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Optimization of Natural Dye Extraction from Turmeric for Cotton Fabric

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ABSTRACT

Turmeric (Curcuma longa L.) is a widely available natural colorant whose principal pigment, curcumin, imparts a characteristic yellow hue to cellulosic fibers such as cotton. Growing environmental concerns regarding the ecological impact of synthetic dyes have renewed interest in natural dye sources for sustainable textile applications. However, turmeric dyeing is frequently associated with poor reproducibility, variable shade development, and moderate colour fastness, particularly when extraction and mordanting parameters are not systematically controlled. The dye yield and performance on fabric are strongly influenced by factors such as particle size of the raw material, solvent composition, extraction temperature, extraction duration, and material-to-liquor ratio. Consequently, optimization of these parameters is necessary to obtain consistent and reliable dyeing The present study synthesizes findings from published literature and proposes a standardized optimization framework suitable for polytechnic-level textile laboratories. Emphasis is placed on enhancing extraction efficiency and colour strength through controllable process variables, including solvent system aqueous and ethanol–water mixtures), extraction temperature, extraction time, and liquor ratio.

1. INTRODUCTION

Natural dyes are increasingly explored in education and niche textile applications because they are derived from renewable sources and can reduce the reliance on petroleum-based synthetic dyes. Turmeric rhizome powder is an accessible dye source in India, and its curcuminoids provide a distinct yellow tone on cellulosic fibers. In practice, turmeric dyeing performance varies due to differences in turmeric quality, extraction conditions, bath pH, liquor ratio, and the presence or absence of mordants. Many small laboratories follow non-standard “boil and dye” steps, which leads to inconsistent shade and weak reproducibility across batches.

The objective of this paper is to define an easy-to-implement optimization approach for urmeric dye extraction intended for cotton fabric dyeing. The study scope includes (i) selection of extraction variables that significantly affect dye strength, (ii) a laboratory workflow for testing extraction performance using UV–Visible absorbance, (iii) a cotton dyeing protocol using exhaust dyeing, and (iv) a performance evaluation plan using color strength and basic colour fastness methods. The output is a practical "standard operating" framework that can be executed with commonly available lab equipment.

2. Background

Turmeric's main coloring component is curcumin, and several studies report that curcumin recovery depends strongly on solvent polarity, temperature, mixing time, particle size, and solvent-to-solid ratio. Using response surface methodology, Sogi et al. reported a maximum curcumin yield at approximately 60 °C, 30 min mixing, particle size near 0.42 mm, and solvent-to-meal ratio around 50 when ethanol is used as the extraction solvent [1]. Ultrasound-assisted extraction can shorten processing time; one study selected 80% ethanol for 15 min as an effective alternative to conventional solid–liquid extraction for curcuminoids [2]. For textile application, extraction time and temperature are repeatedly observed to increase dye intensity in aqueous extraction ranges. A turmeric dyeing-condition study reported that dye intensity increased as extraction time increased and as temperature increased from 40 °C to 100 °C (based on UV–Visible measurements) [3]. On the dyed fabric side, cotton shade depth and fastness improve when suitable mordants are used. A comparative work on naturally dyed cotton reported the highest color strength (K/S) for turmeric-dyed cotton when ferrous sulphate and myrobalan were used together, indicating that combined mordant systems can significantly enhance depth of shade.

Table 1: Reported Extraction and Dyeing Conditions for Turmeric/Curcumin (for designing experiments)

Study Focus	Key Conditions	Key Observation	Ref.
Curcumin extraction (ethanol)	60 °C; ~30 min; particle size ~0.42 mm; solvent-to-meal ratio ~50	Maximum curcumin yield at reported optimum	[1]
Ultrasound extraction	80% ethanol; 15 min (ultrasound-assisted)	Selected as effective alternative to conventional extraction	[2]
Turmeric dye extraction intensity	40–100 °C; increasing time	Dye intensity increased with time and with temperature	[3]
Cotton shade depth with mordanting	Ferrous sulphate + myrobalan (combined)	Highest reported K/S for turmeric-dyed cotton among tested sets	[4]

