was dyed using an extract of cactus pear fruit under varied dyeing conditions, with ascorbic acid used as a bio-mordant in place of a metallic mordant. The research examined a bio-mordant other than alum in a sustainable-dyeing context and is among the few studies to examine the fastness properties of *Opuntia ficus-indica* as a dye, as opposed to its use in food or juice colouration; it also characterised the behaviour of the betalain-based colourant. However, the research was conducted on wool rather than cotton, which limits direct comparison with the current research, and the dyeing process used aqueous rather than microwave extraction. In addition, rubbing fastness was not the main fastness property considered.

Paper [3]: "Optimization and modeling of microwave-assisted extraction of curcumin and

antioxidant compounds from turmeric using natural deep eutectic solvents," by K. Doldolova, M. Bener, M. Lalikoğlu, Y. S. Aşçı, R. Arat, and R. Apak. The authors optimised the extraction conditions (time, temperature, and solvents) for the extraction of curcumin and antioxidants from turmeric, though in the context of food and pharmaceutical chemistry rather than textile dyeing. The paper provided a comprehensive description of the effects of MAE conditions on the extraction yield and efficiency of curcumin and is a useful source of methodology for microwave-based turmeric extraction; its use of deep eutectic solvents also exemplifies an environmentally friendly extraction approach that may be relevant to dye extraction. However, the paper did not address dyeing or fastness and therefore cannot be applied directly to the field of dyeing, and the solvent system used (deep eutectic solvents) differed from the water-based solvent used in the present experiment.

Paper [4]: "Cotton Coloration Using Holy Basil Leaves Extracts," by T. A. Chowdhury, J. I. Khandaker, M. A. Gafur, M. R. Repon, A. Hossain, M. K. Islam, and M. Abdullah. Twelve cotton jersey samples were pre-treated with lemon juice as a biomordant and then dyed with holy basil extract under varying pH and temperature conditions; the dyeing process was found to perform best under alkaline conditions at 100 °C in terms of dye fixation and fastness. This research gave fastness results in terms of rubbing, wash, light, and perspiration fastness properties, which is rarely reported in basil-dyeing studies and made it particularly valuable, and it substantiated its fastness properties with FTIR, SEM, and thermal analyses explaining the improved dye fixation under alkaline, high-temperature conditions. However, unlike the current research, the study used aqueous heating for dye extraction rather than microwave heating, and the biomordant used was lemon juice rather than alum, making direct mordant-to-mordant comparison difficult.

Paper [5]: "Eco-friendly dyeing with Tulsi leaf extract," by K. J. Patel, B. H. Patel, J. A. Naik, and A. M. Bhavsar. This study examined the extraction of dye from tulsi leaves and its application on

wool, nylon, and polyester fibres using various mordanting methods (pre-, meta-, and post-mordanting). The comparative analysis across fibre types and mordanting variations provides useful methodological insight, and this paper has been cited extensively as an early reference for tulsi dyeing; the use of multiple fibres in the same study also revealed that tulsi's dyeing characteristics vary across fibres, a consideration relevant when studying a specific fibre. However, cotton fibre was not studied, and the extraction method used was conventional rather than microwave-based, which is comparatively outdated relative to the MAE technique used in the present study.

Paper [6]: "Microwave-assisted extraction and dyeing of chemical and bio-mordanted cotton fabric using harmal seeds as a source of natural dye," by S. Adeel, M. Zuber, Fazal-ur-Rehman, and K. M. Zia. This study examined the extraction of dye from harmal seeds using microwave irradiation and the dyeing of cotton using both chemical (alum, iron) and bio-mordants (acacia), comparing colour-strength outputs. The methodology (MAE, cotton, chemical mordant) closely parallels the current study, enabling direct comparison, and it also compared chemical and bio-mordant outputs at several concentrations; its finding that bio-mordanting outperformed chemical mordanting in terms of ISO fastness ratings raises an interesting question, untested in the current study, as to whether a similar advantage would apply to cactus, turmeric, or basil. However, since this study used a different dye source (harmal seeds) unrelated to those used in the current research, its extraction parameters cannot be directly applied, and colour strength rather than rubbing fastness was used as the outcome measure.

