



Evaluation of Antimicrobial Properties of Linen Fabrics Dyed with Medicinal Herbal Extracts

Amit Sain^{1*} and Shalini Juneja²

^{1*}Faculty of Fine Arts, Banasthali Vidyapith, Rajasthan, India Email: Amitsain05@gmail.com

²Department of Home Science, Banasthali Vidyapith, Rajasthan, India and shalinijuneja@banasthali.in

Abstract

The demand for sustainable and multifunctional textiles has driven research into natural dyeing using medicinal herbs with antimicrobial properties. This study evaluates the antimicrobial efficacy of linen fabrics dyed with aqueous extracts, of neem (*Azadirachta indica*), tulsi (*Ocimum sanctum*), and turmeric (*Curcuma longa*). A total of 120 linen samples were dyed under controlled conditions and tested against *Staphylococcus aureus* and *Escherichia coli* using the AATCC 100 quantitative method. Statistical analyses including one-way ANOVA and Tukey's HSD test confirmed significant bacterial reduction confirmed significant bacterial reduction (>95%) for neem and tulsi, and moderate reduction (~89%) for turmeric. Expert evaluation via a detailed 25-item questionnaire (n=30) assessed aesthetic, functional, and medical suitability. Results demonstrate the potential of herbal dyes as eco-friendly antimicrobial finishes for linen textiles, with durability and safety suitable for medical and hygienic applications.

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1. Introduction

The textile industry is increasingly focusing on sustainable practices due to environmental regulations and consumer demand for safe, functional products. Linen, a natural fiber from flax, is prized for its durability, breathability, and biodegradability. However, its susceptibility biodegradability. However, its susceptibility to microbial contamination limits its use in medical and hygiene-sensitive applications.

Synthetic antimicrobial finishes, though effective, raise environmental and health concerns including toxicity, bioaccumulation, and antimicrobial resistance. Medicinal herbs such as neem, tulsi, and turmeric, known for their antimicrobial and antioxidant phytochemicals, offer promising natural alternatives. These herbs can be used as natural dyes, imparting both colour and antimicrobial functionality, reducing reliance on synthetic chemicals. Recent research (2015-2025) has renewed interest in herbal-dyed textiles, but comprehensive studies on linen with rigorous statistical validation and expert feedback remain scarce. This study aims to fill this gap by evaluating the antimicrobial properties of linen dyed with neem, tulsi and turmeric extracts, supported tulsi, and turmeric extracts, supported by detailed statistical analysis and expert assessment.

2. Review of Literature:

2.1 Natural Colour and Functional Textiles

Metwally et al (2025) demonstrated significant antimicrobial activity of textiles dyed with natural pigments, varying by fabric and microbe. A 2023 study in Journal of Natural Fibers confirmed that herbal dyed cotton maintained antibacterial properties and colour fastness supporting industrial viability.

Available online at: <https://jazindia.com>

For linen, a 2022 study found herbal dyes (turmeric, aloe vera, neem, beetroot, pomegranate, onion) enhanced colour fastness and reduced skin allergies, highlighting environmental and health benefits over synthetic dyes.

2.2 Antimicrobial Mechanisms of Herbal Dyes

Bioactive compounds such as azadirachtin (neem), eugenol (tulsi), and curcumin (turmeric) disrupt microbial membranes. El-Khatib and Ali (2023) showed chitosan pretreatment enhances dye uptake and antimicrobial efficacy. A study on lac-dyed linen pretreated with chitosan demonstrated strong antibacterial effects against *S. aureus* and *E. coli*.

2.3 Comparative Efficacy of Medicinal Herbs

Adivarekar et al. (2020) reported neem and tulsi extracts achieved 98% bacterial reduction on cotton, with turmeric slightly less effective (~95%). These findings align with traditional uses and modern research confirming neem and tulsi as superior antimicrobial agents.

2.4 Sustainability and Health Benefits

Herbal dyes reduce skin irritation and allergic reactions, making them suitable for sensitive applications like medical dressings and hospital linens.

2.5 Research Gaps

Standardisation of extraction, application, durability testing, and scale-up remain challenges. This study addresses these by using standardised protocols, rigorous testing, and expert evaluation.

3. Objectives

- Dye linen fabrics with aqueous extracts of neem, tulsi, and turmeric under standardised conditions.
- Evaluate antimicrobial efficacy against *S. aureus* and *E. coli* quantitatively.
- Analyse statistical differences using ANOVA and Tukey's HSD.
- Assess expert perceptions of aesthetics, comfort, and medical suitability via a detailed questionnaire.
- Recommend applications for herbal-dyed linen in medical textiles.

4. Materials and Methods

4.1 Materials

- 100% plain-woven linen fabric, pre-washed, cut into 10x10 cm samples.
- Fresh neem leaves, tulsi leaves, dried turmeric rhizomes (certified suppliers).
- Distilled water no synthetic mordants.

4.2 Preparation of Herbal Extracts and Dyeing

- 100 g of each herb boiled in 1L distilled water for 60 min, filtered.
- Linen samples dyed at 80°C for 60 min, air-dried, cured at 100°C for 5 min.
- Samples: 30 each for neem, tulsi, turmeric, and 30 undyed controls (total 120).

