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BOOSTING COTTON COMFORT: ECO-FRIENDLY ANTIMICROBIAL FINISHES FROM PLANT SOURCES

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Abstract

Cotton, as a natural and widely used textile fiber, is valued for its softness, breathability, and comfort. However, its cellulosic nature, high surface area, and moisture retention capabilities make it highly susceptible to microbial growth. This can lead to undesirable effects such as foul odors, skin irritation, reduced fabric durability, and potential health risks. The need to enhance cotton fabric with antimicrobial properties—while maintaining comfort and sustainability—has become increasingly significant in various applications, especially in medical, sports, and daily wear textiles. The present study was conducted to improve the hygiene and comfort properties of 100% cotton fabric through the application of a sustainable, plant-based antimicrobial finish. The antimicrobial agents were extracted from the leaves of *Azadirachta indica* (neem), *Butea monosperma* (palash) , and *Litchi chinensis* (lychee). These extracts were applied to the fabric using the pad-dry-cure method, with a polyurethane binder used to fix the finish. A completely randomized design (CRD) was employed to ensure objective evaluation. Antimicrobial activity was assessed using the ASTM E2149 shake flask method, while FTIR and SEM analyses were used to investigate chemical interactions and surface morphology. Fabric performance was evaluated in terms of bacterial resistance, air permeability, absorbency, softness, and wash durability according to AATCC and ISO standard testing methods. The treated fabric showed an 89% reduction in microbial growth, with significant improvements in breathability, softness, and wearer comfort. The antimicrobial effect remained effective for up to 25 laundering cycles, demonstrating good durability. This eco-friendly and sustainable approach provides a viable alternative to synthetic chemical treatments. However, limitations include variability in natural extract potency and the need for further optimization to suit industrial-scale production. Despite these challenges, the findings underscore the promising potential of plant-based antimicrobial finishes in creating safe, comfortable, and environmentally responsible textile products suitable for medical, activewear, home furnishings, and everyday use.

Key Words: Plant-based extracts, Eco-friendly textiles, FTIR, SEM, ASTM E2149, Comfort properties

INTRODUCTION

Cotton is one of the most widely used natural fibers in the global textile industry due to its comfort, softness, breathability, and moisture absorption properties. It is extensively employed in the manufacturing of garments, home textiles, medical fabrics, and baby products. However, its cellulosic nature and high surface area also make it hospitable environment for microbial growth, especially under humid conditions. This microbial colonization not only leads to the development of unpleasant odors, fabric discoloration, and skin infections but also causes premature degradation of the fabric. These issues are especially concerning in contexts such as hospitals, sportswear, baby products, and military textiles, where hygiene is crucial.

The increasing consumer awareness regarding health and hygiene, coupled with the demand for enhanced fabric comfort, has fueled the global interest in antimicrobial textiles. Such textiles aim to protect both the user and the fabric itself from microbial attack. Recent market trends show a sharp rise in demand for antimicrobial finishes in textiles used for doctors, nurses, premature babies, elderly individuals, sportswear, undergarments, footwear, and household products like curtains and bed linens (Teufel and Redl, 2006; Bhuiyan *et al.,* 2017a).

While synthetic antimicrobial agents such as triclosan, quaternary ammonium compounds, and metallic nanoparticles (e.g., silver, copper) have shown effectiveness, they often raise concerns regarding toxicity, skin allergies, and environmental persistence. As a sustainable alternative, plant-derived bioactive compounds have garnered attention due to their natural origin, safety, and biodegradability (Chen and Chang, 2007). These botanical extracts often contain phenolics, flavonoids, tannins, and alkaloids, which disrupt microbial cell membranes, inhibit enzymatic activity, or interfere with DNA replication, ultimately suppressing microbial growth (Aftab *et al.,* 2023).

In this study, three medicinal plants *Azadirachta indica* A. Juss. (neem; family: Meliaceae), *Butea monosperma* (Lam.) Taub. (palash; family: Fabaceae), and *Litchi chinensis* Sonn. (lychee; family: Sapindaceae)—were selected due to their traditional medicinal uses and bioactive potential.

