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Efficacy Assessment of Eco-Friendly Antimicrobial Finished Fabric Using *Azadirachta indica, Butea monosperma* and *Litchi chinensis*

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ABSTRACT

Aim of the Study: Antimicrobial textiles have gained importance since the COVID-19 pandemic highlighted the close link between clothing, microbes and human hygiene. This study was designed to develop and assess the efficacy of an eco-friendly, cost-effective and naturally extracted antimicrobial finish for clothing intended to limit microbial growth.

Methodology: A true-experimental pre-test/post-test control-group design was used. Antimicrobial finishes were extracted from the leaves of *Azadirachta indica*, *Butea monosperma* and *Litchi chinensis* and applied to 50/50 cotton/polyester fabric at 100% and 50% concentrations using the pad-dry-cure method, with a polyurethane binder for wash durability. Microbial presence before and after finishing, and after repeated laundering up to 25 washes, was assessed using the ASTM E2149 shake-flask method.

Findings: The finish resisted microbial growth at the 22-hour and 6-day readings and remained effective up to 25 washes. The combined finish from the three plant extracts produced a 95% reduction in microbes (17 of 18 treated samples), and one-way ANOVA confirmed a significant difference between treated and control samples ($p = .04$).

Conclusion: Naturally extracted finishes from *A. indica*, *B. monosperma* and *L. chinensis* offer a durable, eco-friendly and low-cost alternative to synthetic antimicrobial agents, with potential application in healthcare, home furnishing and apparel textiles.

Keywords: Antimicrobial Finish, *Azadirachta indica*, *Butea monosperma*, *Litchi chinensis*, Natural Plant Extract, Cotton/Polyester, Eco-friendly Textile.

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1. INTRODUCTION

In the current era, textiles are an imperative element of human life and its surroundings. Humans have used clothing for thousands of years, and considerable importance has been placed on the environmental impacts of textile and laundering industries (Sanders *et al.*, 2021). The relationship between fabrics and disease was first scientifically demonstrated by Joseph Lister in 1867, who introduced antiseptic treatment of bandages to prevent infection in wounds (Sanders *et al.*, 2021).

Microorganisms, mainly bacteria, are present everywhere in our environment, clothes and body. In the human body, bacteria are found mainly on the skin, nasal cavities and genital areas (Sanders *et al.*, 2021). On textiles and clothing, pathogenic species such as *Escherichia coli* and *Staphylococcus aureus* are commonly present (Morais *et al.*, 2016). The pathogenic nature of these microorganisms has driven researchers to develop textiles with antimicrobial properties for the betterment of human health and hygiene standards.

With the outbreak of the COVID-19 pandemic, global awareness increased that clothing and harmful microorganisms are closely related and affect human health and wellbeing (Sanders *et al.*, 2021). The microhabitat of human skin can be altered by fabric and its treatment, and the clothing of sick individuals can transmit disease to healthy individuals. This has driven the development of methods to reduce, prevent or eliminate microbial growth on textiles and clothing (Morais *et al.*, 2016).

The term 'antimicrobial' in textiles refers to substances that provide protection from potentially harmful microbial agents. The chemical characteristics, working mechanism, cost, durability and environmental impact of antimicrobial agents vary significantly (Gulati *et al.*, 2022). Antimicrobial agents act through biostatic (growth-inhibiting) and biocidal (pathogen-killing) mechanisms, with biocidal effects involving damage to the cell wall and protein, inhibition of nucleic acid synthesis and disruption of metabolic pathways (Morais *et al.*, 2016).

Antimicrobial textiles are important in healthcare (face masks, lab coats, gloves, scrubs, bandages and hospital bedding), households (bed sheets, blankets, curtains and carpets), apparel (sanitary products, undergarments, sportswear and casual dresses) and the commercial sector (uniforms, vehicle seat covers and carpets) (Gulati *et al.*, 2022).

