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Assessment of UV Protection, Antioxidant Activity and Functional Performance of Linen Fabrics Dyed with Medicinal Herbal Extracts

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Abstract
This study investigates the multifunctional enhancement of linen fabrics dyed with selected medicinal herbal extracts, focusing on ultraviolet (UV) protection, antioxidant activity, and key physical properties. Linen samples were dyed with turmeric, henna, and pomegranate rind extracts using ecofriendly protocols. The fabrics were evaluated for Ultraviolet Protection Factor (UPF), antioxidant activity (via DPPH assay), tensile strength, air permeability, and colour fastness. Statistical analyses (ANOVA, correlation) were performed to compare effects of different herbal treatments. perception was assessed via a comprehensive questionnaire. Results indicate significant improvements in UPF and antioxidant activity without compromising essential textile properties, suggesting strong potential for sustainable, high-performance linen textiles in protective and wellness applications.

Keywords: Antioxidant activity, Functional textiles, Linen, Medicinal herbs, Natural dyeing, UV protection

1. Introduction

The textile industry is rapidly evolving towards sustainability, driven by environmental regulations, consumer health awareness, and the need for innovative functional textiles. Linen, a natural bast fiber, is highly valued for its breathability, moisture management, and biodegradability, making it ideal for ecc friendly apparel. However, linen's inherent UV protection and antioxidant properties are limited, exposing users to risks such as skin cancer, photoaging, and oxidative stress.

Natural dyeing with medicinal herbs offers a promising solution, leveraging the bioactive compounds in plants to impart functional benefits to textiles. Turmeric (Curcuma longa), henna (Lawsonia inermis), and pomegranate rind (Punica granatum) are traditionally used in medicine for their antioxidant, antimicrobial, and photoprotective properties. Their application in textiles not only addresses environmental concerns but also aligns with the global trend toward wellness and sustainable fashion.

Despite growing interest, there is a lack of systematic research on the combined impact of medicinal herbal extracts on the UV protection, antioxidant activity, and physical performance of linen fabrics. existing studies focus on antimicrobial or coloristic aspects, leaving a gap in comprehensive functional evaluation, especially using robust empirical and statistical methods. This study addresses this gap by investigating the enhancement of linen fabric properties through herbal dyeing, employing both laboratory measurements and user-centered primary data.

2. Literature Review

2.1 Sustainability and Functional Potential of Medicinal Plant-Based Dyes

Recent years have witnessed a surge in research on natural dyes sourced from medicinal plants, driven by environmental, health, and regulatory concerns over synthetic dyes. A 2025 review highlights that medicinal plants offer sustainable, biodegradable, non-toxic, and low allergenic alternatives, addressing pollution issues and supporting circularity in textile production. The bioactive components in these plants-such as flavonoids, tannins, and phenolics-not only provide colour but also impart therapeutic and functional properties to textiles, including UV protection and antioxidant activity.

2.2 Global Research Trends: Hot Spots and Functional Applications

A comprehensive bibliometric review of 474 papers (2015-2024) mapped the evolution of herbal dyeing research, identifying four major trends:

- Exploration of new raw materials and dyeing technologies
- Innovations in sustainability and ecofriendly mordants
- Development of functional and medical textiles
- Investigation of bioactivity including antimicrobial, antioxidant, and UV-protective effects

This review underscores a shift from simple coloration to multifunctional, health-promoting textiles, with herbal dyeing positioned as a bridge between traditional knowledge and advanced material science 1.

2.3 Chromatic and Medicinal Properties: Recent Systematic Reviews

A 2023 systematic review analyzed the chromatic and medicinal properties of six major natural dyes (eucalyptus, weld, madder, annatto, indigo, and woad), confirming that natural dyes can enhance antibacterial and anti-UV functionalities in textiles. The review also noted that dye parameters, auxiliary products, and fit type significantly influence both colour and bioactivity outcomes, and that combining natural dyes with eco-friendly auxiliaries can further expand their functional palette .

2.4 Medicinal Plant Dyes: Mechanisms and Textile Applications

A 2024 review emphasized the distinction between natural and synthetic dyes, highlighting that medicinal plant-based dyes offer unique bioactivity—including UV protection and antioxidant effects—due to their phytochemical profiles. These properties are increasingly exploited in the development of wellness and medical textiles, with studies reporting effective color, durability, and added health benefits when applied to various fibers, including linen.

2.5 Eco-Friendly Processing and Environmental Impact

Herbal textiles are produced using dye extractions without chemical additives, preserving the medicinal value of the herbs and minimizing environmental contamination. Even processes like bleaching can be performed naturally (e.g., sunlight exposure), further reducing the ecological footprint. Recent research also explores the use of plant-based biomordants and colorants, advancing the sustainability agenda in textile finishing.

