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ANTIMICROBIAL FINISHING OF JUTE COTTON UNION FABRIC USING EXTRACT OF DIFFERENT NATURAL ANTIMICROBIAL AGENTS

Zakaria Ahmed
Technology Wing, Bangladesh Jute Research Institute, Manik Mia Avenue, Dhaka 1207, Bangladesh

ABSTRACT

There are many prospects for the application of new finishes due to the fast rise of technical fabrics and their end uses like medical and healthcare applications. In the present study, an antimicrobial agent is extracted from different natural agents to investigate the effect of antimicrobial activity on jute cotton union fabric. Jute cotton union fabrics were mordanted with two different mordant (Alum and $CuSO_4.7H_2O$) and treated with different extracts separately at a fabric-to-liquor ratio of 1:20 using the dip-dry-cure method. These finished samples were subjected to an antimicrobial activity test. The study found that samples treated with neem leaf extract, banana peel extract, and $CuSO_4.7H_2O$ mordanted showed zones of inhibition against *E. coli* and *S. aureus*, respectively. The treated and non-treated fabrics were characterized by thermal conductivity and this analysis showed that there were no changes of the treated fabric. The experiment found lower K-value in untreated samples and lower thermal conductivity in treated fabrics treated with desi jute leaf extract with $CuSO_4.7H_2O$ mordant, indicating proper attachment of antimicrobial active agent to fabrics. The surface morphology of treated and non-treated fabric was studied respectively where the banana peel shows maximum pore size and poor smooth structure, while neem leaf extract's confirms attachment to jute cotton union fabric and others show no significant changes.
Keywords: Jute, Fabric, Leaf extract, Anti-microbial, Mordant.

ABTSRAK

Terdapat banyak prospek untuk penggunaan kemasan baharu disebabkan peningkatan pesat fabrik teknikal dan kegunaan akhir mereka seperti aplikasi perubatan dan penjagaan kesihatan. Dalam kajian ini, agen antimikrob diekstrak daripada agen semula jadi yang berbeza untuk menyiasat kesan aktiviti antimikrob pada fabrik gabungan kapas jut. Fabrik penyatuan kapas jut dileburkan dengan dua mordan berbeza (Alum dan CuSO4.7H2O) dan dirawat dengan ekstrak berbeza dengan secara berasingan pada nisbah fabrik kepada minuman keras 1:20 menggunakan kaedah celup-kering-penawar. Sampel siap ini tertakluk kepada ujian aktiviti antimikrob. Kajian mendapati bahawa sampel yang dirawat dengan ekstrak daun neem, ekstrak kulit pisang, dan CuSO4.7H2O mordanted menunjukkan zon perencatan terhadap E. coli dan S. aureus, masing-masing. Fabrik yang dirawat dan tidak dirawat dicirikan oleh kekonduksian terma dan analisis ini menunjukkan bahawa tiada perubahan pada fabrik yang dirawat. Eksperimen mendapati nilai K yang lebih rendah dalam sampel yang tidak dirawat dan kekonduksian terma yang lebih rendah dalam fabrik yang dirawat dengan ekstrak daun desi jute dengan mordan CuSO4.7H2O, menunjukkan pelekatan yang betul agen aktif antimikrob pada fabrik. Morfologi permukaan fabrik yang dirawat dan tidak dirawat telah dikaji masing-masing di mana kulit pisang menunjukkan saiz liang maksimum dan struktur licin yang lemah, manakala ekstrak daun neem mengesahkan lampiran pada kain gabungan kapas jut dan lain-lain tidak menunjukkan perubahan ketara.
Kata kunci: Jute, Fabrik , Ekstrak daun, Anti-mikrob, Mordant.

Correspondence:
Zakaria Ahmed
Technology Wing, Bangladesh Jute Research Institute, Manik Mia Avenue, Dhaka 1207, Bangladesh
Email: zakariaahmed70@gmail.com

Introduction

Textiles in medicine have expanded significantly, particularly in hygiene products for hospital wards and operating rooms. Protective clothing is recommended to prevent bacteria transfer from surgical personnel to patients, as they may encounter blood-borne diseases. Protective healthcare textiles include emergency room textiles, barrier materials, and surgical gowns. Nonwoven textiles, made by mechanical, chemical, thermal, or combining methods, are produced in large quantities and used in various medical fields [El-Shafei et al 2017]. Nonwoven textile materials are widely used in healthcare and medical industries due to their cost-effectiveness and ability to be made directly from fibers. They are ideal for producing disposable goods, contributing to high cleanliness standards and reducing cross-infections. Most protective equipment in operating rooms is made of nonwoven textiles, such as gowns, drapes, masks, overheads, and overshoes. These garments are breathable, comfortable, reliable, and inexpensive. Clothes, often referred to as the "second skin," offer health benefits like wrinkle resistance, water repellency, flame retardancy, and microbial resistance. However, textiles can harbor bacteria, causing health issues, fabric deterioration, and unpleasant smells.

Antimicrobial technologies offer textile materials with varying microbe protection levels [Islam et al 2023]. The market for these textiles is growing due to hygiene and active lifestyles, leading to increased research and development of bio-functional fabrics with antibacterial activity [Shalini and Anitha 2016]. The antimicrobial agents can be applied to the textile substrates by exhaust, pad-dry-cure, coating, spray and foam techniques. The substances can also be applied by directly adding into the fiber spinning dope. The inherent properties of the textile fibers provide room for the growth of microorganisms. Besides, the chemical processes may induce the growth of microbes. Textiles can be treated with natural and synthetic antimicrobial finishes, including plant or animal ingredients and metals like copper, zinc, and silver [Ashraf and Rahman 2021]. Antimicrobials primarily function in two different ways. The conventional leaching types of antimicrobials leave the textile and chemically enter or react with the microorganism acting as a poison. The unconventional bound antimicrobial stays affixed to the textile and, on a molecular scale, physically stabs (the membrane) and electrocutes (the biochemical in the membrane) the microorganism on contact to kill it. Ashraf and Rahman [2021] suggest that plant leaf extracts can be applied to bleached cotton fabric for antimicrobial treatments in textile products. Synthetic antimicrobial compounds effectively prevent textile bacteria growth, but they have negative health and water pollution effects. There's a need for environmentally friendly, anti-microbial textile-based chemicals [Ali et al 2014]. As a result, research on bacterial adhesion to textile materials is crucial to stopping the development and spread of these dangerous organisms [Mishra and Babel 2017]. The process of giving textiles antibacterial properties that aid in preventing the growth of bacteria, fungus, and other diseases is known as antimicrobial finishing. Textiles treated to prevent the growth of germs including bacteria, fungus, and viruses are known as antimicrobial textiles. To lower the danger of infection, odor, and deterioration, these materials are extensively employed in a variety of applications, including sportswear, outdoor gear, medical textiles, and domestic textiles. Natural agents are important environmentally friendly technologies. Plant extracts, polysaccharides, and natural pigments, including neem plants, have been identified as natural antibacterial agents, aiding in the management of various illnesses, infections, and allergies, particularly in neem plants [Mishra and Babel 2017, Yadav et al 2020]. This study explores the use of neem leaf extract as an anti-microbial agent in creating eco-friendly, non-toxic, and antimicrobial cotton textiles for healthcare and medical applications. With advent of new technologies, the growing needs of the consumer in the wake of health and hygiene can be fulfilled without compromising the issues related to safety, human health and environment.