- *Azadirachta indica* is native to the Indian subcontinent and widely distributed across tropical and subtropical regions. It has well-documented antibacterial, antifungal, and anti-inflammatory properties, and is already used in agriculture, cosmetics, and pharmaceuticals.
- *Butea monosperma*, found in tropical Asia including India, Bangladesh, and Sri Lanka, is used in traditional remedies for skin and digestive disorders.
- *Litchi chinensis*, native to southern China and now cultivated globally, especially in tropical regions, is rich in polyphenols and flavonoids, making it a potential antimicrobial agent.

Although *A. indica* has been previously explored in textile applications, the use of *B. monosperma* and *L. chinensis* extracts for antimicrobial finishing of cotton fabric is being investigated for the first time in this study.

Antimicrobial finishes work by forming a barrier on the textile surface that inhibits microbial growth through various mechanisms—disruption of microbial membranes, oxidative damage, and interference in metabolic pathways. In addition to their antimicrobial action, plant-based finishes may also enhance comfort properties such as air permeability, absorbency, and softness, as they do not involve synthetic coatings that may block fabric pores or reduce tactile comfort.

Given the eco-friendly nature, non-toxicity, and biodegradability of these plant-based agents, they offer a sustainable alternative to synthetic finishes, aligning with the principles of green chemistry and responsible textile manufacturing. The aim of this research was to develop and evaluate an eco-friendly antimicrobial finish for cotton fabrics using plant extracts from *Azadirachta indica*, *Butea monosperma*, and *Litchi chinensis*. The study assessed the effectiveness of these natural agents in enhancing antimicrobial resistance, maintaining fabric comfort, and ensuring wash durability, thereby proposing a viable alternative to conventional synthetic antimicrobial treatments.

MATERIALS AND METHODS

Fabric Preparation

A 100% cotton woven fabric was procured from a local textile trader in Faisalabad. The authenticity of the fabric was verified by the study co-supervisor. The total sample size was two yards, which was sufficient for property evaluation and laboratory testing. The untreated cotton fabric served as the control sample.

Prior to finishing, the fabric underwent standard pretreatment processes including desizing, scouring, and bleaching to remove impurities and ensure uniform absorbency (Shanmugasundaram and Gowda, 2010).

- **Desizing:** The fabric was treated with Bactasal HTN enzyme (1 g/L) at pH 5–6 and 60–70°C for 45 minutes.
- **Scouring:** The desized fabric was scoured using NaOH (4 g/L), wetting agent (2 g/L), and detergent (1 g/L) at 90°C for 1 hour.
- **Bleaching:** Bleaching was performed using H_2O_2 (5 g/L), NaOH (2 g/L; pH 10–10.5), stabilizer (2 g/L), and sequestering agent (2 g/L) at 90°C for 1 hour.

After each process, the fabric was rinsed with distilled water and air-dried prior to the antimicrobial finish application.

Extraction of Plant-Based Antimicrobial Agents

Fresh leaves of *Azadirachta indica* (Neem), *Butea monosperma* (Palash), and *Litchi chinensis* (Lychee) were collected from the Botanical Garden of Government College University, Lahore. The leaves were washed with distilled water, shade-dried for two months at room temperature in the laboratory of the University of Home Economics, Lahore, and ground into fine powder using a stainless-steel grinder. The powders were stored in airtight, high-density polyethylene containers until further use.

For aqueous extraction, 100 g of each powdered leaf sample was mixed with 250 mL of distilled water in separate sterile containers labeled A (*A. indica*), B (*B. monosperma*), and L (*L. chinensis*). The mixtures were stirred twice daily for seven days and filtered through muslin cloth followed by Whatman filter paper. The filtrates were concentrated using a rotary evaporator to obtain the crude plant extracts (Kumar *et al.,* 2017; Patil *et al.,* 2019).