2.6 Research Gap and Future Directions

Despite these advances, recent reviews concur that further work is needed to optimize dyeing processes, improve fastness properties, and systematically evaluate the multifunctional performance of herbal-dyed textiles, especially on under studied fibers like linen. There is also a call for more primary data on user perception and real-world functional benefits, to support commercial adoption.

3. Materials and Methods

3.1 Materials

- Linen fabric: 100% plain weave, 150 GSM, scoured and bleached.
- Herbal extracts: Turmeric, henna, and pomegranate rind (authenticated, locally sourced).
- Mordant: Alum (10% owf).
- Chemicals: DPPH (2,2-diphenyl-1picrylhydrazyl), ethanol, standard laboratory reagents.

3.2 Extraction of Herbal Dyes

Dried plant material (100 g) was boiled in 1L distilled water for 60 min, filtered, and concentrated to 500 ml. Extracts wer stored at 4°C until use.

3.3 Dyeing Procedure

Linen samples (20×20 cm, $n = 30$ per group) were pre-mordanted with alum at 60°C for 30 min. Dyeing was conducted at 80°C for 60 min at a liquor ratio of 1:20. Post-dyeing, samples were rinsed and air-dried.

3.4 Experimental Design and Sample Size

- Groups:
  - Control (undyed linen)
  - Turmeric-dyed
  - Henna-dyed
  - Pomegranate-dyed
- Replicates: 30 per group (total $n = 120$)
- Sample size justification: Calculated for ANOVA with effect size $f = 0.4, a = 0.05$, power $=$ 0.8, requiring at least samples per group.

3.5 Testing Methods

3.5.1 UV Protection

UPF measured per AATCC 183 using a UVVis spectrophotometer (280-400 nm).

Formula:

$$UPF = \frac{\sum E_\lambda S_\lambda \Delta\lambda}{\sum E_\lambda S_\lambda T_\lambda \Delta\lambda}$$

Where E_λ : Erythemal spectral effectiveness, S_λ : Solar spectral irradiance, T_λ : Spectral transmittance.

3.5.2 Antioxidant Activity

DPPH radical scavenging assay: $1\ cm^2$ fabric incubated with DPPH solution, absorbance at $517\ nm$, % inhibition calculated.

Formula:

$$\%\ \text{Inhibition} = \frac{(A_0 - A_1)}{A_0} \times 100$$

Where A_0 : Absorbance of control, A_1 : Absorbance of sample.

3.5.3 Functional Performance

- Tensile Strength: ASTM D5035 strip method, measured in Newtons (N).
- Air Permeability: ASTM D737, measured in mm/s.
- Colour Fastness: ISO 105-C06 (washing), ISO 105-B02 (light), rated on standard scales.

3.5.4 User Perception

Structured questionnaire administered to 100 volunteers, assessing comfort, appearance, perceived protection, and acceptability (see Appendix).

3.6 Statistical Analysis

- Descriptive statistics: Mean $\pm$ SD.
- Inferential statistics: One-way ANOVA for group comparisons; Pearson correlation between dye concentration, UPF, and antioxidant activity.
- Sample size calculation for ANOVA:

$$n = \frac{2(\sigma^2)\left(Z_{\alpha/2} + Z_\beta\right)^2}{\delta^2}$$

- Software: SPSS v27.

4. Results

Table 1. UV Protection (UPF) of Linen Fabrics Dyed with Medicinal Herbal Extracts

Group	Mean UPF	SD	Classification*
Control	13.2	1.6	Poor
Turmeric-dyed	39.5	2.7	Very Good
Henna-dyed	47.3	3.0	Excellent
Pomegranate-dyed	34.1	2.3	Good

*Based on AS/NZS 4399:2017 standards.
Source: Laboratory analysis, methods as per Section 3.5.1.

Table 2. Antioxidant Activity (DPPH % Inhibition)

Group	Mean (%)	SD
Control	9.0	1.3
Turmeric-dyed	83.7	3.8
Henna-dyed	94.2	2.9
Pomegranate-dyed	78.5	3.6

Source: Laboratory analysis, methods as per Section 3.5.2.

Table 3. Functional Performance of Dyed Linen Fabrics

Property	Control	Turmeric	Henna	Pomegranate
Tensile Strength (N)	321	317	314	319
Air Permeability (mm/s)	181	176	173	179
Wash Fastness (1-5)	—	4	4.5	4
Light Fastness (1-8)	—	5	6	5

Source: Laboratory analysis, standards as per Section 3.5.3.

Table 4. User Perception Survey Results (n = 100)

Parameter	Mean Rating (1-5)
Comfort	4.4
Breathability	4.3
Appearance	4.1
Perceived UV Protection	4.5
Softness	4.2
Odor	4.6
Maintenance	4.3
Colour Fastness (after wash)	4.2
Suitability for summer	4.7
Overall satisfaction	4.5
Recommendation for summer use	92% Yes
Preference for herbal-dyed	88% Yes

Source: User questionnaire, see Appendix.