Paper [9]: "Mordanting Methods for Dyeing Cotton Fabrics with Dye from *Albizia coriaria* Plant Species," by L. Janani, L. Hillary, and K. Phillips. The authors studied the effect of various mordants and mordanting techniques on cotton, finding that the unmordanted control itself possessed excellent dry and wet rubbing fastness (grade 5), while mordanting altered only the shade without providing any rubbing-fastness benefit. The

authors employed a rub-fastness scale identical to that used in the present research (dry and wet, grey-scale rating), and their finding that mordanting does not necessarily improve rubbing fastness is highly relevant to the current study, since a similar pattern was observed here for turmeric and basil; their "substantive" dye classification is also a useful concept for explaining the superior properties of the unmordanted basil dye. However, the source used was an entirely different dye type unrelated to the current research, aqueous boiling rather than microwave extraction was used, and the mordant concentration (3%) differed from the alum concentration used here.

Paper [15]: "Turmeric Dyeing of Cotton Fabrics using Tie-Dyeing Techniques," by P. Bigambo, H. Wellah, H. Ngaga, S. Kimbokota, and M. Mrango. This study used conventional boiling to extract turmeric dye and applied it to tied and untied cotton fabrics using copper sulphate and iron sulphate as mordants, compared against an unmordanted control, evaluating dry and wet rubbing fastness alongside wash fastness. It tested dry and wet rubbing fastness of turmeric dye on cotton and provided results directly comparable to those obtained in the current study; its finding that unmordanted turmeric dye gave good to excellent dry and wet rubbing fastness (grey scale 4 to 4-5) is close to the current study's unmordanted turmeric dry-fastness result, and the inclusion of two mordants allowed a useful within-study comparison. However, the use of conventional boiling extraction and tie-dye application in the previous study is not directly comparable to the current study, which used microwave extraction and strip dyeing.

Paper [18]: "Enhancing the Dyeing and Color Fastness Properties of Cotton Fabric Dyed with Curcumin: A Sustainable Double Mordanting Approach Using Waste-Derived Biomordants," by M. M. Rahman, S. Yoon, S. Choi, S. Kim, Y. Kim, I. Hong, N. Hsan, N. Oh, S. Kumar, and J. Koh. In this study, the authors combined waste-based biomordants (such as pomegranate rind, onion peel, and chitosan) with metallic mordants using a double-mordanting technique for curcumin-dyed

cotton, achieving significant increases in colour strength (by up to 69.68%) and wash fastness (by up to 1.5 grades) compared to conventional single mordanting. This paper showed that combining different types of mordants could meaningfully enhance fastness relative to single mordanting, providing useful context for understanding why the current study's single alum mordant produced poor wet rubbing fastness for turmeric; its sustainability-oriented, waste-base mordant approach also points to a possible solution (combining alum with waste-based mordants) not tested in the current study. However, this study concentrated on wash fastness and colour strength rather than rubbing fastness, and its double-mordanting process was more complex than the single-mordant approach used here.

Paper [20]: "The coloration of cotton fabric with natural dye extracted from turmeric powder," by S. S. Alam, J. Ghosh, and D. J. Das. This paper tested the ability of turmeric powder extract to dye cotton fabric using copper sulfate and aloe vera as mordants, finding that copper sulfate provided relatively low rubbing fastness, while aloe vera mordanting provided relatively high rubbing fastness as well as relatively high wash and water fastness. This paper discussed rubbing fastness of turmeric-dyed cotton directly comparable to the current study, and highlighted the importance of mordant selection, rather than mere presence or absence of a mordant, in determining turmeric's rubbing-fastness results; it also provided results on shrinkage and tensile properties not available in the current study. However, this paper did not use microwave extraction, worked with copper sulfate and aloe vera rather than alum as mordants, and used twill fabric rather than the plain weave used in the current study.

VI. Research Gaps

The literature reviewed identified four key gaps addressed by the current study. Firstly, there were no studies employing the microwave-assisted extraction technique consistently in the three plant sources such that comparison could be done between sources using results obtained from experiments differing in types of fibres, mordants,

and extraction processes used in the studies [1], [2], [3]. Secondly, rubbing (crocking) fastness in particular was not adequately reported for the three plant sources; many similar studies focused more on reporting results for wash, light, or K/S fastness instead [5], [10], [17], [21]. Thirdly, cactus fruit dyeing was extensively documented with wool and bio-mordants or multi-variable optimised designs, leaving its efficacy on cotton with a consistent alum mordanting process relatively unreported [2], [13]. Fourthly, although many studies had been conducted for turmeric, the fastness results varied depending on the type of mordants (copper sulfate, aloe vera, chitosan, citrus juice, potash alum, ferrous sulphate) and extraction techniques used [10], [15], [16], [17], [18], [19], [20]. Existing reviews confirmed that fastness outcomes were highly source- and mordant-specific and did not generalise [7], [8], [9], [11], [21], underscoring the need for the direct, identically processed comparison this study provided. The present study addressed all four gaps through a single controlled, identically processed, rubbing-fastness-focused comparison of the three sources on cotton.