Many studies have explored the antibacterial properties of plant extracts, particularly from leaves, flowers, and other parts, for use on fabrics. Researchers have investigated the antimicrobial activities of plant-derived compounds due to their natural origin, biodegradability and eco-friendly nature [Samanta and Agarwal 2009, Hussain et al 2010, Rajendran et al 2011]. Mechanisms of action of most of these plant extracts contain bioactive compounds like phenolics, flavonoids, tannins, essential oils, and alkaloids, which disrupt bacterial cell membranes, interfere with enzymatic processes, or inhibit protein synthesis. These properties make them effective as natural antibacterial agents on fabrics. These studies have contributed to developing antibacterial textiles that can be used in medical environments, clothing, and home furnishings, providing protection against infections and odor caused by bacterial growth [Choudhary et al 2011, Ali and Hussain 2009, Rajendran R et al 2011]. Beykzadeh et al [2013] explores the in-situ synthesis of silver nanoparticles on cotton using lavender extract as a reducing agent where the treated fabric exhibited significant antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*. Lavender extract treated fabrics showed promising antibacterial effect because of the main contributors Linalool and linalyl acetate. Seyfarth et al [2008] and Tadtong et al [2015] evaluates the antimicrobial effects of lavender essential oil and its major components, while it focuses on lavender oil rather than fabric, the findings are relevant for understanding its antibacterial potential in textile applications. Selvi and Thilagavathi [2011] investigated the antimicrobial finishing of cotton fabrics using lavender essential oil and it confirms the antibacterial effectiveness of lavender oil-treated cotton, particularly against *Staphylococcus aureus* and *Escherichia coli*. Maheswari and Radhai [2012] investigated the antibacterial effect of lavender essential oil on bacteria commonly found in hospital textiles, suggesting its potential application for antimicrobial medical textiles. Again, Pomegranate peel extract**,** is rich in polyphenols and tannins, possesses antimicrobial properties. In Cinnamon bark extract which contain high content of cinnamaldehyde (an antimicrobial compound) showed strong antibacterial activity against *Staphylococcus aureus* and *Escherichia coli* [Sathianarayanan et al 2010]. Selvi and Thilagavathi [2011] investigated various herbal extracts, including cinnamon bark extract, applied to cotton fabrics for antibacterial purposes. The study confirms the strong antibacterial action of cinnamon bark, particularly against *Staphylococcus aureus*. The treatment not only enhanced the fabric’s resistance to bacteria but also provided a pleasant aroma. Salem and Abdel-Ghany [2014] evaluated the antibacterial effect of natural dyes extracted from cinnamon bark on wool fabrics where the results show significant bacterial inhibition, especially against *Escherichia coli* and *Staphylococcus aureus*. Ganesh et al [2012] and Agarwal and Rajani [2017] discussed the use of cinnamon bark for antimicrobial finishing of textiles where cinnamon to provide long-lasting antibacterial protection for treated fabrics. Research was also conducted on rosemary extract applied to fabrics for its antibacterial properties due to compounds like rosmarinic acid. Perumal K et al [2012] explores the antimicrobial properties of rosemary extract applied to cotton fabrics, where it was found that the effectiveness of rosemary against bacterial strains such as *Escherichia coli* and *Staphylococcus aureus*, demonstrating its potential for use in textile treatments. Sahouan et al [2019] incorporated rosemary essential oil into textile materials to observe its antimicrobial efficacy. The application of rosemary oil on textiles for providing antibacterial protection. Gülümser and Akalin [2021] focuses on the use of rosemary essential oil in textiles as a green alternative for antibacterial finishes. The study provides detailed insights into the antibacterial effects of rosemary on fabric. Agarwal and Rajani [2016] investigated the use of rosemary for antimicrobial finishing on cotton fabrics where it showed significant antibacterial activity against common pathogens such as *Escherichia coli* and *Staphylococcus aureus*. Moreno et al [2006] emphasized its active compounds like polyphenols and suggests that rosemary extracts can be used for antimicrobial treatments on textiles, especially in preventing bacterial contamination. Fabrics treated with rosemary extract demonstrated moderate antibacterial activity, primarily against *Staphylococcus aureus* and *Escherichia coli*. The extract's antimicrobial activity was attributed to its essential oil content. These findings show that plant extracts offer a sustainable and eco-friendly alternative to synthetic chemicals for antibacterial textile treatments. The goal of the present study is to create an antimicrobial finish on cotton fabric using natural leaf extracts treated with mordants and compare their antimicrobial properties with mordant-treated and mordant-untreated samples.

Material and Methods

The fabric samples were collected from Jutex, Real Creesset, 5/3 F/G. Middle Paikpara, Dhaka, Bangladesh. As an antibacterial agent, natural leaf extract of tulshi, jute, banana peel, and neem were made. The reagents utilized in this investigation were all of the reagent grade variety, acquired from Merck in India.

Table 1: Different samples and their abbreviations.

Serial No.	Samples	Abbreviation
1	Untreated sample	UT
2	Neem leaf extract + Alum	NA
3	Neem leaf extract +$CuSO_4.7H_2O$	NC
4	Neem leaf extract without mordant	NWM
5	Desi Jute leaf extract + Alum	DA
6	Desi Jute leaf extract +$CuSO_4.7H_2O$	DC
7	Desi Jute leaf extract without mordant	DWM
8	Tulshi leaf extract+ Alum	TA
9	Tulshi leaf extract+$CuSO_4.7H_2O$	TC
10	Tulshi leaf extract without mordant	TWM
11	Tossa Jute leaf extract + Alum	TOA
12	Tossa Jute leaf extract +$CuSO_4.7H_2O$	TOC
13	Tossa Jute leaf extract without mordant	TOWM
14	Banana peel extract+ Alum	BA
15	Banana peel extract+ $CuSO_4.7H_2O$	BC
16	Banana peel extract without mordant	BWM

Preparation of extracts:

The fully expanded fresh leaf or peel of different antimicrobial agents from the plants like Neem leaf, Desi Jute leaf, Tossa Jute leaf, Tulshi leaf and Banana peel were collected and washed with distilled water. These samples were kept in dark condition at room temperature for shadow drying. Shadow-dried samples were converted into fine powder by grinding. This fine powder was treated with methanol in the material-to-liquor ratio of 1:5. The mixture was shelved for seven days at room temperature in dark conditions to allow the active material to be dissolved in methanol. After seven days, active substances were achieved as a solution by filtration. This methanolic extract of samples was used as an antimicrobial agent to finish cotton fabric. Alum and $CuSO_4.7H_2O$ were added as a crosslinking agent to the prepared extracts.

