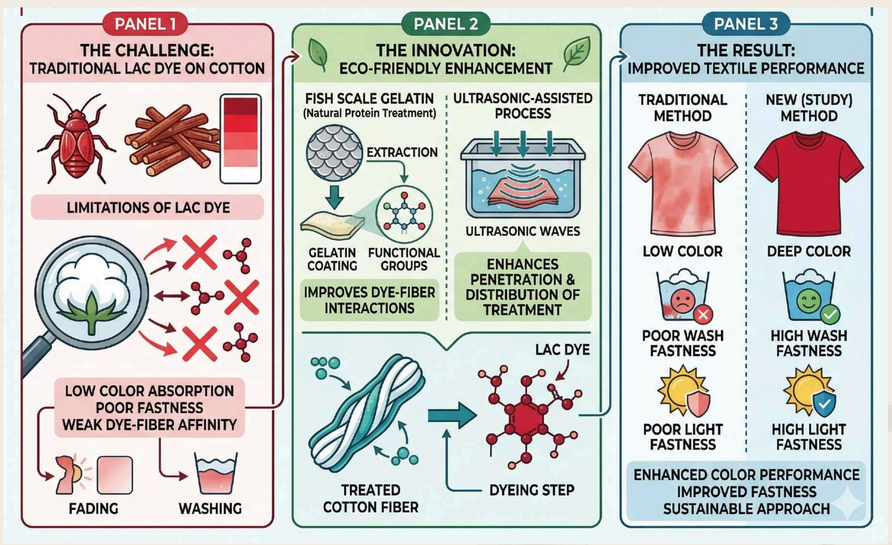
Eco-friendly Surface Treatment of Cotton Fabric using Fish Scale Gelatin and Ultrasonic-assisted Process for Enhancing the Color Performance and Fastness of Lac Natural Dye

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Abstract

In recent years, the application of natural dyes in textile coloration has attracted significant research interest. This study investigates an eco-friendly approach to enhancing the dyeing performance and functional properties of cotton fabrics using lac natural dye. The research integrates ultrasonic-assisted extraction and dyeing processes with surface modification using fish scale gelatin. The optimal extraction parameters, including temperature, duration, and pH, were evaluated using UV–Vis spectrophotometry. The results indicated that ultrasonic assistance significantly improved colorant extraction efficiency at elevated temperatures. Dyeing at pH 7 yielded color strength (K/S) values ranging from 1.22 to 1.69. The application of an aluminum mordant in conjunction with ultrasonic power markedly enhanced the K/S values to 1.90–3.46, depending on the mordant concentration. Furthermore, fabrics pretreated with fish scale gelatin, with and without citric acid as a cross-linking agent, exhibited K/S values ranging from 1.70 to 1.78. Characterization of the dyed fabrics using scanning electron microscopy (SEM) confirmed changes in surface morphology and chemical structure. Assessment of colorfastness revealed that aluminum mordanting improved washing fastness from grades 1–2 to 2–3, however, gelatin-treated fabrics demonstrated improved light fastness. Additionally, the dyed fabrics exhibited functional properties, showing UV protection improvement in the range of 64.4–82.4%. These findings suggest that the developed lac dyeing process represents a viable and sustainable alternative to synthetic dyes, adding multifunctional value to textiles and supporting green manufacturing processes.

Introduction



Objectives

- To determine the optimal conditions for lac dye extraction and dyeing on cotton using conventional heating and ultrasonic-assisted methods
- To evaluate the effect of dyeing auxiliaries and fabric surface treatment on dye uptake and color fastness.