4.3 Antimicrobial Testing

- Organisms: *S. aureus* (ATCC6538), *coli* (ATCC 25922).
- AATCC 100 quantitative method.
- Samples inoculated with 1 ml. bacterial suspension (10^5 CFU/mL), incubated 24 h at 37°C.
- Bacteria eluted, serially diluted, plated; CFU counted.
- Bacterial reduction (%) calculated:

$$\text{Reduction} = \frac{CFU_{\text{control}} - CFU_{\text{sample}}}{CFU_{\text{control}}}$$

4.4 Expert Questionnaire

- 30 textile professionals.

- 25-item Likert scale questionnaire (1-5) on colour, handle, fastness, antimicrobial perception, safety, medical suitability, durability, and environmental impact.

4.5 Statistical Analysis

- Descriptive stats (mean, SD)
- One-way ANOVA Tukey's HSD for pairwise comparisons.
- Significance at $p < 0.005$.
- Software : SPSS v26

5. Results:

5.1 Antimicrobial Activity

Table 1: Mean Bacterial Reduction (%) by Dye Type (n=30)

Dye Type	S.aureus Reduction (%)	SD	E.coil Reduction (%)	SD
Neem	97.5	1.2	97.0	1.1
Tulsi	95.9	1.4	95.4	1.3
Turmeric	89.3	2.0	88.7	1.9
Control	13.8	3.1	15.5	2.9

Source : Adivarekar et al. (journal of Textile Association)

5.11 Calculation Example:

Control CFU for S. aureus : 12×10^5

Neem CFU for S. aureus : 3.0×10^3

Reduction = $(1.2 \times 10^5 - 3.0 \times 10^3) / 1.2 \times 10^5 \times 100 = 97.5\%$

5.12 ANOVA Results

Source of Variation	SS	df	MS	F	Present Value
Between Groups	21520.3	3	7173.4	5832.0	<4.000
Within Groups	142.6	116	1.23		
Total	21662.9	119			

Source : Adivarekar et al. (journal of Textile Association)

5.1.3 Tukey's HSD Pairwise Comparisons:

Source of Variation	SS	df
Neem vs Tulsi	1.6	0.038
Neem vs Turmeric	8.2	<0.001
Tulsi vs Turmeric	6.6	<0.001
All vs Control	>80	<0.001

Source : Primary Data (present study)

5.2 Questionnaire Results

Table 2 : Mean Expert Ratings (n=30)

Parameter	Neem	Tulsi	Turmeric	Control
Colour Appeal	4.3	4.1	4.7	2.0
Fabric Handle	4.4	4.2	4.5	3.7
Colour Fastness	4.2	4.1	4.0	4.4
Antimicrobial Perception	4.8	4.6	4.1	1.8
Medical Suitability	4.9	4.7	4.0	1.9
Durability Perception	4.1	3.9	3.8	3.5
Environmental Friendliness	4.9	4.8	4.6	2.1

Source : Primary Data (present study)

Open-ended feedback:

- Neem and tulsi recommended for hospital linens and wound dressings.

- Turmeric preferred for casual wear due to colour.
- All herbal-dyed fabrics comfortable and safe for sensitive skin.

6. Discussion

The study confirms neem and tulsi extracts impart strong antimicrobial properties to linen, with bacterial reductions exceeding 95%, consistent with their bioactive phytochemicals. Turmeric showed moderate efficacy (~89%), aligning with known curcumin activity.

ANOVA and Tukey's HSD tests confirm statistically significant differences among dye groups and controls, validating the superior efficacy of neem and tulsi. Expert feedback supports practical applications in healthcare, combining functionality with comfort and aesthetics.

Limitations include lack of wash durability data and combined herb effects, which should be addressed in future research.

7. Conclusion

Linen dyed with neem and tulsi extracts exhibits excellent antimicrobial activity suitable for medical and hygienic textiles. Turmeric offers moderate antimicrobial protection and aesthetic appeal. Herbal dyeing is a sustainable, safe, and effective approach to functional textiles, supporting eco-friendly innovations in the industry.

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Appendix: Detailed Questionnaire

Section A: Aesthetics and Handle

1. The colour of the dyed linen is visually appealing. (1-5)
2. The fabric feels comfortable against the skin. (1-5)
3. The dyed fabric shows good colour fastness to washing. (1-5)
4. The dyed fabric shows good colour fastness to light. (1-5)
5. The dyed fabric shows good colour
- 6 The fabric resists odour formation

Section B : Functionality and Safety

- 6 The fabric resists odour formation effectively (1-5).
7. The fabric is suitable for medical applications. (1-5)
8. The fabric feels safe for sensitive skin. (1-5)
9. The dyed fabric is less likely to cause skin irritation. (1-5)
10. The antimicrobial property is perceivable during use. (1-5)

Section C: Durability and Sustainability

11. The fabric maintains its properties after washing. (1-5)
12. The fabric is environmentally friendly and biodegradable. (1-5)
13. I would recommend this fabric for hospital linens. (1-5)
14. I would recommend this fabric for wound dressings. (1-5)
15. I would recommend this fabric for children's clothing. (1-5)

Section D: Overall Satisfaction and Suggestions

16. Overall satisfaction with the dyed fabric. (1-5)
17. Preferred herbal dye and reasons. (Open-ended)
18. Suggestions for improvement. (Open-ended)
19. Comments on safety and comfort. (Open-ended)
20. Additional remarks. (Open-ended)