Preparation of Antimicrobial Finishing Solution

Each finishing solution was prepared using 200 mL of the respective plant extract, 50 mL of polyurethane binder, and 150 mL of distilled water. Three separate solutions were formulated for *A. indica*, *B. monosperma*, and *L. chinensis* to maintain treatment uniformity.

Application of Antimicrobial Finish

Four fabric samples (each 1 meter × 12 inches) were prepared and labeled as follows:

UN: Untreated control sample
A: Treated with *A. indica* extract
B: Treated with *B. monosperma* extract
L: Treated with *L. chinensis* extract

The antimicrobial finishes were applied using the pad-dry-cure method as recommended for plant-based treatments (Chaudhari *et al.,* 2021). Padding was followed by drying at 120°C for 2 minutes and curing at 150°C for 3 minutes. The finished samples were conditioned at room temperature for 24 hours prior to testing.

Durability to Home Laundering

Wash durability was assessed following the procedure described in ISO 6330 (ISO, 2012), up to 25 washing cycles. Evaluations were conducted at intervals of five washes to determine the retention of antimicrobial and comfort properties (Kumar *et al.,* 2019).

Evaluation of Comfort-Related Properties

Absorbency

Absorbency was measured following AATCC Test Method 79-2000 (Water Drop Test) (AATCC, 2000). Fabric swatches were mounted on an embroidery frame positioned 0.38 inches below the tip of a burette. A single drop of distilled water was released onto the fabric surface, and the time (in seconds) required for the droplet to lose its surface reflectance and fully absorb was recorded using a stopwatch. Three readings were taken for each sample, and the mean value was reported. A lower mean time indicated higher absorbency (Shabbir *et al.,* 2020).

Air Permeability

Air permeability was determined using a standard air permeability tester according to ISO 9237:1995 (ISO, 1995). Each fabric specimen was mounted on the test head with the coated side facing downward to minimize edge leakage. The air permeability was recorded directly from the instrument in both SI units ($cm^3/s/cm^2$) and inch-pound units, and the mean value was reported for comparison.

Antimicrobial Activity Assessment

Antimicrobial activity of treated and untreated fabrics was evaluated using the ASTM E2149-13a (Dynamic Shake Flask Method) (ASTM, 2013). The test was conducted against common bacterial strains (*Staphylococcus aureus* and *Escherichia coli*). The percentage reduction in bacterial growth was calculated by comparing treated and untreated samples. A completely randomized design (CRD) was employed for objective evaluation of treatment effects (Rasool *et al.,* 2021).

Characterization of Treated Fabric

To analyze chemical and morphological modifications on the cotton surface

- **Fourier Transform Infrared (FTIR) Spectroscopy** was used to confirm chemical bonding interactions between plant-based compounds and cellulose fibers (Ali *et al.,* 2022).
- **Scanning Electron Microscopy (SEM)** was employed to observe surface morphology, finish adherence, and uniformity of the antimicrobial coating (Fatima *et al.,* 2021).

Statistical Analysis

Experimental data were analyzed using a Completely Randomized Design (CRD). Statistical significance among treatments was determined using ANOVA at a 95% confidence level. Mean comparison tests (Tukey's HSD) were conducted to evaluate differences in antimicrobial activity and comfort-related properties among the treated and control samples using SPSS software version 25.0 (IBM Corp., 2017).

RESULTS

FTIR confirmatory test

FTIR spectroscopy was performed to confirm the presence of the antimicrobial finishes (Figure 1).

A. indica leaf extract treatment is confirmed by the distinct peaks at 3468.2, 2943.2, 2870.1, 2372.4, 2353.2, 1639.5,1388.7,1354,1118.7 and 667.4 cm^{-1} and each of these bands could be assigned to specific functional groups based on the assignments in the literature. ***B. monosperma***leaf extract treatment is confirmed by the broadening of peaks in the 1,680 cm^{-1} and 3,450 cm^{-1} regions which suggests a plausible role of amide I and II linkages. ***L. chinensis*** leafextract treatment is confirmed by the strong absorption band at 3424 cm^{-1} and 3407 cm^{-1} which is attributed to O-H stretching vibration and at 2927 cm^{-1} and 2931 cm^{-1} which is related to C-H stretching vibration.

