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Development of Chitosan-Based Antimicrobial and Fluid-Repellent Cotton Fabric for Eco-Friendly Surgical Gowns

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ABSTRACT Bacteria and other hazardous substances are produced onto the surgical gowns during various surgical operations. These undesirable substances cause problems for the medical staff and the patients as well. To avoid the production of bacteria, and to avoid the absorption of liquid contaminations, the surgical gown fabric is given both an antibacterial and fluid repellent treatment. Pure cotton fabric is used due to its properties of high absorbency, high tensile strength, comfortability, and durability. Three finishes are applied by pad dry-cure method in different concentrations onto the pure cotton fabric, including antibacterial RUCO-BAC (MED), fluid repellent RUCO-GUARD AFR, and Chitosan, to achieve antibacterial, fluid repellent, high strength, comfortable and durable effects. In this investigation, one untreated control sample and fifteen treated samples, three replicates for each finish combination, were examined. The following standardized test procedures were used to evaluate the treated cotton fabric: AATCC 147 (qualitative zone of inhibition test) for antibacterial activity, ISO 22958:2005 (water resistance to penetration through impact) for fluid repellency, ASTM D737-96 for air permeability, ISO 13934-2 (constant rate of extension method) for tensile strength, and the cup method for moisture vapor transmission rate (MVTR) to determine breathability. Chitosan-treated samples exhibited improved breathability and moisture management due to their hydrophilic nature, whereas repellent-treated samples showed reduced vapor transmission, where the OMMC value was '0' because of pore blockage within the fabric structure. Air permeability and tensile strength tests demonstrated that the applied finishes maintained acceptable comfort and mechanical properties of the cotton fabric. Among all formulations, the chitosan (2 g/L) and RUCO-GUARD AFR (30 g/L) combination showed the best performance across all evaluated parameters, with acceptable antibacterial activity, sufficient fluid repellency, adequate air permeability, and maintained tensile strength. Hence, Chitosan and RUCO-GUARD AFR (repellent) treated cotton fabric exhibited superior antimicrobial activity along with sufficient repellency, better tensile

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strength, air permeability, and MVTR as compared to the fabric treated with RUCO-BACMED (antibacterial) in combination with RUCO-GUARD AFR (repellent). Basically, chitosan is a natural eco-friendly substance and does not cause any degradation in the environment while the other finishes were fluorine based, which is carcinogenic and toxic in nature, causing various harmful diseases. So, chitosan is the preferred material to utilize in the manufacturing of surgical gowns. The developed fabric can be effectively utilized in eco-friendly surgical gowns to provide protection, hygiene, and comfort for healthcare professionals.

INDEX TERMS antibacterial, chitosan, cotton, fluid repellent, RUCO-BAC MED, RUCO-GUARD AFR, surgical gown

I. INTRODUCTION

Medical textiles are some of the most swiftly expanding sectors in the global technical textiles [1]. Medical textiles are basically products based on fibres used for first aid purposes and other clinical treatments. The use of disposable surgical gowns is a common practice in veterinary hospitals. Medical textiles, including surgical gowns, both protect the patient from bacterial contamination by the surgeon and protect the surgeon from exposure to a possibly contaminated patient. Surgical gowns function as personal protection equipment for perioperative staff members, and shield patients from pathogens [2].

According to the World Health Organization (WHO), hundreds of millions of patients worldwide are affected annually by HAIs, making infection prevention a major healthcare priority. Consequently, significant research efforts have focused on developing multifunctional surgical gown fabrics with enhanced antimicrobial and fluid-repellent properties while preserving comfort characteristics such as air permeability and moisture vapor transmission. Natural biopolymers such as chitosan have attracted considerable attention owing to their biodegradability, biocompatibility, non-toxicity, and inherent antimicrobial activity, making them promising alternatives to conventional synthetic antimicrobial finishes used in medical textiles [3, 4].

When we talk about medical textiles, the first thought that comes to our mind is protection and comfort. The major purpose of medical textiles is to provide protection to human beings against different kinds of microbes of various harmful contaminations as well as providing ecofriendly gadgets for achieving a hazards free environment [3, 5].

Some important features of medical textiles include them being non-toxic, non-allergenic, non-carcinogenic, bio compatible, and able to sterilize. Surgical gowns are assumed to be one of the most domineering protective wears used during various surgical operations [6].

The currently used surgical gowns have some drawbacks, for instance having high PES percentage and low cotton percentage provides high blood and water repellency but poor comfort properties i.e. air and heat exchangeability. Therefore, the best option is to use cotton, as cotton is the soft, staple, fluffy vegetable based natural fiber which comes out from the fruit of cotton plant [7]. A large number of cotton fibers are being used in different areas, like household, apparels, furnishings, nonwovens as well as in personal care, due to its different structural properties [8].

Keeping in view that surgical gowns are the major component of medical textiles, their properties are continuously enhanced by applying various antimicrobial and fluid repellent agents, or giving a special mechanical action to their fabric [9]. Chitin are the polysaccharides which are abundantly found in nature [10], having linear chains of acetyl glucosamine linkages in their structure. Chitosan is derived from the partial de-acetylation of chitin in which acetyl groups from the molecules of chitin are removed, resulting in the formation of chitosan along with a reactive amino group [11].