Antimicrobial Finish

Extracted solutions were applied on cotton fabrics using the dip-dry-cure method. The cotton fabrics were immersed in different extracts at room temperature for 2h in the fabric-to-liquor ratio of 1:20. The conventional method for determining the fabric-to-liquor ratio in textile processing [Khare and Chauhan 2015, Saxena and Raja 2014]. The cotton fabrics were separately treated at same conditions with 2 different mordant of Alum and $CuSO_4.7H_2O$ as an across-linking agent. Then, the fabric samples were dried at 40°C for 30 minutes. Finally, the leaf-treated cotton fabrics were obtained.

Antimicrobial Activity Test

The Kirby-Bauer Test of antimicrobial activities against *B. cereus, S. aureus, E. coli, P. aeruginosa* cultures was performed by the agar diffusion plate method. The prepared petri plates were incubated at 37°C for 48h and then the plates were examined for bacterial growth. The presence of a clear zone between the agar and the inhibition zone across the specimen was measured. In a disk diffusion test, small circular samples of treated fabric are placed on an agar plate that has been pre-inoculated with a microbial culture. Once the treated fabric is placed on the agar, the active antimicrobial compounds slowly leach out from the fabric's surface into the surrounding agar. This release is gradual to ensure a sustained antimicrobial effect over time, as the agents diffuse through the agar. As the antimicrobial agents diffuse outward from the fabric disk, they create a "zone of inhibition", where microbial growth is either prevented or reduced. The size of this inhibition zone (measured in millimeters) is an indicator of the antimicrobial efficacy. Larger zones suggest a stronger or more effective release of active chemicals. Higher concentrations of antimicrobial agents on the fabric lead to stronger inhibition and a larger zone of microbial clearance. The solubility and molecular size of the antimicrobial compounds influence how quickly they diffuse from the fabric into the agar. The type of fabric and how the antimicrobial agent is bonded or coated onto it affect the release rate. Coated fabrics may release chemicals more quickly than impregnated or embedded fabrics, where agents are trapped deeper in the fibers. Factors like humidity, temperature and the composition of the agar (pH, nutrients) can also affect the release rate and efficacy of the antimicrobial compounds. Different microbes have varying levels of susceptibility to antimicrobial agents. A more susceptible microbe will show a larger inhibition zone, while resistant strains may only show minor or no inhibition.

Thermal Conductivity Analysis

Thermo-conductive analysis (TCA) was completed using a Perkin Elmer simultaneous thermal analyzer (STA 8000, Germany). The tests were conducted between 30-600°C under a nitrogen atmosphere. The heating rate and the airflow rate were 20°C /min and 200ml/min respectively.

Statistical Analysis

Statistical analysis of variance (ANOVA) was carried out using statistical package Minitab to determine variation between treatments. The Least Significant Difference (LSD) test was used for comparison of mean.

Results and Discussion

Natural agents and mordants like *neem leaf, banana peel, and copper sulfate ($CuSO_4 \cdot 7H_2O$) have gained popularity in fabric treatment for several reasons, particularly in eco-friendly and sustainable textile processing. These substances offer specific advantages in terms of antimicrobial properties, dye fixation, and environmental safety.

Antimicrobial Activity Measurement

Neem is well-known for its natural antibacterial, antifungal, and antiviral properties due to compounds like azadirachtin, nimbolide, and nimbin. When used in fabric treatment, neem leaves can inhibit the growth of harmful microorganisms, making textiles more hygienic. Neem-treated fabrics can repel insects, which is beneficial for outdoor clothing or fabric used in areas with high insect activity. Being a natural product, neem leaves are non-toxic and biodegradable, making them ideal for sustainable textile processing. In the present experiment, Neem leaf extract treated sample showed 1.5mm (Alum mordanted) and 1.2 mm ($CuSO_4.7H_2O$ mordanted) whereas Banana peel extract treated sample showed 2.0 mm (Alum mordanted) zone of inhibition (ZOI) against *E. coli*, respectively. *S. aureus* was susceptible to banana peel extract showing 1.3 ZOI $CuSO_4.7H_2O$ mordanted sample. Researchers have applied pomegranate peel extract to fabrics to assess its antibacterial potential and found that fabrics treated with pomegranate peel extract exhibited antibacterial activity against both *Staphylococcus aureus* and *Escherichia coli*. The tannins in the peel contributed to this antimicrobial effect [Kumbhar et al 2012]. Sivakumar and Dhanalakshmi [2014] incorporated Neem extract into fabrics to inhibit the growth of *Escherichia coli* and *Staphylococcus aureus* and found that the fabrics exhibited significant antibacterial activity against both Gram-positive and Gram-negative bacteria. Neem's bioactive compounds, like nimbidin and azadirachtin, were responsible for this activity. Whereas Aloe Vera extract treated fabrics showed an antibacterial effect against *Pseudomonas aeruginosa* and *Staphylococcus aureus*. The active components in aloe vera, including anthraquinones and saponins, contributed to the antimicrobial properties (Mahmood et al 2010, Sathianarayanan et al 2010). In the present study, tulshi leaf extract treated with *E. coli* and *S. aureus* were found susceptible against $CuSO_4.7H_2O$ mordanted samples showing 1.6 and 1.0 ZOI, respectively. The Tulsi leaves extracts are rich in essential oils and phenolic compounds that have been applied to cotton fabrics which makes them suitable for antibacterial applications. Fabrics treated with tulsi extract demonstrated good resistance to bacterial growth, particularly against *Escherichia coli*. Eugenol and other bioactive molecules were responsible for these antibacterial effects (Sathianarayanan et al 2010, Ganesan and Rajendran 2017). Again, Deshi jute leaf extract treated $CuSO_4.7H_2O$ mordanted samples showing 1.8 ZOI (Fig. 1). These zones were attributed to the gradual release of active chemicals from the fabric's surface. Zone of inhibition testing is especially well suited for determining (albeit qualitatively) the ability of water-soluble antimicrobials to inhibit the growth of microorganisms. Several samples can be screened for antimicrobial properties quickly using this test method. Liquid coated antimicrobial surfaces, and antimicrobial-impregnated solid products can all be tested for their ability to produce a zone of inhibition. Tea tree oil is a well-known antimicrobial agent due to its terpinen-4-ol content. Studies have explored its use in treating fabrics to provide antibacterial protection where it was found that cotton fabrics treated with tea tree oil demonstrated good antibacterial activity, especially against *Escherichia coli*. The oil's effectiveness in reducing microbial load made it a viable option for antibacterial textiles [Gutiérrez et al 2009]. Selection of the right fabric-to-liquor ratio and treatment method depends on the fabric type, the desired result, and environmental factors like water and energy consumption where lower liquor ratios are increasingly popular due to their eco-friendly benefits. In textile processing, fabric-to-liquor ratio refers to the amount of fabric in relation to the amount of liquid (water or chemicals) used during treatments such as dyeing, bleaching, or finishing. The fabric-to-liquor ratio plays a significant role in determining the efficiency and outcome of these processes. The ratio can be expressed as: High