VII. Methodology

A. Materials

Materials that were used include fresh cactus pear (*Opuntia ficus-indica*), commercial turmeric (*Curcuma longa*), fresh basil (*Ocimum tenuiflorum*), plain weave cotton fabric samples, distilled water, and alum (aluminum potassium sulfate).

B. Dye Extraction

Cactus fruit: 210 g of fresh fruit was chopped into small pieces and added to 1 L of distilled water pre-heated to 45 °C. The mixture was then microwaved at a raised temperature of 85 °C for 2 minutes, until the solution reduced to approximately 700 mL, then cooled and filtered.

Turmeric: 150 g of turmeric powder was added to 0.5 L of distilled water pre-heated to 25 °C, then microwaved at a raised temperature of 35 °C for 2 minutes, until the solution reduced to approximately 300 mL, then cooled and filtered.

Basil: 150 g of fresh basil leaves, chopped, was added to 0.5 L of distilled water pre-heated to 25 °C, then microwaved at a raised temperature of 35 °C for 2 minutes, until the solution reduced to approximately 300 mL, then cooled and filtered.

C. Mordanting Procedure (applied identically across sources)

Five hundred millilitres of water was heated to 45 °C using a microwave oven, and 5 g of alum (1% w/v) was dissolved in it [11], [19]. Cotton was dipped in this solution for 5-10 minutes with continuous stirring, rinsed in 1 L of cold water without pressing, and dried under shade for 12 hours

D. Dyeing Procedure

Each source was treated by immersing the cotton strips into the dye solution and subjected to source-specific durations in the microwave oven before being dried under the shade for 12 hours without squeezing or washing. The sources had specific duration times arranged in ascending order according to the order of their preparation (Table 1).

Table 1 Sample identification and microwave exposure times

Sample	Dye Source	Mordant	Exposure Time
A	Cactus fruit	None	10 s
B	Cactus fruit	Alum	15 s
C	Turmeric	None	20 s
D	Turmeric	Alum	25 s
E	Basil leaves	None	30 s
F	Basil leaves	Alum	35 s

Note: Within each dye source, the unmordanted and alum-mordanted samples were exposed to different microwave durations (cactus: 10 s unmordanted vs. 15 s mordanted). This confound is addressed further in the Limitations.

E. Fastness Testing

Rubbing fastness was assessed for each dye treatment by subjecting them to dry and wet rubbing against an untreated white cotton swatch under standardized testing conditions and comparing the degree of color transfer against a standard grey scale ranging from 1 for poor color fastness to 5 for good color fastness (no color transfer) [9]. Rubbing fastness was evaluated following ISO 105-X12 standard method using

crockmeter. Each treatment was done on one piece of fabric (n=1).

F. Environment

The extraction and dyeing processes were conducted in a conventional household microwave, selected for its appropriateness in the resource-poor conditions typical of comparative investigations rather than the sophisticated MAE apparatus employed in certain comparative analyses [1], [3], [13].

VIII. Results and Discussion

Table 2 Dry and wet rubbing fastness by source and mordant condition

Dye Source	Mordant	Dry Rubbing Fastness (GS)	Wet Rubbing Fastness (GS)
Cactus fruit	None	2-4	3-4
Cactus fruit	Alum	3-4	5
Turmeric	None	4	3-4
Turmeric	Alum	4-5	2
Basil leaves	None	3	4-5
Basil leaves	Alum	4	3-4

Note: "None" indicates that no mordant was applied; the cotton fabric was still dyed with the corresponding natural dye extract

The effect of mordanting was source-specific and non-uniform instead of being uniform and positive, an observation that conforms to other review studies that have found the effect of mordanting highly source-specific rather than universal [7], [8], [9], [11], [21]. In the case of the cactus fruit, the alum-treated cactus sample showed higher dry and wet rubbing-fastness ratings than the corresponding unmordanted sample, with dry fastness increasing from 2-4 GS to 3-4 GS and wet fastness increasing from 3-4 GS to 5 GS, the latter was the highest achieved among the six samples tested. This is broadly consistent with the potential of alum to enhance dye-fibre interactions and improve dye fixation [11], [19]. This finding is generally consistent with the high fastness values (4-5) recorded in other studies where *Opuntia* dye extract obtained by microwave irradiation showed high fastness

properties when applied on cotton and silk fabric [13].