The main purpose of this project is to enhance the comfort and antimicrobial properties of surgical gowns to facilitate the medical staff. Basic concerns will be on antimicrobial property, fluid repellence, breathability, wash resistance, higher tensile strength as well as non-toxicity. Antimicrobial finish like chitosan, along with fluorocarbon finishes are applied onto 100% cotton fabric for achieving the desired characteristics.

II. MATERIALS AND METHODS

A. MATERIALS

The bleached fabric used was 100% cotton plain woven fabric with 150 g/m^2 specific weight, 120 ends/inch and 100 picks/inch, kindly donated by Nishat mills. RUCO-GUARD AFR (water repellent finish) and RUCO-BAC MED (Antibacterial finish) was purchased from RUDOLF CHEMIE. Chitosan was purchased from Sigma Aldrich (St. Louis, MO, USA). Acetic acid was obtained from Zodiac International B.V., based in Mijdrecht, Netherlands, and Carboxylic acid from RUDOLF CHEMIE POLAND. All solutions were made in distilled water, with

electrical conductivity below 3 mS/cm. After that, cotton fabrics were cut into specific dimensions and padded twice in a finishing bath by keeping 75% pickup. The finishing bath was prepared according to the prescribed methods in table 1.

B. PAD DRY-CURE METHOD

Pad Dry-cure method was used for the application of Chitosan, RUCO-BAC MED (Antibacterial) and RUCO-GUARD AFR (Fluid repellent) onto the cotton fabric. For this process, firstly the solution for each finish was made in the required concentrations and conditions as shown in Table 1. Distilled water was used in the formation of finishing solution, acetic acid was used as buffer to maintain solution pH. The prepared finishing solution was then poured into a trough, also termed as a padder. The fabric was then dipped into the trough for the optimum absorption of the treating chemicals. It was then passed through the padding mangle where the excessive liquor was squeezed by the application of pressure by the squeezing rollers. The drying of the treated samples was carried out at 110°C for about 3-5 minutes. After the drying process, the curing was performed at the high temperature of 150-160°C for about 1-2 minutes. At the end, washing was done for the removal of unfixed fishing material or other undesirable contents.

C. CONTROL SAMPLE

A control sample is an untreated specimen that goes through the same mechanical processing (curing, drying, and padding) as the treated samples, but no finishing chemicals are added. To assess how the applied finishes affect the fabric's characteristics, the control sample was used as a baseline.

TABLE I

DESIGN OF EXPERIMENT

Sr#	RUCO-BAC MED (g/l)	RUCO-GUARD AFR(g/l)	Chitosan (g/l)	pH	Curing Temperature (°C)
A1	35	-	-	5-6	170 °C
A2	45	-	-	5-6	170 °C
A3	55	-	-	5-6	170 °C

Sr#	RUCO-BAC MED (g/l)	RUCO-GUARD AFR(g/l)	Chitosan (g/l)	pH	Curing Temperature (°C)
B1	-	20	-	2-5	160 °C
B2	-	30	-	2-5	160 °C
B3	-	40	-	2-5	160 °C
C1	-	-	1	2	150 °C
C2		-	2	2	150 °C
C3	-	-	3	2	150 °C
D1	35	20	-	2-6	160- 170 °C
D2	45	30	-	2-6	160- 170 °C
D3	55	40	-	2-6	160- 170 °C
E1	-	20	1	2-5	150- 160 °C
E2	-	30	2	2-5	150- 160 °C
E3		40	3	2-5	150- 160 °C

D. TESTING METHODS

1) DETERMINATION OF ANTIBACTERIAL ACTIVITY

AATCC 147 test technique is the qualitative test that was used to measure the antimicrobial activity of the treated fabric samples. The effectiveness of the antimicrobial treatment was evaluated by comparing the reduced bacterial concentration of the treated sample with that of the control sample as a percentage drop in the standard time [12]. Antibacterial activity was carried out through AATCC 147 testing method to find out the zone of inhibition [13].

2) DETERMINATION OF MVTR

The amount of water vapors that moves through a fabric specimen during a predetermined amount of time under regulated temperature and relative humidity conditions is measured by the moisture vapor transmission rate (MVTR). This test evaluates a textiles' breathability, a crucial factor in determining how comfortable protective gear like surgical gowns is. Water vapors diffuse through the fabric from a place of higher vapor pressure (inside the test cup) to a region of lower vapor pressure (the controlled atmosphere outside), according to the method's underlying theory. The test assembly's weight loss over time is used to calculate the rate of vapor transmission. To test the water vapours, permeability cup method was used, individually based on a perspicuous principle [14]. This test aims to determine the consistent water vapor transfer values across permeable and semi-permeable materials, stated in the appropriate units mentioned in the equation (1).

$$WVT=G/tA= (G/t) A \quad (1)$$

3) DETERMINATION OF FLUID REPELLENCE

The water resistance of the textile fabrics was checked using the ISO 22958:2005 test method, which tested the textiles' resistance to water penetration through impact, and was thus used to determine the textile fabrics' practical water penetration resistance. This test determined the textile fabrics' potential water penetration resistance by measuring it through impact.

4) DETERMINATION OF AIR PERMEABILITY

The air permeability of the treated cotton fabric was checked by ASTM D737-96 test method.

5) DETERMINATION OF TENSILE STRENGTH OF FABRIC

The potential strength of the woven fabric inside a product in resistance to tension was described by the ISO 13934-2 test technique, which was used to determine the breaking force and elongation of the textiles. It described the woven fabric's potential strength to withstand stress inside a product. The treated fabric was precisely cut into 200 x 100 mm specimens. Test samples were subjected to a constant rate of extension while mounted along the long dimension of a tensile tester. At the moment of rupture or breakdown, the loading force was measured as tensile strength.