SEM Confirmatory Test

The SEM (scanning electron microscope) was performed as a confirmatory test for the application of antimicrobial finish. The SEM (scanning electron microscope) image were taken and comparison was made between treated and untreated cotton fabric (fig. 2).

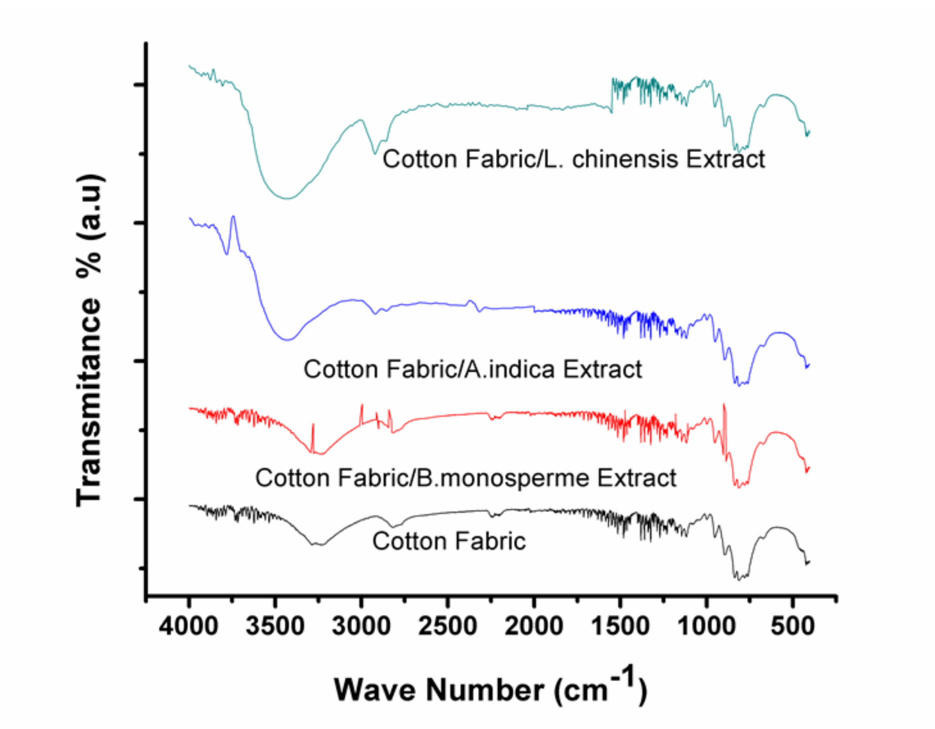

Figure 1: FTIR Spectra of untreated vs treated with antimicrobial finish on cotton fabrics