Traditionally, natural dyes have served as antimicrobial agents. The bioactive compound of turmeric, curcumin, was used as a non-toxic natural dyeing agent, and pad dyeing of curcumin on cotton and wool imparted both colour and antimicrobial properties with good wash durability (Han & Yang, 2005). Similarly, *Artocarpus heterophyllus*, *Terminalia catappa*, *Tectona grandis* and *Morinda citrifolia* provided antimicrobial activity against microbes on fabrics (Prusty *et al.*, 2010).

Both synthetic and natural substances are used as antimicrobial agents in textiles. Synthetic agents include quaternary ammonium compounds (Yao *et al.*, 2008), triclosan (Gao & Cranston, 2008), metal-oxide composites of zinc, silver and copper (Mahltig *et al.*, 2017), polyhexamethylene biguanide (Ren *et al.*, 2016) and N-halamines (Ren *et al.*, 2016). Natural agents include seaweed, *Terminalia chebula*, *Mirabilis jalapa* and pomegranate rind (Saha & Mondal, 2021), Ugandan *Ficus natalensis* (Butler *et al.*, 2021), *Diplotropis ferruginea* (Cerqueira *et al.*, 2011), *Ocimum tenuiflorum* (Ijaz *et al.*, 2020), Aloe vera (El-Sayed *et al.*, 2021) and other documented herbal extracts (Kumar *et al.*, 2021).

Eco-friendly herbal antimicrobial agents are generally regarded as harmless and non-allergic, which makes the study of plants as antibacterial agents valuable. The plants selected for this study (*A. indica*, *B. monosperma* and *L. chinensis*) are documented antibacterial agents and offer a cost-effective alternative to synthetic and metallic (silver) agents for producing protective clothing.

1.1 Significance and Objective of the Study

The purpose of the present study was to develop an antimicrobial finish from the leaves of *A. indica*, *B. monosperma* and *L. chinensis* and to apply it to cotton/polyester fabric. The study is significant because an eco-friendly antimicrobial agent can serve as a substitute for synthetic antibacterial finishes, supporting safer and more sustainable textile production. The three selected plant species are shown in Figure 1.

Azadirachta indica (neem) *Butea monosperma* (flame tree) *Litchi chinensis* (lychee)

Figure 1: *Plant leaf sources used for the antimicrobial finish — A. indica, B. monosperma and L. chinensis*

2. LITERATURE AND THEORETICAL FRAMEWORK

A growing body of research supports the use of plant-based extracts as antimicrobial finishes for textiles. Curcumin from turmeric imparts both colour and antimicrobial activity to wool and cotton with good wash durability (Han & Yang, 2005; Reddy *et al.*, 2013), while methanolic extracts of *Ocimum tenuiflorum* (tulsi) and other herbal infusions have shown antibacterial activity on cotton fabric (Ijaz *et al.*, 2020; Thilagavathi *et al.*, 2005). Herbal extracts of chamomile, sage and green tea retained antimicrobial activity on cotton even after ten washing cycles (El-Shafei *et al.*, 2018), and biologically active natural compounds such as propolis and chitosan have produced durable antibacterial finishes against *S. aureus* and *E. coli* (Abramiuc *et al.*, 2013). These studies indicate that natural finishes can rival synthetic agents while remaining eco-friendly, but their wash durability and spectrum of activity require further investigation.

2.1 Mechanism of Antimicrobial Action

Antimicrobial agents applied to textiles act through two broad mechanisms. Biostatic agents inhibit the growth and reproduction of microorganisms, whereas biocidal agents actively kill them, and most commercial antimicrobial textiles rely on the biocidal route (Morais *et al.*, 2016). At the cellular level, biocidal activity is associated with damage to the microbial cell wall and membrane, denaturation of proteins, inhibition of nucleic-acid synthesis and disruption of metabolic pathways, which together prevent the organism from sustaining essential functions (Morais *et al.*, 2016; Gulati *et al.*, 2022). Plant-derived finishes are particularly attractive because their bioactive constituents, such as flavonoids, alkaloids, tannins and terpenoids, can disrupt microbial membranes while remaining non-toxic and non-allergic to the wearer, in contrast to some synthetic and metallic agents that raise cost, environmental and skin-sensitivity concerns (Gulati *et al.*, 2022). The durability of a finish to repeated laundering is therefore a critical performance criterion, since an agent that washes out quickly offers little practical protection in everyday clothing (Balamurugan & Babuskin, 2018).