III. RESULTS

It is crucial to quickly describe the rationale behind the choice of the particular finishing agent concentrations utilized in this investigation before providing the experimental findings. In order to find the best balance between protective performance and comfort characteristics, the dosage levels were established based on initial screening trials and manufacturer recommendations.

A. ANTIMICROBIAL ACTIVITY

Figure 1 shows the different treated samples along with one untreated sample placed in the petri dish in which *Escherichia Coli* bacterias have been immersed. The sample U represents the untreated sample of cotton fabric on which no finish is applied, since no zone of inhabitation was found around the untreated sample. On the samples A1, A2, and A3, antibacterial finish RUCO-BAC MED was applied, which showed excellent resistance towards the bacteria and created a clear zone of inhibition, as the concentration of antibacterial finishes increased from A1 to A3. The zone of inhibition was accessed to find out the antibacterial activity of treated cotton samples. Samples C1, C2, and C3 had an antibacterial treatment by applying chitosan finish, which demonstrated a strong resistance to microorganisms [3]. Compared to high molecular weight samples, low molecular weight chitosan exhibited greater antibacterial activity [15]. Chitosan has an extensive inhibition spectrum for Gram-positive and Gram-negative bacteria. A positive charge on the glucosamine monomer's NH3 + group at a pH of less than 6.3 permits interactions with negatively charged microbial cell membranes, which results in the escape of intracellular components, which is how chitosan's antimicrobial activity works [16]. On samples D1, D2, and D3, two finishes were applied separately, firstly the antibacterial finish (RUCO-BAC MED) and then the fluid repellent finish (RUCO-GUARD AFR) was applied. The samples D1 and D2 show a slight zone of inhibition due to the less concentration of the antibacterial finish as compared to D3 along-with the application of repellent finish.

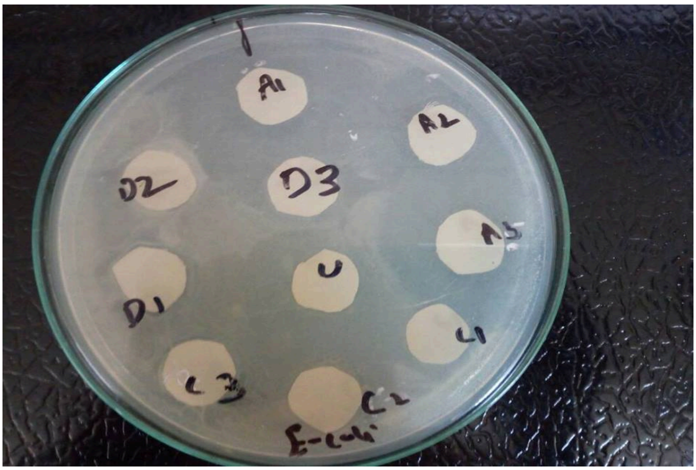

FIGURE 1. Antibacterial activity of samples against *Escherichia coli* treated with (RUCO-BAC MED), chitosan and combined finish (RUCO-BAC MED) and (RUCO-GUARD AFR)

In the above Figure 2, the samples E1, E2, and E3 were treated with the chitosan and repellent finish respectively. The antibacterial activity was increased with the increase in the concentrations of chitosan and correspondingly the zone of inhibition.

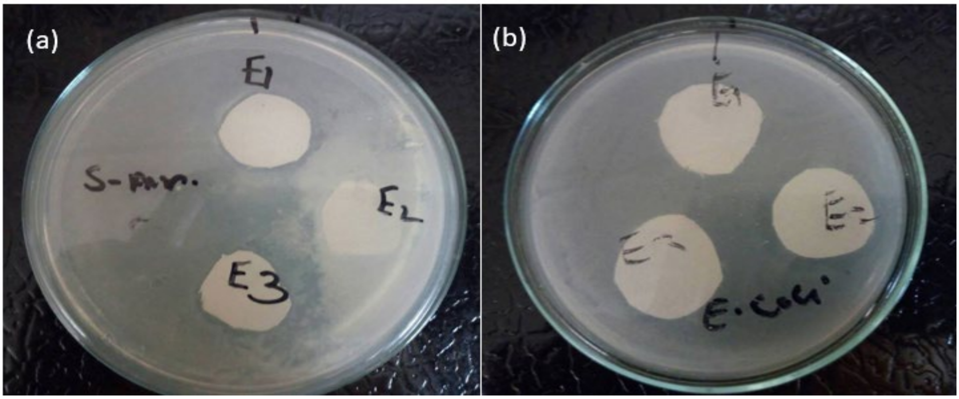

FIGURE 2. Antibacterial activity of samples treated with chitosan and RUCO-GUARDAFR)

Another bacterial colony of staphylococcus aureus had been cultivated on which the finished samples were placed to check the antibacterial activity of the treated samples.