Liquor Ratio where more liquid compared to the fabric weight, such as 1:20 or 1:30 (1 part fabric to 20 or 30 parts water). This is common in traditional dyeing methods where a lot of water is needed for uniform dyeing and easier control of temperature and chemicals. The second one is Low Liquor Ratio where less liquid compared to fabric weight, like 1:5 or 1:6. This is used in modern methods where water conservation and chemical efficiency are priorities. The choice of ratio impacts is that Water consumption (Lower ratios use less water), Energy use (Higher ratios require more energy for heating the extra water) and Chemical concentration (Lower ratios increase the concentration of chemicals, affecting how they interact with the fabric) [Saxena et al 2014]. Kandasamy and Arumugam [2018] treated cotton fabrics with turmeric extract which showed effective antibacterial activity against *Staphylococcus aureus* and *Klebsiella pneumoniae*. On the other hand, Eucalyptus leaves extract which contain compounds like eucalyptol that have demonstrated strong antimicrobial properties. Researchers have applied eucalyptus extracts to fabrics to inhibit bacterial growth. It has been found that Eucalyptus-treated fabrics showed significant antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*. The antibacterial effect was attributed to the high concentration of phenolic compounds [Ali et al 2017]. The “zone of inhibition” is a visible representation of the antimicrobial activity at work, showing the balance between agent diffusion, microbial susceptibility and chemical interaction with the environment. The size and clarity of the zone depend on a variety of factors, including the nature of the antimicrobial agent, its diffusion rate, the microbe's susceptibility, and environmental conditions. This zone is a critical measure of the effectiveness of an antimicrobial treatment, providing insights into how well the agent can control microbial growth. The “zone of inhibition” observed in antimicrobial testing, reflects the area around an antimicrobial agent where microbial growth is prevented or slowed. This phenomenon results from the interaction between the antimicrobial agent, the microbial cells and the diffusion medium (typically agar). Once the antimicrobial agent reaches the microbial cells in the agar, it disrupts vital cellular processes, preventing their growth. The nature of this interaction depends on whether the antimicrobial is bacteriostatic (inhibiting growth) or bactericidal (killing the microbes). Antimicrobial agents interfere with bacterial cell wall formation by inhibiting the synthesis of peptidoglycan. Without a functional cell wall, bacteria cannot maintain structural integrity, leading to cell lysis and death. The diffusion of these agents through the agar creates an area around the disk where bacterial cell division and growth are halted. Antimicrobials also target bacterial ribosomes, preventing them from synthesizing essential proteins. Protein synthesis inhibition cripples the bacteria's ability to grow and divide, leading to a growth-free zone in the agar. It also disrupts DNA replication and transcription, thus inhibit nucleic acid synthesis which prevents cell division and induces bacterial death, forming a zone of inhibition around the disk. Again, it targets the bacterial cell membrane, causing leakage of intracellular contents and cell death. Since cell membrane disruption leads to rapid bacterial death, these agents typically produce large inhibition zones if they diffuse effectively. Some antimicrobials interfere with essential metabolic pathways (e.g., folic acid synthesis) where without access to necessary nutrients or cofactors, the bacteria stop growing and die in the affected zone.

<table>
<tr><th>Sample</th><th>Organism</th><th>Mordant</th><th>Pictorial illustration</th><th>Zone of inhibition (mm)</th></tr>
<tr><td rowspan="2">Neem leaf extract treated</td><td rowspan="2">E. coli</td><td>Alam</td><td rowspan="2">
</td><td>1.5</td></tr>
<tr><td>$CuSO_4.7H_2O$</td><td>1.2</td></tr>
<tr><td rowspan="2">Banana peel extract treated</td><td>E. coli</td><td>Alam</td><td>
</td><td>2.0</td></tr>
<tr><td>S. aureus</td><td>$CuSO_4.7H_2O$</td><td>
</td><td>1.3</td></tr>
</table>

Tulshi leaf extract treated	***E. coli***	**$CuSO_4.7H_2O$**		**1.6**
	S. aureus	**$CuSO_4.7H_2O$**		**1.0**
Deshi jute leaf extract treated	***E. coli***	**$CuSO_4.7H_2O$**		**1.8**

(b)

Figure 1: Antimicrobial activity of different sample of jute-cotton union fabrics.

Thermal Conductivity Analysis

In Figure 2, illustrated the changes of thermal conductivity of treated samples. In thermal conductivity (TC), the K-value measures a product's thermal conductivity in units of W/m/K and generally good insulation will have as low a K-value as possible to reduce heat loss. Usually, traditional textiles typically have a low thermal conductivity but on fiber surfaces, there is a viable approach to enhance thermal conductivity [Hooda et al 2013]. However, the TC curve of both untreated and treated fabric shows endothermic peak. The width value of all the treated samples were in the range of 1.0-1.26, where the width of extracts shows loosely bound than untreated fabric which clearly indicate that the antimicrobial active agent has been attached to the fabrics properly. In the thermal conductivity values, ANOVA analysis is done to see the significant differences across the different treatments. The one-way ANOVA test resulted in F value is 2.48 and P-value is 0.136. Since the p-value is greater than 0.05, there is no statistically significant difference in the thermal conductivity values between the different treatment groups at the 95% confidence level. This means that, based on this data, the type of treatment ($CuSO_4.7H_2O$, Alum, Without Mordant, Untreated) does not significantly affect the thermal conductivity of the samples