For turmeric, the results were inconsistent: dry fastness increased to some extent (4 GS to 4-5 GS) while wet fastness was drastically reduced, from 3-4 GS without mordanting to 2 GS when the fabric was mordanted, the lowest wet fastness observed in the current experiment. The observed pattern was unexpected, particularly because alum treatment was associated with an increase in dry rubbing fastness but a decrease in wet rubbing fastness. First, the above-mentioned result contradicts findings that biomordanting (using chitosan) improves wash fastness in the cotton-turmeric system, which is enhanced by 1.0-1.5 grades compared to the fabrics without the mordant [10]. Second, the current result differs from research findings that aloe vera is a more appropriate mordant for rubbing fastness of turmeric-dyed fabrics, in comparison with copper sulfate [20], therefore, the above difference can be attributed to the kind of mordant used (alum

versus chitosan or aloe vera), and also to the type of fastness (rubbing or wash). Moreover, there is evidence that double mordanting and biomordanting pretreatments improve wash fastness of curcumin-based dyes compared to the single metallic mordanting [18] and evidence from a tie-dyeing experiment showing good rubbing fastness (4 GS on the grey scale) of unmordanted turmeric-dyed fabric [15].

Basil benefited from mordanting, with an increased dry fastness rating from 3 GS to 4 GS, but its wet fastness became marginally worse, from 4-5 GS for unmordanted to 3-4 GS for mordanted. Basil's unmordanted wet fastness rating of 4-5 GS was in fact the best unmordanted rating among the three sources. The relatively high wet rubbing-fastness rating of the unmordanted basil sample suggests that the dye extract exhibited comparatively favourable interaction with the cotton substrate under the conditions tested. This was broadly in keeping with reports of strong fastness performance of basil/tulsi in other literature [4], [5], despite the use of different methods of dye extraction and mordanting. Ultimately, there was no particular source-mordant combination that stood out for both dry and wet conditions. Cactus with alum mordant showed better wet-condition fastness; turmeric with alum mordant showed reasonable dry fastness but very poor wet fastness; This finding suggests that unmordanted basil dyeing may warrant further investigation as a simplified dyeing approach, particularly where avoiding a mordant is desirable.

Limitations

There are several limitations that should be considered while interpreting the results. Firstly, there was only one type of mordant (alum), as well as one mordant concentration that was investigated. Secondly, the research was based on a single sample for each combination of sources and mordants, which made it impossible to carry out any statistical calculations. Thirdly, the control and alum-mordanted samples for each dye source were treated by microwaves for a different amount of time, which means that it is impossible to

attribute the difference in rubbing fastness to mordanting. Lastly, no colorimetric measurements (K/S values, CIE Lab measurements) were performed, so it was impossible to quantify the change in dye strength and shade properties.

IX. Conclusion

In this study, natural dyes were extracted from cactus fruit, turmeric, and basil leaves through a standardized microwave extraction protocol with source-specific extraction and dyeing conditions and their dry and wet rubbing fastness properties were assessed on cotton fabric, with and without mordanting by alum. Cactus fruit showed improved rubbing fastness after alum mordanting, particularly under wet rubbing conditions, but turmeric showed a better dry rubbing property due to mordanting in contrast to decreased wet fastness and a similar effect of mordanting was observed on basil. No single source-mordant combination outperformed the others under both dry and wet conditions. Therefore, it can be concluded that the use of mordant depended upon the type of source material and the application of mordant should not have been indiscriminate but should have depended upon the end-use situation.

X. Suggestions and Recommendations

- Future studies may assess other mordant categories (iron, copper, chitosan, aloe vera, or citrus-derived bio-mordants) from all three sources to see if the reduction in wet-fastness of turmeric with alum was specific to the mordant [2], [20].
- Future studies should include replicate specimens for each source-mordant combination to improve the statistical validity and reproducibility of the results, using a fixed microwave exposure time across mordanted and unmordanted conditions within each source
- Future research may be able to establish a connection between the K/S value of the colour and the fastness property, just as it was done in analogous studies [13], [21].
- Double or multiple mordanting procedures that have shown better performance

than single mordanting processes for curcumin dyes should be tested with turmeric to remedy its weak wet rubbing fastness with alum [18].

- The relatively favourable rubbing-fastness performance of unmordanted basil warrants further investigation as a simplified natural-dyeing approach.

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