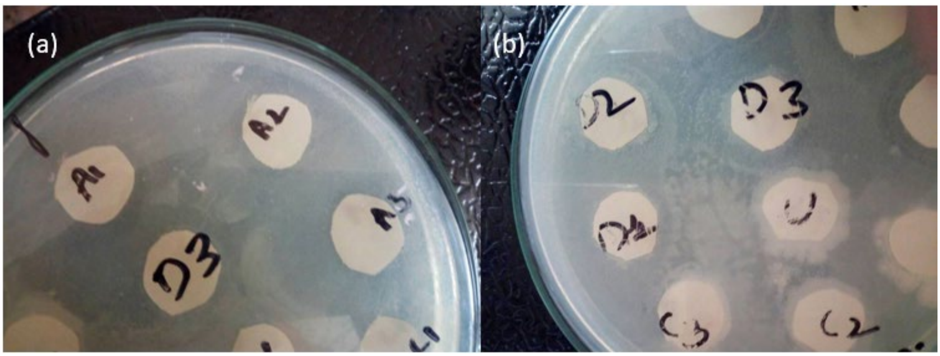

FIGURE 3. Antibacterial activity of different samples against *S. aureus* by applying RUCO-BAC MED (a); combined finish RUCO- BAC MED and (RUCO-GUARD AFR)

Antibacterial finish (RUCO-BAC MED) was applied onto the above samples of A1, A2, and A3 in Figure 3(a) showing the vibrant inhibition spectrum nearby the samples A1, A2 and A3, as these samples were given antibacterial treatment that prohibited the bacterial growth.

In Figure 3(b), U represents the untreated sample of cotton fabric on which no finish was applied, while the samples D1, D2, and D3 were given both antibacterial and fluid repellent finish treatment correspondingly. The figure shows the clear zone of inhibition around the samples of D1, D2, and D3, as they show excellent resistance to get rid of bacteria.

B. MOISTURE VAPOR TRANSMISSION RATE (MVTR)

This test was done to determine the water vapor permeability by testing the samples under the appropriate temperature and relative humidity. Moisture vapor transmission rate provides breathability for the fabric [17]. Different samples show variable water vapor permeation value according to the fabric construction characteristics and the treatments given to the testing fabric samples. MVTR indicates how well the gown allows perspiration vapors to escape, preventing heat stress. OMMC indicates how well the gown can absorb and transport liquid sweat away from the skin, maintaining skin dryness.

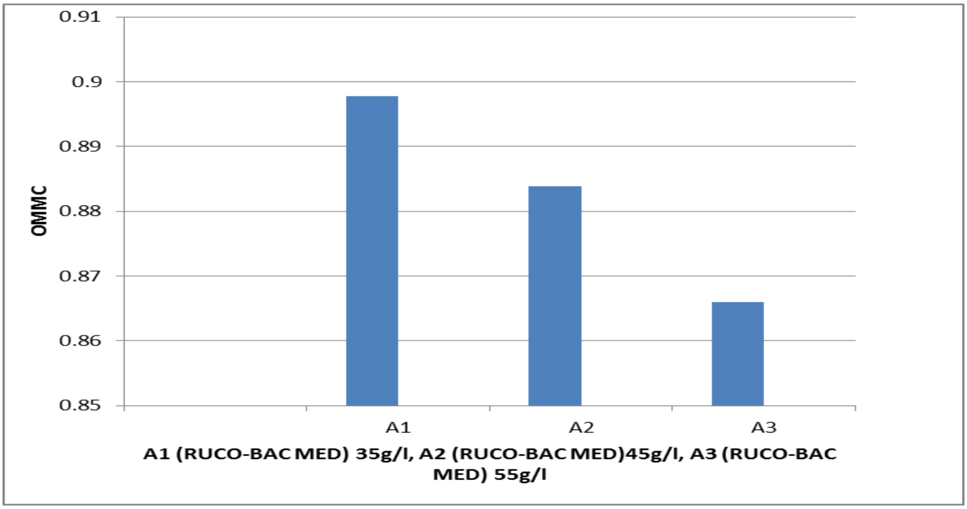

FIGURE 4. Overall moisture management content of A1, A2, A3

Figure 4 shows the decrease in the OMMC (Overall Moisture Management Content) of the samples with the increase in the concentration of finish because the application of the finish causes the reduction in the pore size that does not allow the water vapor transmission through the fabric. The overall moisture management content of the samples B1, B2, and B3 is zero because fluid repellent finish (RUCO-GUARD AFR) is applied that completely diminishes the transmission of the water vapors from [18] the fabric, as shown in Table II.

TABLE II

OVERALL MOISTURE MANAGEMENT CONTENT OF B1, B2, B3 (RUCO-GUARD AFR)

Sample	Wetting Time Top (sec)	Wetting Time Bottom (sec)	Top Absorption Rate (%/sec)	Bottom Absorption Rate (%/sec)	Top Max Wetted Radius (mm)	Bottom Max Wetted Radius (mm)	Top Spreading Speed (mm/sec)	Bottom Spreading Speed (mm/sec)	Accumulative one-way transport Index (%)	OMMC
B-1	13.875	21.313	90.5436	2.8383	5	5	0.36	0.2327	-605.4083	0
B-2	12.766	26.359	77.1516	3.6996	5	5	0.39	0.1886	-589.0751	0
B-3	13.235	2.36	88.2514	3.1495	5	0	0.37	0	-275.2617	0
Mean	13.292	16.6773	85.3156	3.2292	5	3.3333	0.37	0.1404	-489.915	0
S.Deviation	0.5567	12.6533	7.1625	0.4361	0	2.8868	0.02	0.1236	186.0745	0
CV	0.0419	0.7587	0.084	0.1351	0	0.866	0.04	0.8802	0.3798	0

Figure 5 shows the increase in the OMMC (Overall Moisture Management Content) of the fabric with the increase in the concentration of chitosan (antibacterial finish). Chitosan possesses highly cationic and hydrophilic qualities that lead to high interaction with the water molecules, causing the increase in the permeation of the water vapors [19].