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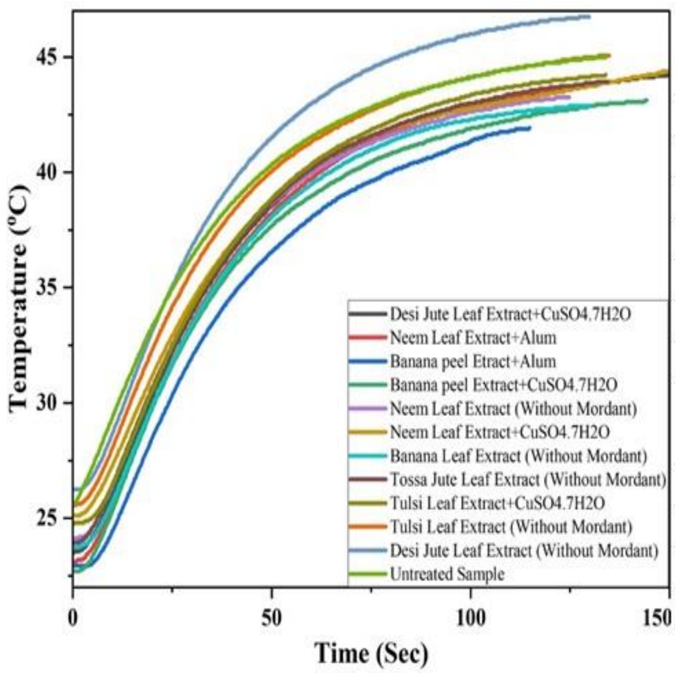
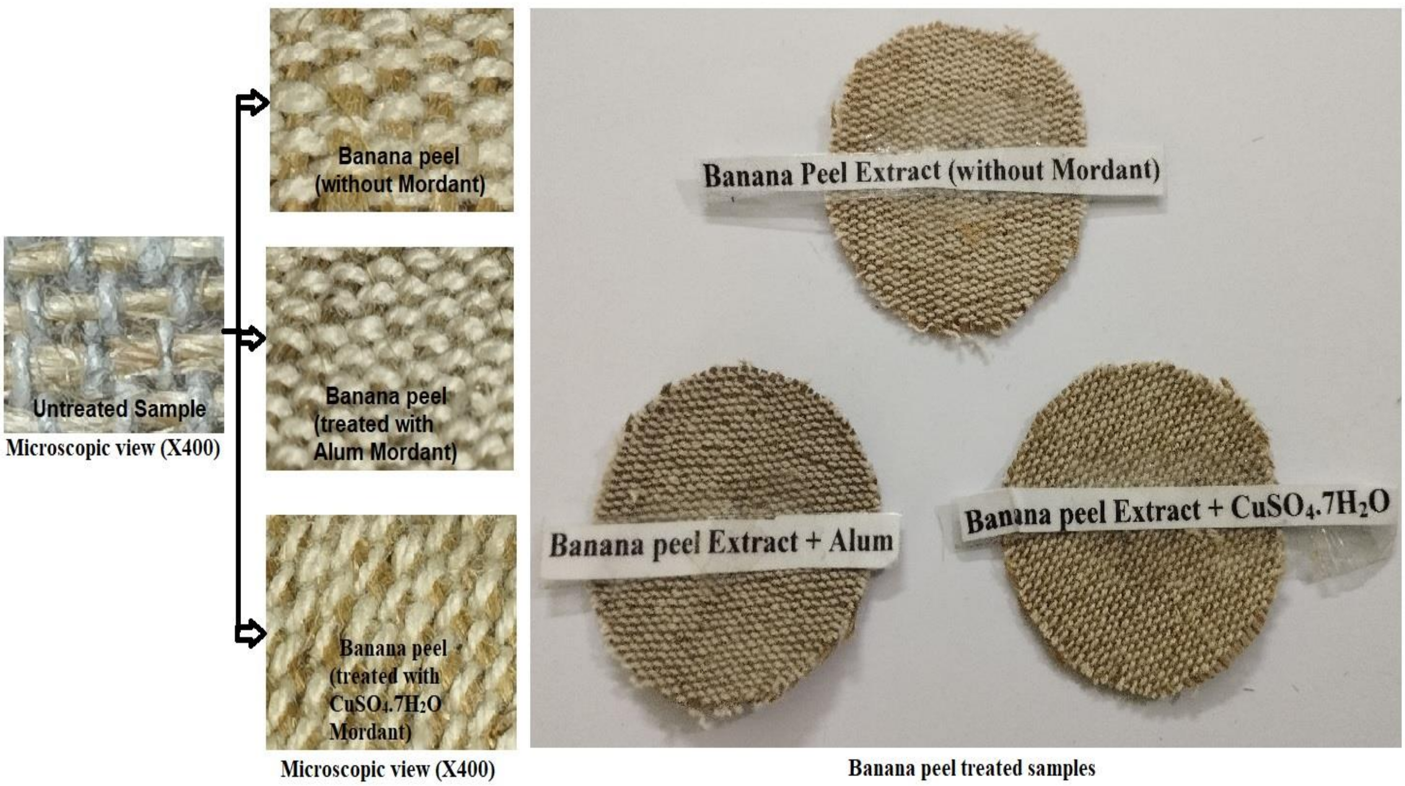


Sample Name	Width	Thermal conductivity (W/m/K)
Desi jute leaf extract+ $CuSO_4.7H_2O$	1.26	0.1104043
Neem leaf extract+ Alum	1.23	0.1227993
Banana Peel extract+ Alum	1.18	0.1586788
Banana Peel extract + $CuSO_4.7H_2O$	1.20	0.1433810
Neem leaf extract (without mordant)	1.20	0.1432740
Neem leaf extract + $CuSO_4.7H_2O$	1.21	0.1318131
Banana Peel extract (without mordant)	1.19	0.1919812
Tossa jute leaf extract (without mordant)	1.22	0.1399620
Tulshi leaf extract+ $CuSO_4.7H_2O$	1.21	0.1341540
Tulshi leaf extract (without mordant)	1.18	0.1434154
Desi jute leaf extract (without mordant)	1.21	0.1234580
Untreated Sample	1.00	0.0987025

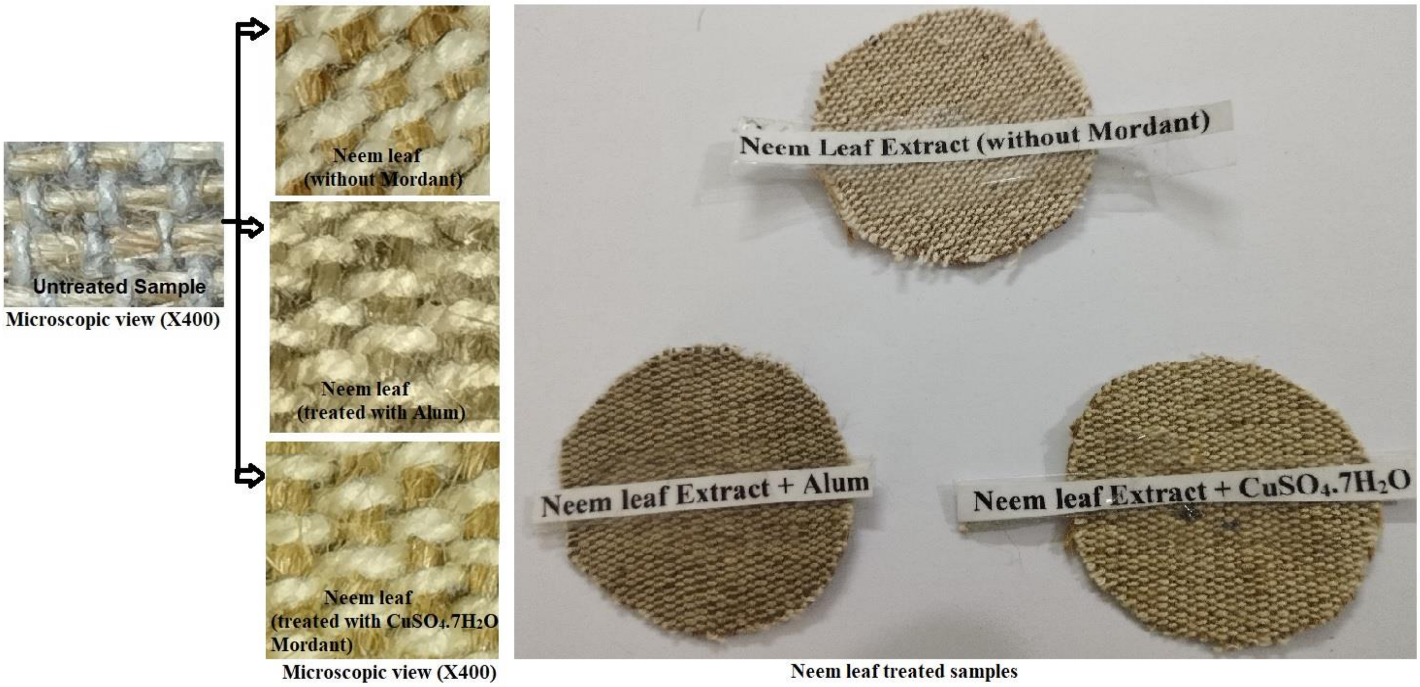
Figure 2: Thermal conductivity of treated and untreated samples