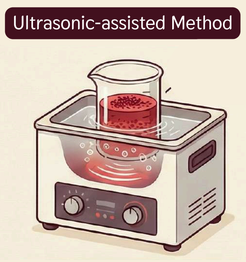
Experimental

- **Extraction of natural dye from lac**

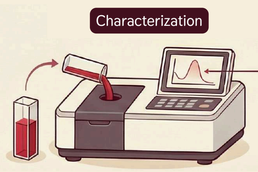
Conventional Heating Method



Ultrasonic-assisted Method



Characterization



Wavelength 450-490 nm

Determination of λmax of lac dye

Parameters

Extraction temperature : 70 °C

Extraction time : 5, 10, 15, 20, 25, 30, 40, 50, 60, 90 and 120 min

pH values : 3, 5, 7, 9, 11 and 13

Solvent ; DI Water
60%v/v Ethanol

- **Dyeing of Cotton Fabric**

Dyeing @70°C for 60 minutes, using a liquor ratio of 1 : 30

Conventional Dyeing Method



Ultrasonic-Assisted Dyeing Method



Mordant-Assisted Dyeing



0.5 % o.w.f 1 % o.w.f 1.5 % o.w.f

Application of Al mordants to improve dye exhaustion and color strength

Cotton Surface Modification with Fish Scale Gelatin



- **Characterization**



Results and Discussion

Extraction of Natural Dye from Lac

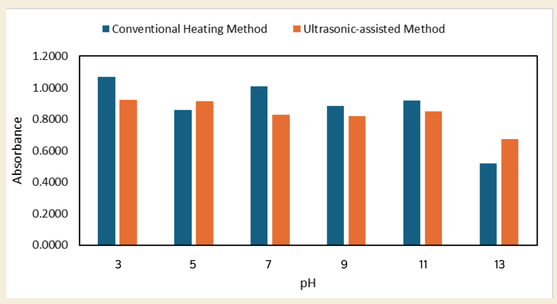


Fig.1 The effect of pH on Absorbance.

- At **pH 3-7**; Absorbance & Concentration
- The conventional heating method generally showed slightly higher absorbance than the ultrasonic-assisted method, except at highly alkaline pH.
- The optimal extraction time was **60 minutes**.

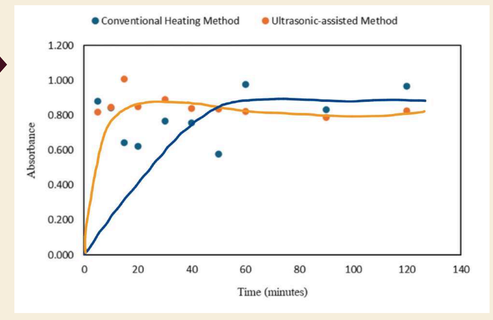


Fig.2 The effect of extraction time on Absorbance.

Dyeing of Cotton fabric

Color Strength of Dyed Fabrics

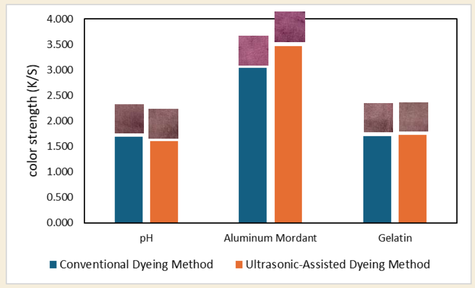


Fig.3 color strength (K/S)

- Al mordant exhibited the highest K/S values in both methods.
- The ultrasonic-assisted method showed slightly higher K/S values.

Al mordant improved the wash fastness, whereas fish-scale gelatin modification of cotton enhanced the light fastness.

Color fastness of Dyed Fabrics

Conditions	Washing Fastness							Light Fastness
	Color change	Color staining						
		wool	acrylic	polyester	nylon	cotton	Acetate	
pH7-H	2	5	5	5	5	5	5	2
pH13-H	1	5	5	5	5	5	5	2
pH7-U	2	5	5	5	5	5	5	2
pH13-U	1	5	5	5	5	5	5	2
0.5% Al-H	3	5	5	5	5	5	5	1
1.0% Al-H	3	5	5	5	5	5	5	1/2
1.5% Al-H	2/3	5	5	5	5	5	5	1/2
0.5% Al-U	3	5	5	5	5	5	5	1/2
1.0% Al-U	2	5	5	5	5	5	5	2
1.5% Al-U	2/3	5	5	5	5	5	5	2
Gelatin-H	2	5	5	5	5	5	5	2/3
Gelatin+Citric acid-H	1/2	5	5	5	5	5	5	2/3
Gelatin-U	2	5	5	5	5	5	5	2/3
Gelatin+Citric acid-U	2	5	5	5	5	5	5	2/3

*H= Conventional heating, U= Ultrasonic-assisted methods
**Washing Fastness; 1= poor/5=excellent I Light fastness; 1= poor/8=excellent