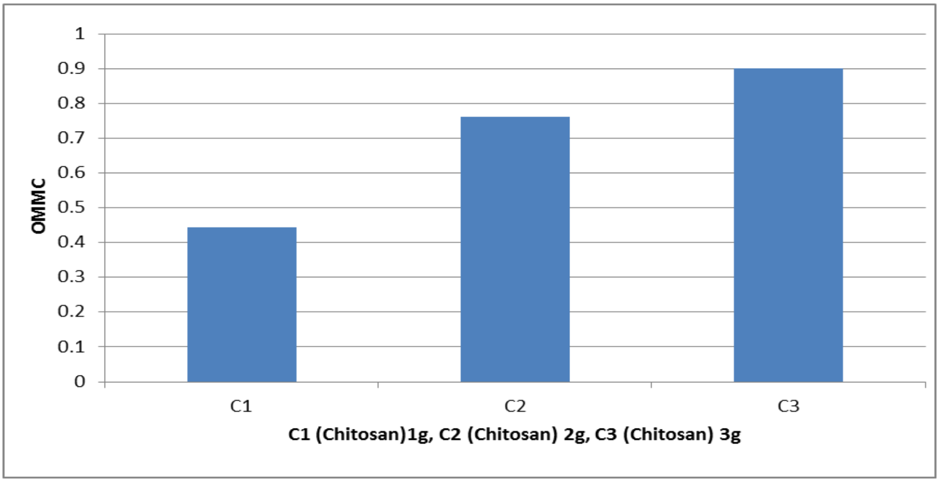

FIGURE 5. Overall moisture management content of samples C1, C2, C3

Figure 6 indicates an increase in the OMMC values of the fabric with the increase in the concentrations of both the finishes, due to the increase in the breathability of the fabric.

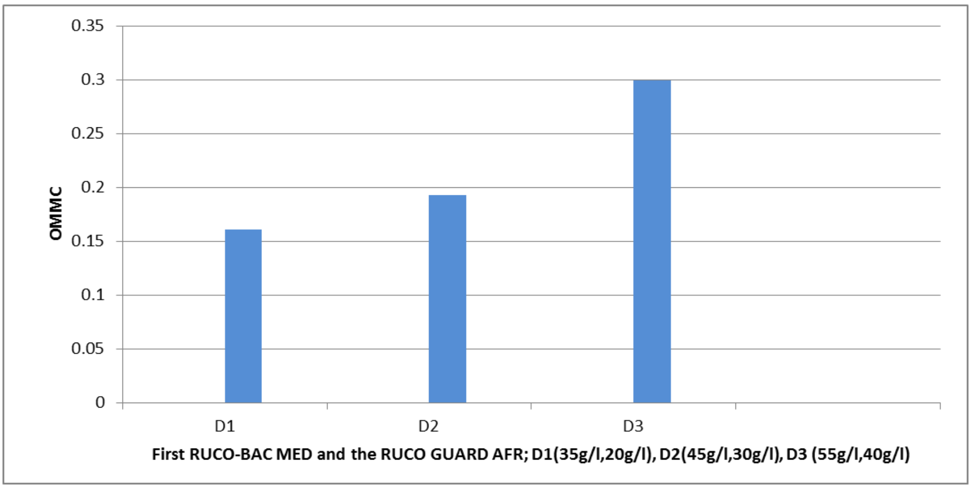

FIGURE 6. Overall moisture management content of D1, D2, and D3 (RUCO-BAC MED and RUCO-GUARD AFR)

Figure 7 shows that only the sample E2 has the property of water permeation due to the application of moderate amount of chitosan that exhibits hydrophobicity to the fabric. While in sample E1, the concentration of chitosan is too small to generate hydrophobicity, so the repellent finish (RUCO-GUARD AFR) prevents the transmission of water vapors. Similarly, in the sample E3, the concentration of the repellent finish is too high as it leaves no pores for the permeation of water vapors.

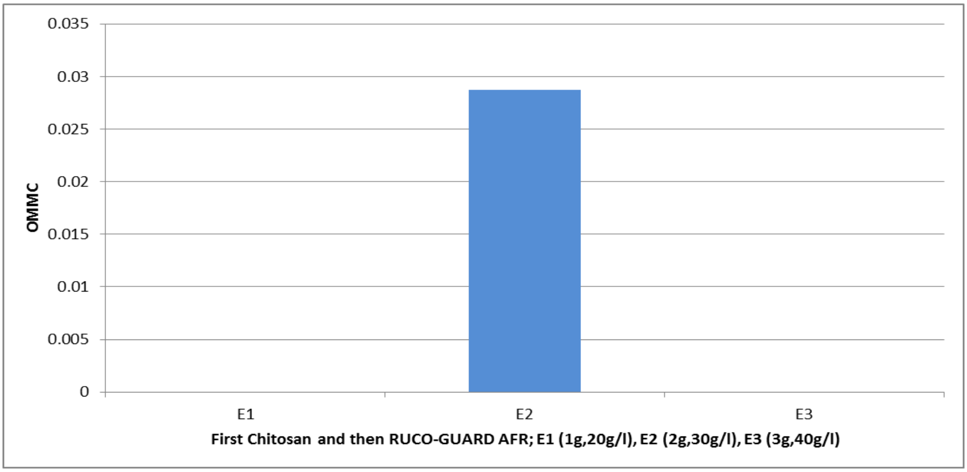

FIGURE 7. Overall moisture management content of C1, c2, C3 (Chitosan and RUCO-GUARD AFR)