2.2 Selected Plant Species

Three plant species were selected for the present study on the basis of their documented antibacterial properties and ready availability. *Azadirachta indica* (neem) is among the most widely studied medicinal plants and its leaf and seed extracts have shown broad-spectrum activity against both Gram-positive and Gram-negative bacteria, supporting its use in healthcare and hygiene textiles (Balamurugan & Babuskin, 2018; Ganesan & Vardhini, 2015). *Butea monosperma* (flame of the forest) is a traditional medicinal tree whose bark, flowers and leaves are rich in phenolic and flavonoid compounds reported to possess antimicrobial and anti-inflammatory activity. *Litchi chinensis* (lychee) contains polyphenols and flavonoids in its leaves and pericarp that have demonstrated antibacterial and antioxidant potential. Although each of these species has been investigated individually, their combined application as a single antimicrobial finish on a cotton/polyester blend, together with an assessment of wash durability up to twenty-five laundering cycles, has received little attention, which is the gap the present study addresses.

2.3 Theoretical Framework

The study followed a true-experimental, pre-test/post-test control-group design. The antimicrobial finish, developed from the leaves of the three selected plants, was the treatment applied to 50/50 cotton/polyester fabric, while microorganisms served as the control condition. Microbial presence was assessed before and after finish application and after successive laundering. The conceptual framework guiding the experiment is presented in Figure 2.

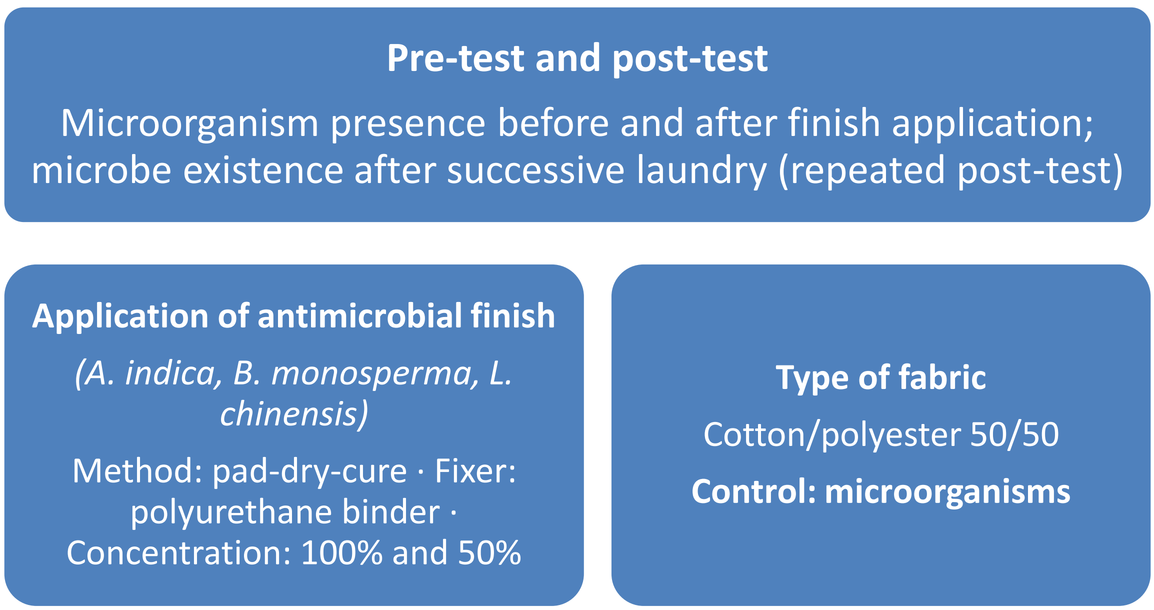

Figure 2: *Theoretical framework for the experimentation*

3. RESEARCH METHODOLOGY

3.1 Research Design

A true-experimental pre-test/post-test control-group design was adopted to evaluate the antimicrobial efficacy of the plant-based finish. The independent variable was the antimicrobial finish (three plant extracts at two concentrations), and the dependent variable was the microbial count on the treated 50/50 cotton/polyester fabric, compared against untreated control samples. The variables of the study are summarised in Table 1.