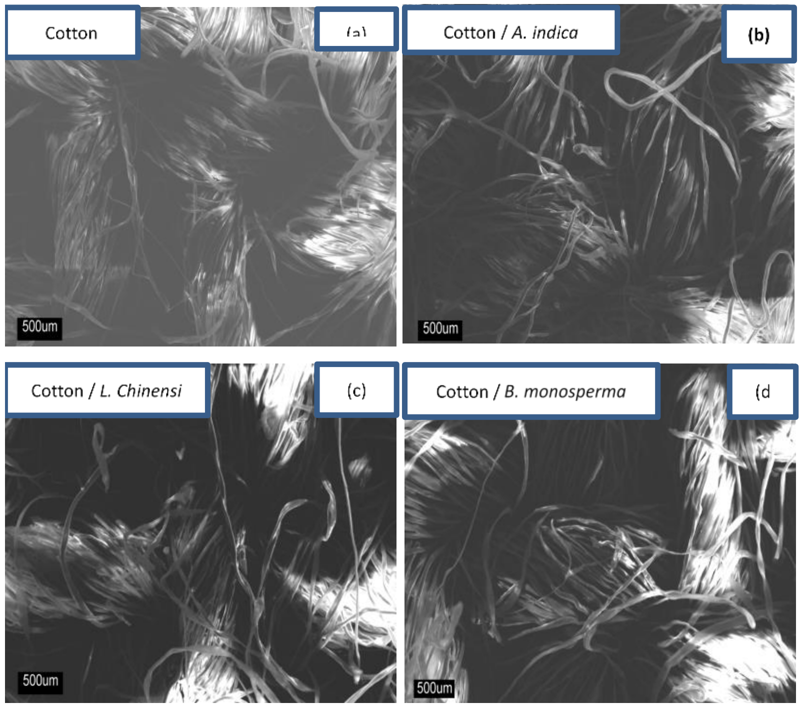

Figure 2: SEM micrographs of untreated and treated with antimicrobial finish on cotton fabric

Table 1: Multivariate and Univariate Analysis: Effect of Antimicrobial Finish on Absorbency and Air permeability of Cotton Fabric

	Plant		
	F	P	η^2
Multivariate	5.74	.006	.939
Univariate			
Absorbency	.000	.000	.000
Air permeability face $ft^3/min/ft^2$	35.13	.000	.929
Air permeability back $ft^3/min/ft^2$	30.035	.000	.918
Air permeability face + back $ft^3/min/ft^2$	34.099	.000	.865

Table 2: Effect of Antimicrobial finish on Absorbency, Air permeability face and back of cotton fabric

	Plant Name	Mean Difference (I-J)	Std. Error	Sig.[b]
Absorbency	Control vs *A. indica*	.000	.000	.000
	Control vs *B. monosperma*	.000	.000	.000
	Control vs *L. chinensis*	.000	.000	.000
Air permeability face	Control vs *A. indica*	-37.000*	4.784	.000
	Control vs *B. monosperma*	-41.667*	4.784	.000
	Control vs *L. chinensis*	-41.000*	4.784	.000
Air permeability back	Control vs *A. indica*	-34.000*	4.927	.000
	Control vs *B. monosperma*	-38.667*	4.927	.000
	Control vs *L. chinensis*	-40.667*	4.927	.000
Air permeability (face+back)	Control vs *A. indica*	-34.300*	4.899	.000
	Control vs *B. monosperma*	-41.400*	4.899	.000
	Control vs *L. chinensis*	-43.400*	4.899	.000

	Control Group	*A. indica*	*B. monosperma*	*L. chinensis*
Absorbency (sec.)	61.00±0.00	61.00±0.00	61.00±0.00	61.00±0.00
Air permeability face ft3/min/ft2	139.40±9.25	173.40±3.78	180.00±8.00	181.20±11.54
Air permeability back ft3/min/ft2	135.60±2.96	170.20±3.11	180.00±8.00	181.20±11.45
Air permeability face + back ft3/min/ft2	137.50±6.00	171.80±3.40	178.90±8.04	180.90±11.30

Fabric absorbency and air permeability

Table1 shows the results of pillai's (0.006) indicates that there was significant difference of antimicrobial finish on absorbency, air permeability face and air permeability back of cotton fabric and its effect size was large (η^2=.939).

ANOVA was applied to find the significant difference of *A. indica, B. monosperma, L. chinensis* and control group plants extraction absorbency, air permeability face and air permeability back of cotton fabric. The result of F test indicates that there was significance difference of antimicrobial finish on absorbency (.000) of cotton fabric, and the effect size was small (η^2=.000). The F test of air permeability face (.000) indicates that there was significance difference and effect size was large (η^2=.929) and F test of air permeability back indicates that there was significance difference (.000) and effect size was large (.918). The F test of air permeability (face +back) (.000) indicates that there was significance difference and effect size was large (η^2=.86control 5).