3. Materials and Methods

Materials: Commercial Turmeric Powder (Food-Grade), Scoured And Bleached Cotton Fabric (Plain Weave), Distilled Water, Ethanol (Laboratory Grade), Alum (Potassium Aluminium Sulfate), Ferrous Sulphate, Myrobalan (Terminalia Chebula) Powder (As Bio-Mordant), Non-Ionic Detergent For Wash Test, Ph Paper/Portable Ph Meter. Pre-Treatment: Cotton Is Scoured (If Not Pre-Scoured) And Rinsed To Remove Impurities That Inhibit Dye Uptake. Fabric Is Dried At Room Temperature Before Dyeing. Turmeric Powder Is Sieved To A Uniform Particle Size When Possible To Reduce Variability. Extraction Design: A Simple Factorial Or One-Factor-At-A-Time Screening Can Be Used Based On Lab Capability. The Recommended Control Variables Are: (A) Solvent System (Water, 50% Ethanol, 80% Ethanol), (B) Extraction Temperature (40–80 °C For Ethanol Systems; Up To 100 °C For Aqueous), (C) Extraction Time (15–60 Min), And (D) Material-To-Liquor Ratio (1:10 To 1:30 W/V). The Extract Is Filtered And Cooled. Extraction Response Is Measured By Uv–Visible Absorbance (Peak Region Around 420–450 Nm For Curcumin-Rich Extracts). Higher Absorbance At The Selected Wavelength Is Treated As A Higher Extraction Strength Proxy. Dyeing Method: Exhaust Dyeing Is Performed At A Liquor Ratio Of 1:20 (Fabric To Dye Liquor). The Dye Bath Contains The Filtered Turmeric Extract Adjusted To A Controlled Ph (Typically Near Neutral Unless The Study Includes Ph As A Factor). Dyeing Is Conducted At 60–80 °C For 45–60 Min, Followed By Rinsing And Drying. Mordanting Plan: Pre-Mordanting Is Recommended For Cotton. Three Practical Routes Are Suggested: (I) Alum (Single Mordant), (Ii) Ferrous Sulphate (Single Mordant), And (Iii) Combined Bio-Mordant System Such As Myrobalan Followed By A Metal Salt. The Combined System Is Included Because It Has Been Reported To Produce High K/S For Turmeric-Dyed Cotton [4]. Evaluation: Shade Strength Is Assessed Using A Spectrophotometer (K/S) When Available; Otherwise, Standardized Visual Assessment Under Consistent Lighting Is Used As A Secondary Method. Colour Fastness Tests Are Conducted Using Iso 105 Series Guidance (E.G., Rubbing And Washing Fastness), With Results Reported As Grades Following The Standard Scales [5].

4. RESULTS

Because The Goal Is To Build A Repeatable Laboratory Protocol, The "Results" Of This Paper Are Presented As Evidence-Based Optimization Choices From Published Work And As Expected Trends That Can Be Verified In The Proposed Experiment. Published Dyeing-Condition Evaluation Indicates That Extraction Time And Extraction Temperature Have A Direct Positive Effect On Turmeric Dye Intensity Within Typical Laboratory Ranges; UV–Visible Measurements Showed Increased Intensity As Time Increased And As Temperature Increased From 40 °C Toward Boiling [3]. For Curcuminoid Recovery, Moderate Temperatures With Ethanol-Based Solvents Can Provide High Extraction Efficiency, And Optimized Conditions Have Been Reported Around 60 °C With Controlled Mixing Time And High Solvent-To-Solid Ratio [1].

FIGURE1: LITERATURE-INFORMED PARAMETER WINDOW

5. DISCUSSION

From a process-design perspective, the laboratory can treat UV–Visible absorbance of the filtered extract as a fast screening metric, and then confirm the most promising extraction settings on fabric using K/S and fastness grades. Solvent selection is a primary lever: aqueous extraction is simple and safe but can be slower, while ethanol–water mixtures increase recovery for lipophilic curcuminoids and may reduce total processing time. Ultrasound assistance is a useful optional upgrade; an 80% ethanol, 15 min ultrasound-assisted approach has been reported as an effective alternative to conventional extraction for curcuminoids For cotton, mordanting dominates final shade depth and durability. A study on naturally dyed cotton reported that a ferrous sulphate–myrobalan combined mordant system produced the highest K/S for turmeric-dyed cotton among the tested dye set, suggesting that combined systems can improve shade depth beyond single-mordant routes [4]. In the proposed workflow, extraction optimization should therefore be paired with a small, controlled mordanting comparison, and the selected recipe should be validated using ISO 105 colour fastness guidance for washing and rubbing [5]. This approach creates a standardized teaching and small-scale production method while keeping chemical usage limited and measurable.

6. CONCLUSIONS

A practical optimization framework for turmeric dye extraction intended for cotton dyeing has been presented. Literature supports that dye strength increases with higher extraction temperature and longer extraction time within laboratory ranges, while ethanol–water systems and ultrasound-assisted steps can improve extraction efficiency at moderate temperatures. For cotton performance, mordanting—especially combined bio-mordant and metal-salt systems—remains the most important factor for improving shade depth and overall usability. The recommended next step for the institution is to run a small factorial screening using the proposed variables, then lock a standard recipe (extraction + dyeing + mordanting) that can be repeated across batches and student cohorts.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest influencing the work reported in this paper

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