Table 1: *Variables of the study*

Factor	Level 1	Level 2	Level 3
Type of fabric	Cotton/polyester	—	—
Antimicrobial plant leaves	*A. indica*	*B. monosperma*	*L. chinensis*
Concentration of extract	100%	50%	—

Two concentration levels were prepared: 100% to assess the maximum effectiveness of the treatment and a 50% diluted ratio. Wash durability was checked up to 25 washes for the 50% diluted ratio. The 50/50 cotton/polyester fabric was a plain weave of 217 GSM.

3.2 Materials

The 50/50 cotton/polyester fabric (plain weave, 217 GSM) was purchased from Faisalabad Fabric Traders and authenticated by the head of the Textiles and Processing Department. Before treatment, the fabric was desized, bleached and scoured using a standard recipe. Fresh leaves of *A. indica*, *B. monosperma* and *L. chinensis* were collected from the botanical garden of GC University, Lahore. A polyurethane binder was used as the fixing agent.

3.3 Extraction of the Antimicrobial Finish

The collected leaves were washed and shadow-dried for two months, then ground into a fine powder using a stainless-steel grinder. In a laminar air-flow hood, the leaf powder was dispensed into an autoclave container and distilled water was added at a ratio of 100 g of ground leaf to 250 ml of purified water. The mixture was soaked for seven days, filtered through muslin cloth and Whatman filter paper, and concentrated using a rotary film evaporator. The complete extraction sequence is shown in Figure 3.

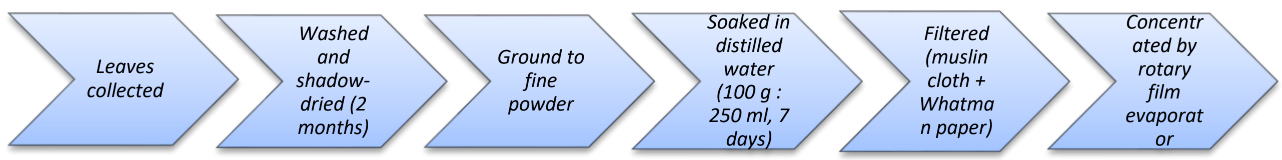

Figure 3: *General flow diagram of the solvent-extraction process*

3.4 Application of the Finish

For the 100% concentrated treatment, 200 ml of leaf extract was used on a fabric sample of one square foot. For the 50% diluted treatment, 200 ml of leaf extract was combined with 150 ml of purified water and 50 ml of polyurethane binder, which was added to improve wash durability. The finish was applied using a pad-dry-cure machine: curing at 150 °C for approximately 3 minutes followed by drying at 120 °C for 2 minutes.

3.5 Microbial Testing and Data Analysis

The microorganisms observed included Gram-positive forms (cocci, small thick rods and coccus clusters) and Gram-negative forms (diplococci, coccus, thin short rods) and yeast; this characterisation was carried out at the Centre of Excellence in Molecular Biology (CEMB). In a laminar air-flow hood, one-inch square fabric samples were cut from the experimental and control groups. The ASTM E2149 shake-flask method was used to evaluate antibacterial activity: each sample was soaked in 50 ml of disinfected medium in a Petri dish for 60 minutes with continuous shaking, after which agar plates were prepared using a pipette set at 50 µL. The first reading was taken after 22 hours and the second after a six-day interval. Colony counts in the range of 30–300 were recorded, and counts above 2000 were treated as countless (lawn).

The liquid agar medium was prepared from 15 g agar, 10 g tryptone, 5 g NaCl, 5 g yeast extract and purified water, autoclaved at 121 °C and 15 psi for 20 minutes and poured into plates after cooling. A flood-smear staining protocol with methylene blue, followed by iodine solution, decolouriser and methylene red, was used before microscopic observation. Wash durability was assessed by repeating the shake-flask test at 5-wash intervals up to 25 washes. Data were analysed using percentage reduction, one-way ANOVA and post-hoc comparisons of treated versus control samples.