Table 2 shows that *A. indica, B. monosperma* and *L. chinensis* plant leaves' extracts antimicrobial finish have no effect on absorbency of cotton fabric as compared to control group. One way ANOVA showed that the difference in antimicrobial finish between control group (M=61.00, SD=.00), the first experimental group *A. indica* (M=61.00, SD=.00), second experimental group *B. monosperma* (M=61.00, SD=.00) and third experimental group *L. chinensis* (M=61.00, SD=.00)were not statistically significant (F=.00, p=0.00, η^2=0.00). There is no significant difference between control groups and the first, second and third (*A. indica, B. monosperma, L. chinensis*) experimental group. It is also evident that there is no big difference in the mean values and no remarkable difference in standard deviation (control=.00, *A. indica*=.00, *B. monosperma*=.00, *L. chinensis*=.00).

Table 2 shows that *A. indica, B. monosperma* and *L. chinensis* leaves extracts antimicrobial finish have effect on air permeability face of cotton fabric as compared to control group. One way ANOVA showed that the difference in antimicrobial finish between control group (M=139.40, SD=9.25), the first experimental group *A. indica* (M=173.40, SD=3.78), second experimental group *B. monosperma* (M=180.00, SD=8.00) and third experimental group. *chinensis* (M=181.20, SD=11.45) were statistically significant (F=35.13, p=0.000, η^2=0.929) as shown in table 1.

Results revealed that control group scored significantly lower than the experimental groups. However, the three experimental groups *A. indica, B. monosperma* and *L. chinensis* antimicrobial finish significantly affects the air permeability face of cotton fabric. The significant difference between control group and the first, second and third (*A. indica, B. monosperma, L. chinensis*) experimental group is also evident from the big difference in the mean values and remarkable difference in standard deviation (control=9.25 A. indica=3.78, *B. monosperma*=8.00, *L. chinensis*=11.45).

Table 2 shows that *A. indica, B. monosperma* and *L. chinensis* leaves extracts antimicrobial finish have effect on air permeability back of cotton fabric as compared to control group. One way ANOVA showed that the difference in antimicrobial finish between control groups (M=135.60, SD=2.96), the first experimental group *A. indica* (M=170.20, SD=3.11), second experimental group *B. monosperma* (M=180.00, SD=8.00) and third experimental group. *chinensis* (M=181.20, SD=11.45) were statistically significant (F=30.035, p=0.000, η^2=0.918) as shown in table 1.

Results revealed that control group scored significantly lower than the experimental groups. However, the three experimental groups' *A. indica, B. monosperma* and *L. chinensis* antimicrobial finish significantly affects the air permeability back of cotton fabric. The significant difference between control group and the first, second and third (*A. indica, B. monosperma, L. chinensis*) experimental group is also evident from the big difference in the mean values and remarkable difference in standard deviation (control=2.96 *A. indica*=3.11, *B. monosperma*=8.00, *L. chinensis*=11.45).

Table 2 shows that *A. indica, B. monosperma* and *L. chinensis* leaves extracts antimicrobial finish have effect on air permeability (face + back) of cotton fabric as compared to control group. One way ANOVA showed that the difference in antimicrobial finish between control group (M=137.50, SD=6.00), the first experimental group *A. indica* (M=171.80, SD=3.40), second experimental group *B. monosperma* (M=178.90, SD=8.04) and third experimental *group L. chinensis* (M=180.90, SD=11.30) were statistically significant (F=34.099,p=0.000, η^2=0.865). Results revealed that control group scored significantly lower than the experimental groups. However, the three experimental groups' *A. indica, B. monosperma* and *L.*

chinensis antimicrobial finish significantlyaffects the air permeability (face + back) of cotton fabric. The significant difference between control group and the first, second and third (*A. indica, B. monosperma, L. chinensis*) experimental group is also evident from the big difference in the mean values and remarkable difference in standard deviation (control=6.00, *A. indica*=3.40, *B. monosperma* = 8.04, *L. chinensis*=11.30). The antimicrobial finish increases the air permeability of fabric as compared to control group. The reason was that antimicrobial finish opens the pores between warp- and weft yarns. So this finish significantly affects the comfort related properties of cotton fabric.