Surface Morphology of the Treated Samples

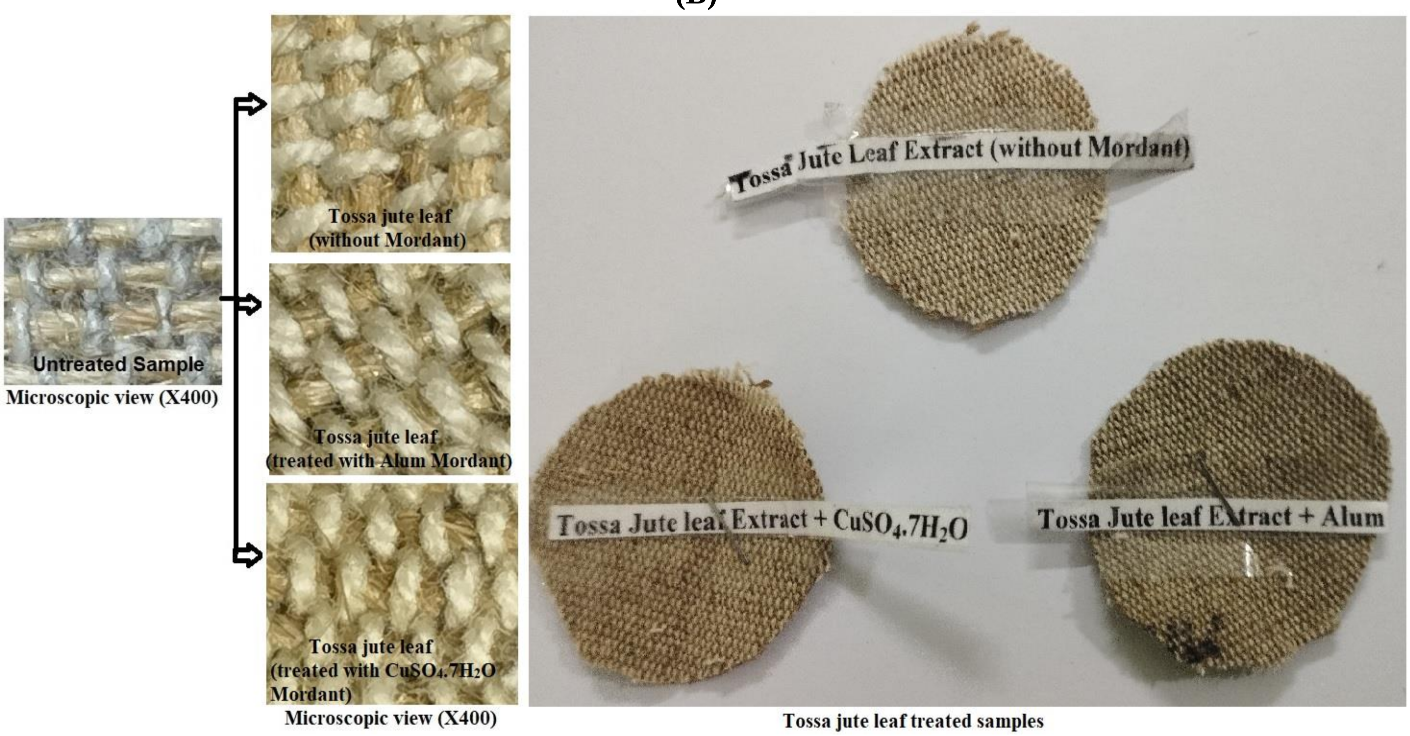
Figure 3A shows Banana peel maximum pore size and poor smooth structure. In fig. 3B, Neem leaf extract produces many small spherical shapes with a uniform size distribution on the cotton surface which in turn confirms the attachment of neem leaf extract on finished cotton fabric which was similar of Islam et al (2020) findings. In fig. 3C, D & E; tossa jute leaf, desi jute leaf and tulshi leaf extracts, respectively, do not have any significant changes. On the other hand, Banana Peel contains tannins, which can act as a natural mordant. Tannins are a class of compounds that help bind dye to fabric fibers, improving dye uptake and color fastness without the need for synthetic chemicals. It also contains antioxidants like dopamine, which contribute to their potential as natural preservatives for textiles and are an abundant agricultural waste product, making them a highly sustainable and renewable resource for fabric treatment. Utilizing banana peels reduces waste and offers an inexpensive alternative to synthetic mordants. The reason of use of Copper Sulfate ($CuSO_4 \cdot 7H_2O$) as mordanting agent because it improves the adhesion of dye molecules to fabric fibers, particularly in protein-based fabrics like wool and silk, and helps produce more vivid and long-lasting colors. Moreover, Copper has inherent antimicrobial properties, and copper-treated fabrics are effective in reducing microbial growth. This makes copper sulfate an excellent choice for medical textiles and hygiene applications. It can also alter the color produced by natural dyes, giving a greenish or blue tint, depending on the dye source and fabric. Copper sulfate is widely available and cost-effective, making it a practical choice for mordanting in both large-scale and artisanal dyeing. Thus, natural agents like neem leaves, banana peels, and copper sulfate are chosen over synthetic chemicals in fabric treatments for their sustainability, biodegradability, cost-effectiveness, and functional properties that improve fabric quality and durability while reducing environmental and health impacts.