4. RESULTS

The antimicrobial finish was applied to the cotton/polyester fabric and antimicrobial testing was carried out at CEMB using the ASTM E2149 shake-flask method. The quantitative results for treated and untreated samples are presented in Table 2.

Table 2: *Quantitative test results of treated and untreated cotton/polyester samples*

Treatment	Untreated	*A. indica*	*B. monosperma*	*L. chinensis*	Reduction %
Reading after 22 hours					
1st reading	0	0	0	0	100%
2nd reading	0	0	0	0	100%
3rd reading	0	0	0	0	100%
Reading after 6 days					
1st reading	2	0	0	0	100%
2nd reading	1	0	0	1	0%
3rd reading	2	0	0	0	100%

Table 2 shows that microbial testing was carried out at two intervals (22 hours and six days). *A. indica* and *B. monosperma* produced a 100% reduction in microbes, while *L. chinensis* showed only a single colony. Of 18 treated samples, 17 showed microbial reduction, corresponding to a 95% overall reduction. The univariate analysis of variance is presented in Table 3.

Table 3: *Univariate analysis of the influence of the antibacterial finish on microbial presence in cotton/polyester fabric*

Source	df	SS	MS	F	p	η^2
Between groups	3	2.833	.944	3.333	.040	.333
Within groups	20	5.667	.283			
Total	23	8.500				

Table 3 shows a significant difference between the antimicrobial treatment and the plant extract, with $p = .04$ and an effect size (η^2) of .333. The post-hoc comparison of control versus experimental groups is given in Table 4.

Table 4: *Influence of the antibacterial finish on microbial presence: control versus experimental groups*

Comparison	Mean diff. (I−J)	Std. error	Sig.
Control vs experimental (A. indica)	.833*	.307	.013
Control vs experimental (B. monosperma)	.833*	.307	.013
Control vs experimental (L. chinensis)	.667*	.307	.042

*Note. * The mean difference is significant at the .05 level.*

Table 4 indicates that the experimental groups significantly reduced microbial presence relative to the control. The significance value for *A. indica* and *B. monosperma* was .013, while that for *L. chinensis* was .042. The wash-durability test, conducted up to 25 washes at 5-wash intervals, showed one colony on the untreated sample after 5 washes and a single colony after 10 washes, with no microorganisms detected at 15, 20 or 25 washes. The colony counter used for observation is shown in Figure 4.

Taken together, the readings in Table 2 show a clear and consistent pattern. At both the 22-hour and the six-day intervals, the untreated control samples continued to support colony growth, whereas the fabric treated with *A. indica* and *B. monosperma* recorded zero colonies at every reading, corresponding to a complete (100%) reduction. The *L. chinensis* treatment produced a single colony at one six-day reading, which accounts for the one untreated sample out of eighteen and yields the overall 95% reduction reported above. The lower mean difference recorded for *L. chinensis* in Table 4 (.667 versus .833 for the other two species) is consistent with this single observed colony, although the difference from the control remained statistically significant ($p = .042$). The stability of these results across repeated laundering, with no microbial recovery from the fifteenth wash onward, indicates that the polyurethane binder successfully fixed the active plant compounds to the blended fabric and that the antimicrobial effect was retained rather than progressively washed out.

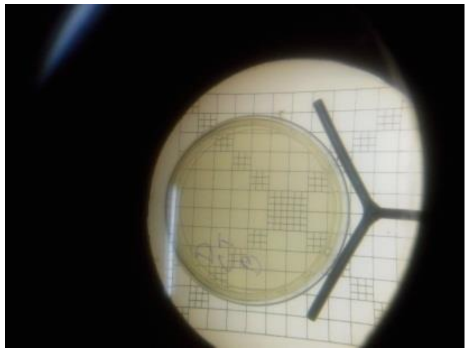

Figure 4: *Colony counter used for microbial enumeration*

5. DISCUSSION AND FINDINGS

The present findings confirm that finishes derived from *A. indica*, *B. monosperma* and *L. chinensis* provide strong and durable antimicrobial protection on cotton/polyester fabric. This is consistent with earlier work showing that pomegranate, neem and turmeric extracts inhibit both Gram-positive and Gram-negative bacteria, and that *Ocimum tenuiflorum* exhibits comparable antibacterial activity on cotton (Ijaz *et al.*, 2020). Methanolic extracts of tulsi leaves have been reported to give about 73% antibacterial activity on cotton (Damuluri, 2019; Joshi *et al.*, 2009), whereas the combined finish in this study achieved a 95% reduction.