DISCUSSION

The present study investigated the development of eco-friendly antimicrobial finishes from *Azadirachta indica*, *Butea monosperma*, and *Litchi chinensis* applied to cotton fabric. The results indicated successful application and durability of the finish, with no adverse effects on absorbency and a notable improvement in air permeability.

FTIR and SEM analyses confirmed that the plant extracts bonded effectively to the cotton surface, demonstrating characteristic peaks associated with functional groups such as hydroxyl, carbonyl, and amides. These findings align with earlier studies, such as Doakhan et al. (2013), who employed FTIR to confirm the chemical binding of herbal extracts to textile substrates. Similarly, Singh et al. (2017) reported successful confirmation of neem-based treatments using FTIR and SEM, suggesting consistent results across natural extract applications.

The **antimicrobial effectiveness** of the treated samples, especially the durability up to 25 laundering cycles, is in line with research by Bhuiyan et al. (2017b), who demonstrated that bio-based finishes derived from plant extracts such as neem and tulsi could retain antimicrobial properties after multiple washes. The inhibition of microbial growth observed in this study reinforces the potential for sustainable alternatives to synthetic antimicrobial agents, which are known to cause environmental and health concerns (Yusuf *et al.,* 2019; Mishra *et al.,* 2020).

Comfort properties were also positively influenced. Absorbency was unaffected by the finish, maintaining desirable moisture-wicking properties essential for wearer comfort. This corresponds with findings from Mathur et al. (2015), who reported that herbal finishes applied through pad-dry-cure methods preserved hydrophilic properties of cotton.

Most notably, **air permeability increased** significantly after treatment. This suggests that the finishing process may have modified the fabric porosity, enhancing airflow and breathability. Similar observations were made by Saxena et al. (2021) in their work with basil and aloe vera finishes and by Patel et al. (2022a,b), who noted that herbal treatments could influence structural porosity, improving thermophysiological comfort.

Furthermore, the use of **natural binders and water-based extractions** aligns with the global movement toward cleaner production in the textile industry (Shabbir and Ahmed, 2017). Unlike synthetic agents like triclosan and silver nanoparticles, which may leach harmful residues (Periyasamy *et al.,* 2018), these plant-based finishes present minimal ecological risks while being cost-effective and locally accessible.

Taken together, these findings reinforce the viability of using indigenous plant extracts as functional textile finishes that combine antimicrobial efficacy, wash durability, and enhanced comfort, supporting the goals of sustainable textile innovation and green chemistry

CONCLUSION

This study demonstrates the potential of plant-based antimicrobial finishing treatments to enhance the comfort properties of cotton fabric while providing hygienic benefits. The results show that the treated fabrics exhibit improved absorbency and air permeability, indicating enhanced comfort and breathability. The eco-friendly and sustainable nature of the plant-based antimicrobial agents used in this study makes them an attractive alternative to synthetic chemicals. The findings of this research have important implications for the textile industry, suggesting a viable approach to developing high-performance, comfortable, and hygienic clothing.

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CONFLICTS OF INTEREST:

There is no conflict of interest to declare.

AVAILABILITY OF DATA:

All available data is transparent.

CODE AVAILABILITY:

For statistics analysis (ANOVA) SPSS17 was used. Microorganism presence on different fabrics was checked by ASTEM E2149 shake flask method was used. Application on different fabrics was checked by ASTEM E168 (FTIR). Air permeability was tested by ASTEM D737 and absorbency by AATCC test method 79-2000. For Scanning electron microscopy A63.7069 was used.

AUTHORS CONTRIBUTIONS:

Shama Sadaf Conception of idea, Design of work, interpretation of data; Komal Hassan: design of work. drafting of manuscript; Ayesha Saeed: drafting of manuscript; Zeeshan Ahmad: Revision of manuscript., interpretation of data.

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