Morphology of cotton fibers

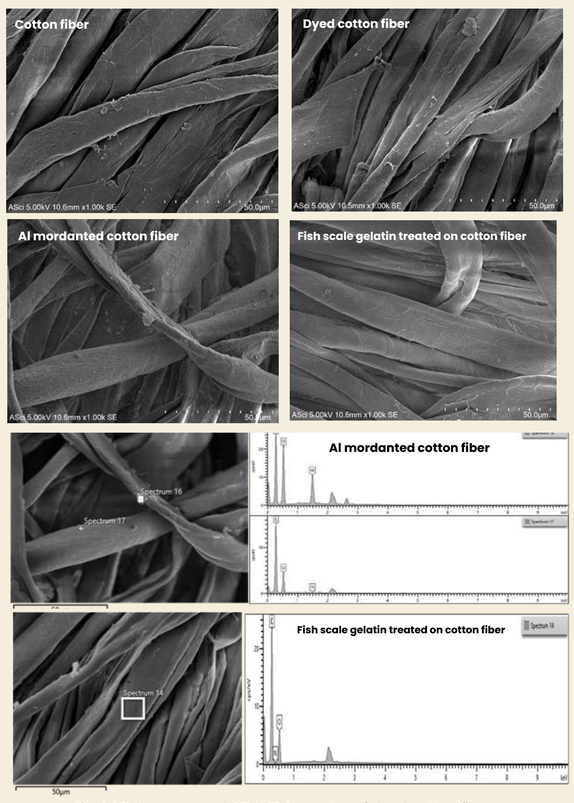
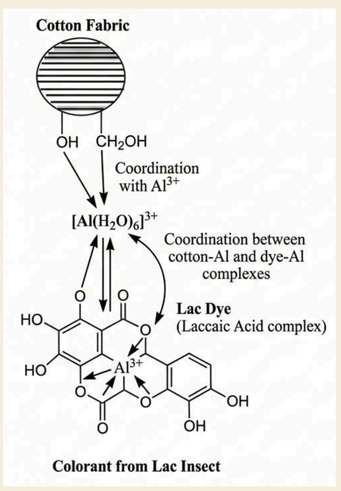
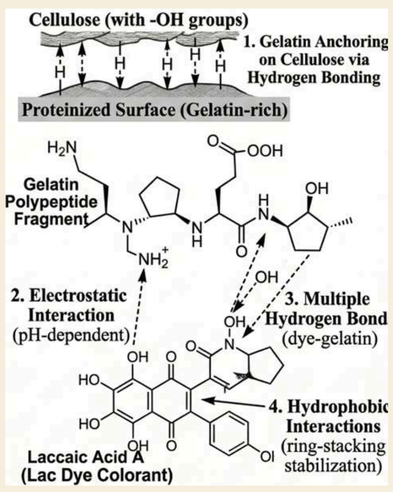


Fig 4 SEM Images and SEM-EDS spectra of dyed cotton fibers

Proposed interaction mechanism



A) Lac dyeing on cotton using Al mordant



B) Lac dyeing on cotton pretreated with fish scale gelatin

Functional Property : UV Protection

- Al mordant: the highest improvement in UV protection.
- The ultrasonic-assisted method showed slightly higher UV protection than the conventional heating method.

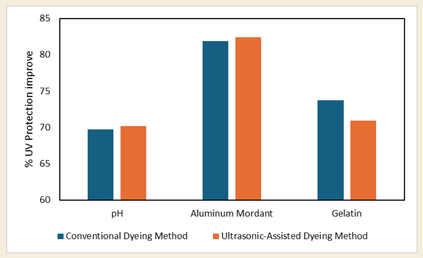


Fig.5 % UV Protection improvement of dye fabrics

Conclusion

- The optimal extraction conditions for both the conventional heating and ultrasonic-assisted methods were at pH 7 with an extraction time of 30 minutes.
- Dyeing with an Al mordant produced the highest color strength and improved the wash fastness of the dyed fabrics.
- Dyeing on cotton fabric pretreated with fish-scale gelatin enhanced the light fastness of the dyed fabrics.
- Cotton fabrics dyed with lac under different conditions exhibited UV protection properties.

References : Banna, B. U., Mia, R., Hasan, M. M., Ahmed, B., & Shibly, M. A. H. (2023). Ultrasonic-assisted sustainable extraction and dyeing of organic cotton fabric using natural dyes from Dillenia indica leaf. Heliyon, 9, e18702.