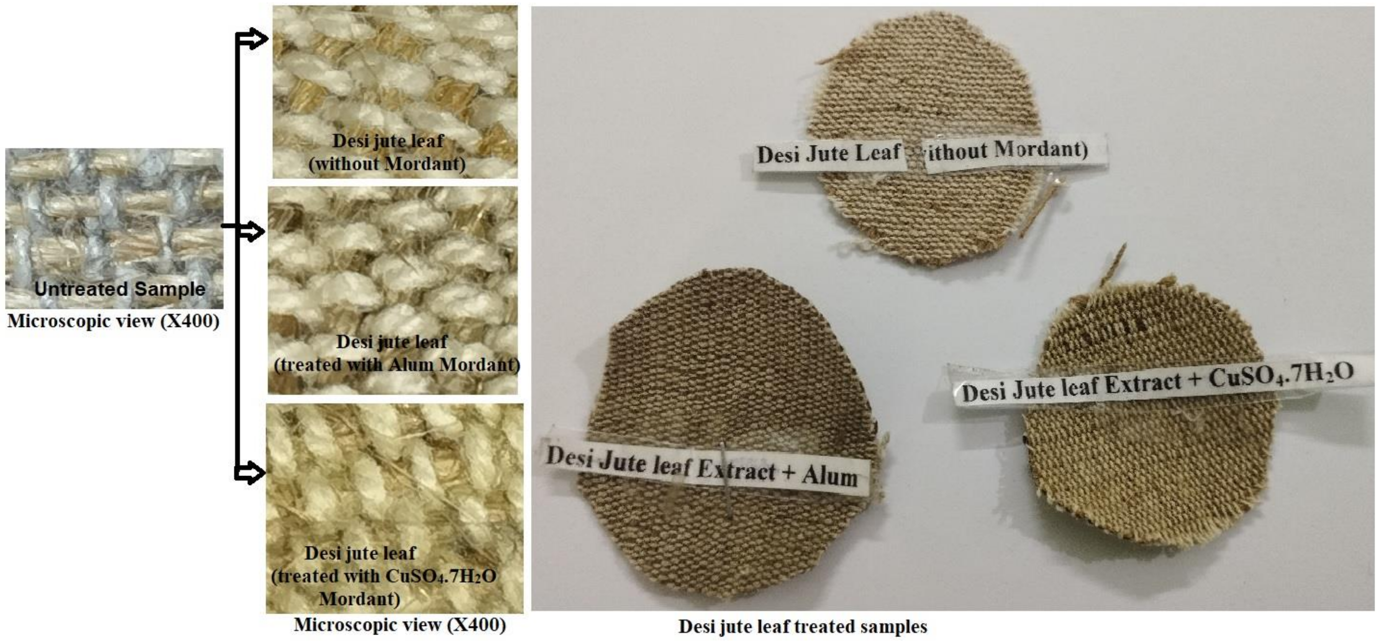
(A)


Untreated Sample
Microscopic view (X400)
Neem leaf
(without Mordant)
Neem leaf
(treated with Alum)
Neem leaf
(treated with CuSO4.7H2O
Mordant)
Microscopic view (X400)
Neem Leaf Extract (without Mordant)
Neem leaf Extract + Alum
Neem leaf Extract + CuSO4.7H2O
Neem leaf treated samples

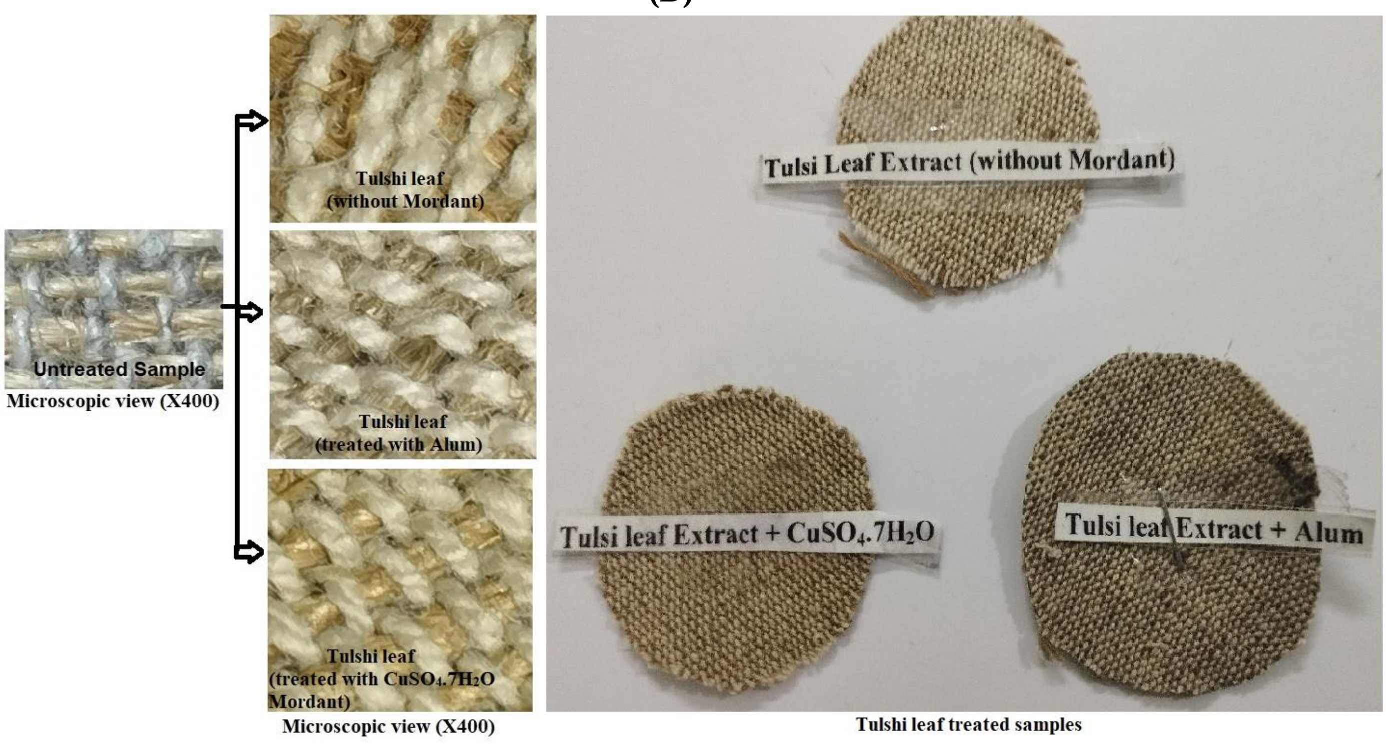
(B)


Untreated Sample
Microscopic view (X400)
Tossa jute leaf
(without Mordant)
Tossa jute leaf
(treated with Alum Mordant)
Tossa jute leaf
(treated with CuSO4.7H2O
Mordant)
Microscopic view (X400)
Tossa Jute Leaf Extract (without Mordant)
Tossa Jute leaf Extract + CuSO4.7H2O
Tossa Jute leaf Extract + Alum
Tossa jute leaf treated samples

(C)



(D)



(E)

Figure 3: Surface morphology of treated and untreated samples: (A) Banana peel, (B) Neem leaf, (C) Tossa jute leaf, (D) Desi jute leaf and (E) Tulshi leaf.