C. FLUID REPELLENCY TEST (SPRAY TEST)

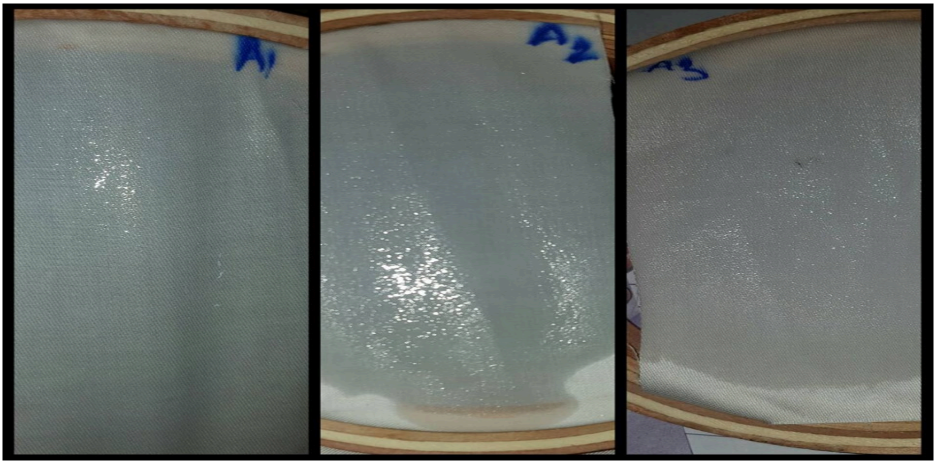

FIGURE 8. Water repellency of samples A1, A2, A3 treated with (RUCO-BAC MED)

This test is implemented for measuring the resistance of the textile fabrics to wetting by the water. It is particularly appropriate for measuring water-repellency of the finishes applied to the fabrics. The basic principle of the test method is that water is sprayed against the stretched surface of the test specimen under the controlled conditions, providing wet configuration whose size depends upon the repellency of fabric[20].

In Figure 8 the samples A1, A2, and A3 are treated only with the antibacterial finish (RUCO-BAC MED) and not given any repellent treatment, so as the water is sprayed onto the fabric it instantly absorbs it. The fluid repellent finish (RUCO-GUARD AFR) is applied onto the samples B1, B2 and B3, showing the rating of 90(ISO 4); producing slight casual wetting of the sample surface.

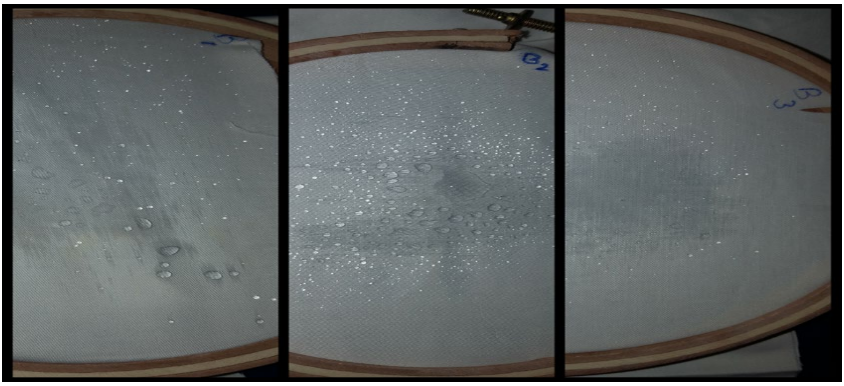

FIGURE 9. Water repellency of samples B1, B2, B3treated with (RUCO-GUARD AFR)

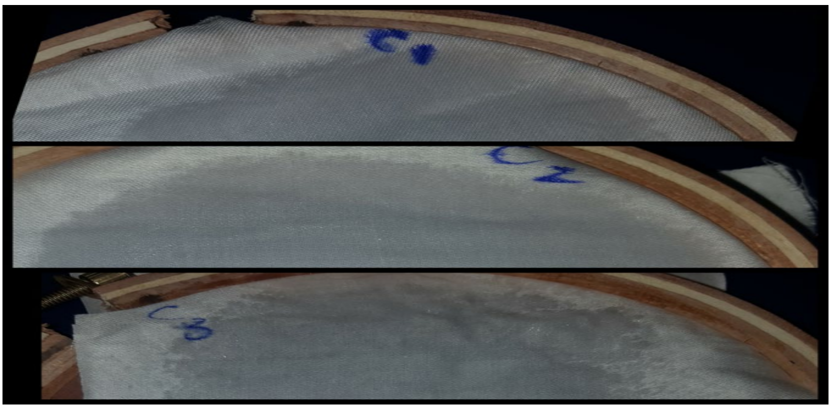

FIGURE 10. Water repellency of samples C1, C2, C3 treated with (Chitosan)

Chitosan is applied onto the samples C1, C2, and C3, since these samples are not given any repellent treatment, the higher absorbency of chitosan causes the absorption of the sprayed water promptly, as seen in Figure 10 [21].