Wash durability is a key advantage of the present finish. Neem- and tulsi-oil finishes have been reported to resist only up to three washes, and eucalyptus-oil finishes only one wash (Balamurugan & Babuskin, 2018). Microencapsulated neem finishes have remained active up to 15 washes (Ganesan & Vardhini, 2015), and methanolic neem extract has resisted microbes up to 15 washes (Ponnuswamy, 2019). In contrast, the finish developed here remained effective up to 25 washes, indicating superior laundering stability.

Comparable durability has been reported for other natural systems. Curcumin-treated wool retained 30% and 45% activity against *E. coli* and *S. aureus* (Han & Yang, 2005); chamomile, sage and green-tea extracts remained active after ten washes (El-Shafei *et al.*, 2018); and chitosan-treated cotton achieved up to 97% reduction in *S. aureus* (Abramiuc *et al.*, 2013). *Solanum incanum* fruit extracts have also shown durable activity with only an 18.75% loss after five launderings (Nalankilli & Tadesse, 2018). Taken together, these comparisons confirm that the three-plant finish is at least as effective as, and more wash-durable than, many previously reported natural finishes, supporting its use as an eco-friendly alternative to synthetic antimicrobial agents.

Beyond laboratory performance, these results carry practical significance. The growing global concern over antimicrobial resistance and the heightened awareness of hygiene following the COVID-19 pandemic have intensified demand for textiles that limit microbial growth in everyday use (Sanders *et al.*, 2021; Morais *et al.*, 2016). A finish that is naturally derived, low-cost and durable to repeated laundering is well suited to high-contact applications such as hospital linen, face masks, lab coats, undergarments and sportswear, where synthetic or metallic agents may raise cost, toxicity or skin-sensitivity concerns (Gulati *et al.*, 2022). The use of a 50/50 cotton/polyester blend, a fabric widely employed in institutional and consumer clothing, further supports the practical relevance of the finish. Because the three plant species are abundant and inexpensive in the region, the approach also offers an economically viable route for local textile processors to add antimicrobial value without specialised synthetic chemistry. Nevertheless, the present findings are based on a controlled laboratory setting, and factors such as colour fastness, mechanical strength after finishing, and skin-contact safety would need systematic evaluation before commercial adoption.

6. CONCLUSION

Antimicrobial textiles are increasingly important for modern health and hygiene. This study demonstrates that naturally extracted, plant-based finishes can deliver durable antimicrobial protection on blended fabrics while remaining low-cost and environmentally friendly. As consumer demand for safer textiles grows, such readily available natural substances offer a practical and sustainable route to producing antimicrobial textiles, with broad relevance for healthcare, home furnishing and apparel applications. Future work could extend the approach to a wider range of fabrics and microbial strains and evaluate large-scale processing.

6.1 Limitations

The study was limited to a single fabric type (50/50 cotton/polyester) and a defined set of microorganisms, and the sample size for the laundering test was small. The antimicrobial assessment was also confined to the bacterial and yeast species observed at the testing facility and did not include a broader panel of clinically relevant pathogens or fungal species. In addition, properties that determine the commercial acceptability of a finished fabric, such as colour fastness, tensile strength, air permeability and direct skin-contact safety, were outside the scope of this work. These factors should be considered when generalising the findings. Future studies could apply the combined finish to a wider range of natural and synthetic fabrics, evaluate it against an extended panel of pathogens, quantify the active phytochemicals responsible for the observed activity, and assess large-scale processing and cost at an industrial level so that the laboratory results can be translated into practical, marketable antimicrobial textiles.

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Data Availability

Not Applicable.

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