Fabrics can be treated with antimicrobial agents (e.g., neem extract, copper sulfate) during or after production. These chemicals are either bound to the fabric or entrapped in microcapsules or other slow-release systems within the fibers. The phrase "gradual release of active chemicals from the fabric's surface" refers to the controlled and sustained release of antimicrobial agents embedded in or coated on the fabric, which then diffuse into the surrounding environment, inhibiting microbial growth. This concept plays a crucial role in the disk diffusion test (also known as the Kirby-Bauer test), a common method for evaluating antimicrobial efficacy. The gradual release mechanism ensures that the fabric continues to inhibit microbial growth over time, rather than delivering all the antimicrobial agents at once. By releasing the active compounds slowly, the risk of microbes developing resistance to the antimicrobial agent may be reduced, as there is sustained pressure on the microbial population. Fabrics with gradual-release treatments maintain their antimicrobial properties even after multiple washes or extended use. Moreover, the gradual release of active chemicals from a treated fabric is crucial in sustained antimicrobial activity. In the disk diffusion test, this release creates a "zone of inhibition" around the fabric, with the size and effectiveness of the zone dependent on factors like concentration, chemical properties, fabric interaction, and microbial susceptibility.

While antimicrobial textiles offer significant advantages in combating microbial growth, especially in healthcare, hygiene, and high-performance applications, they face limitations related to durability, potential resistance, toxicity, cost, inconsistent efficacy, and regulatory challenges. Addressing these limitations through further research, technological innovation, and stricter regulations is crucial to fully realize the potential of antimicrobial textiles while minimizing their risks to human health and the environment. Antimicrobial textiles are fabrics treated with agents that inhibit or kill microorganisms such as bacteria, fungi, and viruses. While they offer significant benefits, particularly in healthcare, sportswear, and hygiene applications, there are several limitations and challenges associated with their use. A critical evaluation of these limitations is necessary for understanding their full potential and areas for improvement. The antimicrobial properties of textiles often diminish after repeated washing and regular use. Many antimicrobial agents are surface-applied or embedded superficially, making them susceptible to wear or leaching out during washing cycles. For instance, silver nanoparticles, one of the most used antimicrobial agents, can be washed away over time, reducing their effectiveness. Exposure to high temperatures (e.g., during ironing or tumble drying) and harsh chemicals (e.g., bleach, detergents) can degrade the antimicrobial agents or alter their activity, further reducing their durability. Some antimicrobial textiles work via the slow release of active agents (e.g., silver ions, copper, zinc). Over time, these active substances get depleted, leading to a decline in antimicrobial efficacy. While antimicrobial textiles may provide short-term protection, their long-term effectiveness remains a concern. Developing technologies that ensure sustained activity over extended periods of use and multiple washes is essential for maximizing their benefits. Just like antibiotics, antimicrobial agents in textiles may lead to the development of resistant microbial strains. Prolonged exposure to sub-lethal concentrations of antimicrobials can enable microorganisms to adapt and develop resistance mechanisms, such as efflux pumps, enzyme production, or mutation in target sites. Continuous low-dose exposure to antimicrobial textiles creates selective pressure for resistant microbes, like what is seen with overuse of antibiotics. This poses a risk not only to the effectiveness of the textile but also to public health, as resistant strains may spread. The risk of promoting antimicrobial resistance in the environment or on human skin is a significant concern. Continuous research is required to monitor the resistance patterns associated with antimicrobial textiles and to develop strategies that mitigate resistance development, such as rotating different antimicrobial agents or using combination therapies. When antimicrobial textiles are washed, active agents such as silver ions or triclosan can leach into wastewater and potentially harm aquatic ecosystems.

Nanoparticles are known to bioaccumulate in organisms, disrupting food chains and negatively impacting biodiversity. Additionally, triclosan is a well-documented environmental pollutant linked to the development of resistant bacteria in natural environments. The potential toxicity and environmental risks of antimicrobial textiles pose significant challenges. There is a need for stricter regulations and the development of eco-friendly and non-toxic antimicrobial agents. Moreover, environmental testing should be mandatory before releasing antimicrobial products into the market. The incorporation of antimicrobial agents, especially advanced technologies like silver or copper nanoparticles, can significantly increase the cost of producing antimicrobial textiles. This makes them less accessible for mass-market applications, particularly in low-income regions where they could offer significant public health benefits. In some cases, the increased cost of antimicrobial textiles may not justify the benefit, especially if their antimicrobial activity depletes quickly or if they are only marginally more effective than regular fabrics. The economic burden of regularly replacing these textiles can be a concern for institutions like hospitals or care facilities. While antimicrobial textiles have clear benefits, their high costs limit their widespread adoption. Research into more cost-effective production methods or alternative antimicrobial agents is necessary to make these textiles more accessible.

Conclusion

In this study, the research has developed fabrics materials with antimicrobial barrier properties. Antimicrobial finishes were applied to fabrics to prevent the growth of microorganisms exposed to the fabrics. The antimicrobial finish inhibited the growth of microorganisms exposed to the fabrics. Results showed that the effectiveness of the antimicrobial finish was not influenced by addition of the Alum and $CuSO_4.7H_2O$. From the results, it can be concluded that neem leaf extract shows better antimicrobial characteristics, and the findings of this study suggested that neem leaf extract-treated finished fabric possessed high antimicrobial activity. These antimicrobial finished fabrics can be used for the preparation of various health and hygiene products like gloves, medical textiles and even storage of things which are vulnerable to bacterial attack. Many antimicrobial textiles are effective against specific types of microorganisms (e.g., bacteria), but their effectiveness against other microbes like fungi, viruses, or multidrug-resistant bacteria is often limited. For example, certain agents like silver nanoparticles may be highly effective against bacteria but less so against fungi or viruses. There is a need for broader-spectrum antimicrobial agents that are effective against a wide range of pathogens, including viruses and fungi. Additionally, real-world testing should be prioritized to evaluate the performance of antimicrobial textiles in diverse and high-risk environments. Not all antimicrobial agents can be effectively applied to all types of textiles. The method of application (e.g., coating, embedding) and the type of fabric (e.g., natural vs. synthetic) can affect how well the antimicrobial agent adheres and performs. For instance, certain agents may bind poorly to cotton or lose effectiveness when applied to synthetic fibers. Some antimicrobial treatments may affect the texture, breathability, or comfort of the fabric. For example, coatings of metal nanoparticles may make fabrics stiffer or less breathable, which could reduce user comfort in applications like clothing or bedding. The limited compatibility of antimicrobial agents with certain fabrics restricts their broader adoption. Further research into integrating antimicrobial agents seamlessly into a variety of textile types without compromising fabric properties is required where the study of FTIR and SEM analysis is needed to confirm the attachment of extract as an active antimicrobial agent.

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