Two finishes are applied onto the samples D1, D2, and D3, including RUCO-BAC MED and the repellent RUCO-GUARD AFR. However, the efficacy of the repellent finish is moderate due to the initial application of antibacterial finish that somehow enhances the absorbency of the fabric, as shown in Figure 11.

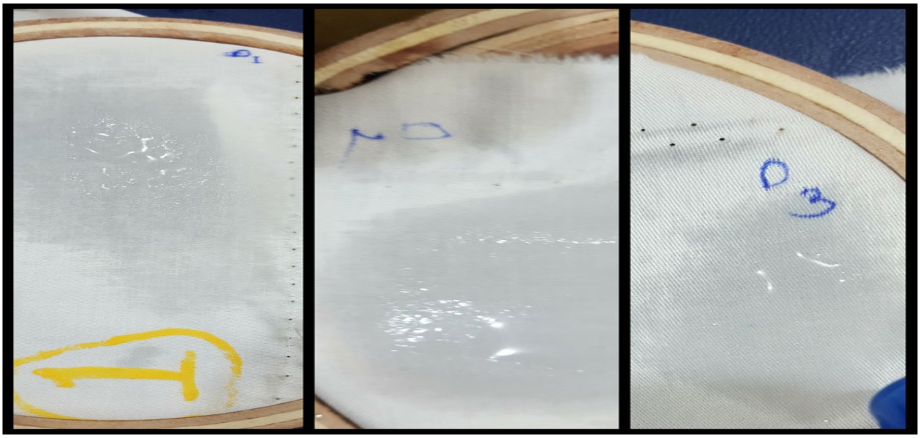

FIGURE 11. Water repellency of samples of samples D1, D2, D3 treated with (RUCO-BAC MED) and (RUCO-GUARD AFR

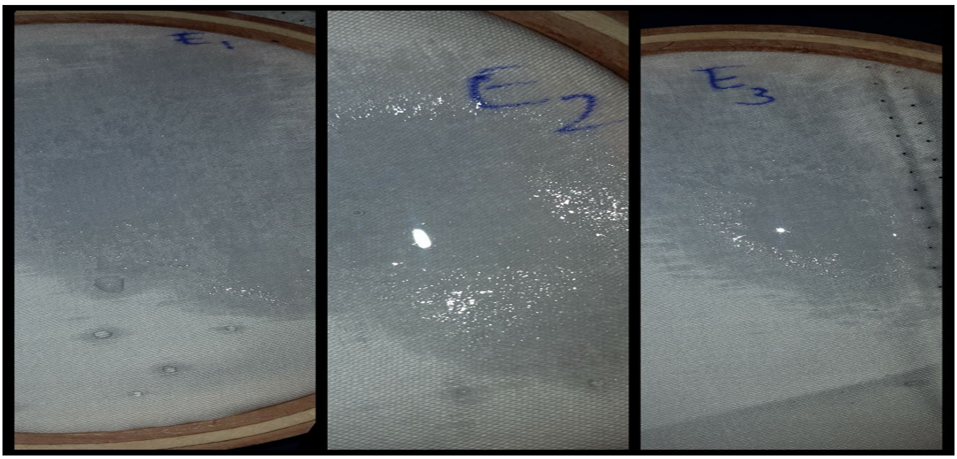

FIGURE 12. Water repellency of samples of samples E1, E2,E3 treated with Chitosan and then repellent (RUCO-GUARD AFR)

In Figure 12, Chitosan and the repellent RUCO-GUARD AFR are applied into the fabric correspondingly. Chitosan enhances the absorbency of the fabric; subsequently it reduces the effectiveness of the fluid repellent finish, causing the partial absorption of the sprayed water.

D. AIR PERMEABILITY TEST

Air permeability is the amount of air that passes through 100 mm² of the fabric in 1 second under a specified pressure difference [22]. In Figure 13, the untreated sample shows the maximum air permeability as it is not given any antibacterial or repellent finish treatment, since the fabric pores are more openChitosan treated samples represent better air permeability as compared to the samples A1, A2, A3 (antibacterial), and B1, B2, B3 (repellent), because of less closing of pores in the fabric polymer structure.

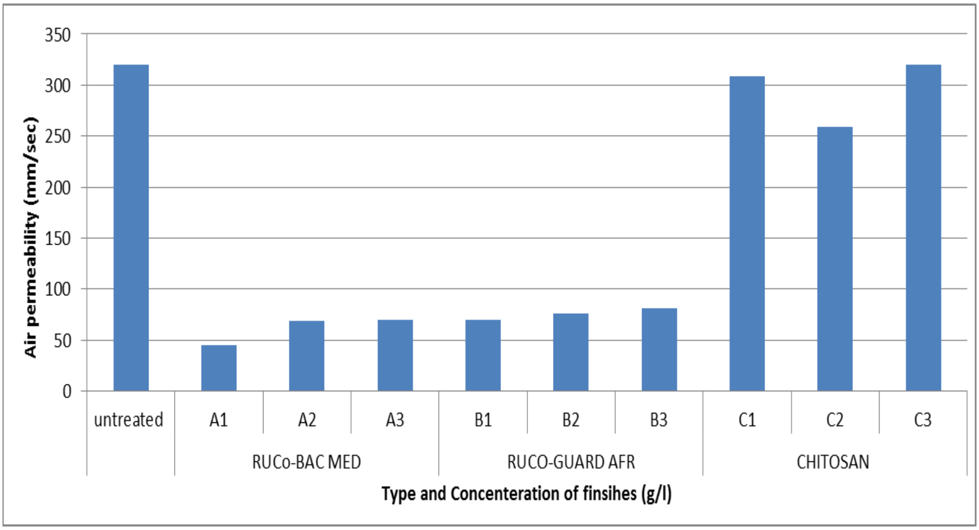

FIGURE 13. Effect of air permeability on A1, A2, A3 (Antibacterial), B1, B2, B3 (Repellent) and C1, C2, C3 (Chitosan