Statistical Analysis

- **ANOVA:** Significant differences in UPF and antioxidant activity between groups ($p < 0.001$).
- **Pearson correlation:** Dye concentration strongly correlated with UPF ($r = 0.87$) and antioxidant activity ($r = 0.93$).

5. **Discussion**

Herbal extracts, especially henna and turmeric, significantly increased the UPF of linen fabrics, consistent with recent studies on the UV-absorbing properties of polyphenols and flavonoids. Henna-dyed linen showed the highest antioxidant activity, attributed to its high lawsone and gallic acid content. Functional performance tests confirmed that dyeing did not significantly compromise tensile strength or air permeability, and colour fastness ratings were within acceptable ranges, indicating suitability for apparel use. User feedback was overwhelmingly positive, supporting the practical application of herbal-dyed linen in protective and wellness textiles.

6. **Conclusion**

Dyeing linen with medicinal herbal extracts such as henna, turmeric, and pomegranate rind offers a sustainable route to multifunctional textiles with enhanced UV protection, strong antioxidant activity, and good physical performance. These findings support further development and commercial application of herbal-dyed linen fabrics in protective and wellness-oriented apparel.

7. **References**

- International Journal of Scientific Research in Science and Technology. (2025). Natural Dyes from Medicinal Plants: An Exploration of Their Potential in Textile Industry.
- Lyu Qian et al. (2025). Hot Spots and Trends of Textiles with Herbal Dyes. Textile Letters Review, 8, 304-325.
- Vaja P. N. et al. (2024). Natural Dyes: A Comprehensive Review on Medicinal Plant-based Pigments. Asian Journal of Pharmaceutical Research, 14(3):227-234.
- Santiago D., Cunha J., Cabral I. (2023). Chromatic and medicinal properties of six natural textile dyes: A review. Heliyon, 9(11):e22013.
- Santiago D., Cunha J., Cabral I. (2023). Chromatic and medicinal properties of six natural textile dyed review. PubMed.
- Karpagavalli V.S., Sumithra M. (2023). Reactive eco-friendly dyeing of natural fabrics using a novel herbal composite. Journal of Industrial Textiles, 53:1-20.

- Kamel, M. M., et al. (2023). Natural dyes and their application in functional textiles. Dyes and Pigments, 210, 110931.
- Sustainable application of novel herbs on cotton fabrics as biomordants and colourants. PubMed, 2022.
- Ali, S., et al. (2022). Antioxidant and UV protective properties of pomegranate rind extract dyed cotton fabrics. Journal of Cleaner Production, 330, 129857.
- Kumar, N., et al. (2020). Curcumin natural dye for functional textiles. Textile Research Journal, 90(11-12).
- Gies, P., et al. (2018). Ultraviolet protection by clothing: An intercomparison of measurements and methods. Photochemistry and Photobiology, 94(2), 339-349.
- Bechtold, T., & Mussak, R. (Eds.). (2017). Handbook of Natural Colorants. Wiley.
- Chattopadhyay, S. N., et al. (2017). Dyeing of linen with natural dyes: A review. Indian Journal of Fibre & Textile Research, 42, 243-250.

Appendix: Comprehensive User Feedback Questionnaire

Section A: Demographic Information

1. Age: _____
2. Gender: ☐ Male ☐ Female ☐ Other
3. Occupation:
4. Skin type (Fitzpatrick scale): ☐ I ☐ II ☐ III ☐ IV ☐ V ☐ VI

Section B: Fabric Experience

5. How would you rate the comfort of the fabric? (1-5)
6. How would you rate the breathability? $(1-5)$
7. How would you rate the appearance (color, texture)? (1-5)
8. How would you rate the perceived UV protection? (1-5)
9. How would you rate the fabric's softness? (1-5)
10. How would you rate the odor (if any) of the dyed fabric? (1-5)
11. How would you rate the fabric's ease of maintenance (washing, ironing)? (1–5)
12. How would you rate the colour fastness after washing? (1–5)
13. How would you rate the suitability of the fabric for summer wear? (1–5)
14. How would you rate the overall satisfaction with the fabric? (1–5)

Section C: Health and Safety

15. Did you experience any skin irritation or allergic reaction after using the fabric?
☐ Yes ☐ No

If yes, please specify:

Section D: Preferences and Perceptions

16. Would you prefer herbal-dyed linen over synthetic-dyed linen? ☐ Yes ☐ No ☐ Not Sure
17. Would you recommend this fabric to others? ☐ Yes ☐ No ☐ Maybe
18. How likely are you to purchase herbal-dyed linen if available in the market? (1–5)
19. What improvements would you suggest for the fabric?
20. Any additional comments or suggestions?