Figure 14 shows that samples treated with Chitosan and RUCO-GUARD AFR represent better air permeability as compared to the samples treated with RUCO-BAC MED and RUCO-GUARD AFR. This indicates that chitosan is inherently breathable while RUCO-BAC MED is not breathable. The change in the air permeability values is more related to the chemical nature of the finish along with treatment conditions such as temperature, solution, and mechanical action as well.

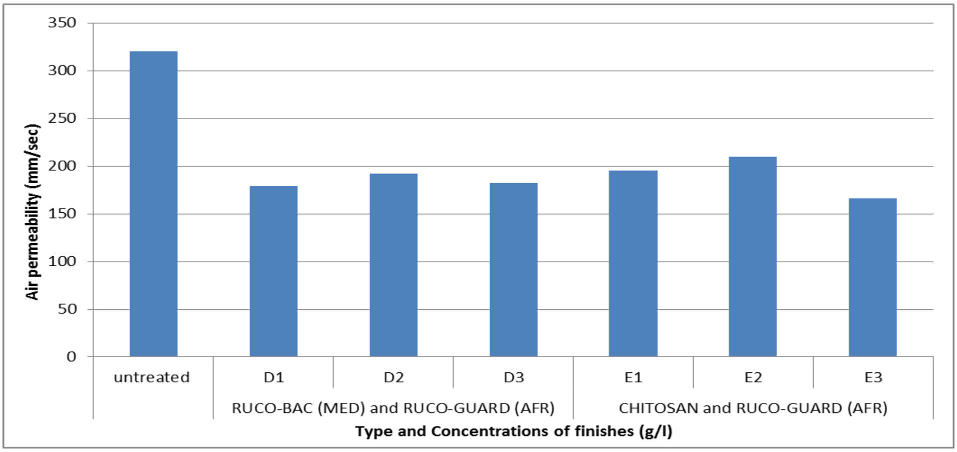

FIGURE 14. Effect of air permeability on D1, D2, D3 (Antibacterial and repellent) and C1, C2, C3 (Chitosan and repellent)

E. TENSILE STRENGTH TEST

Tensile strength can be expressed as the least amount of the tensile stress, force per unit area, that is required to split the textile material apart [17]. After the application of antibacterial, repellant and chitosan finishes, a significant increase is produced in the tensile strength of cotton fabric.

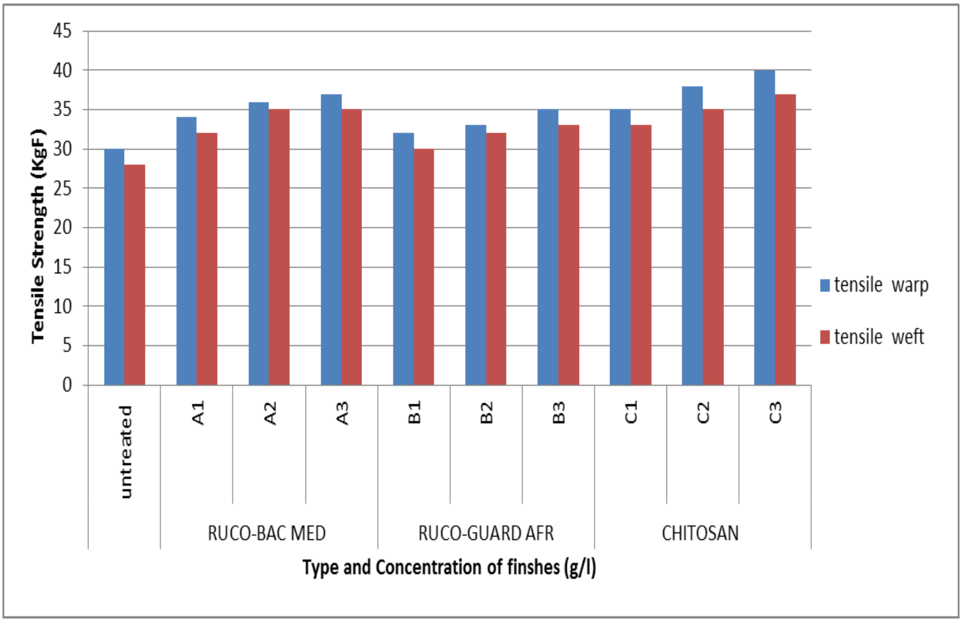

FIGURE 15. Warp and Weft Tensile strength of sample A, B and C

The Figure 15 shows an increase in warp and weft tensile strength when the cotton fabric is treated with antibacterial, repellent, and chitosan finishes. In the finished fabric, the tensile strength increases due to the increase in the inter-yarn slippage of the fiber polymer system that will ultimately sustain more stress.

The results in Figure 16 show that the finished fabric has more tensile strength as compared to unfinished fabric because a finishing material enhances the binding between the fiber polymer system that results in the increase in tensile strength of the fabric.

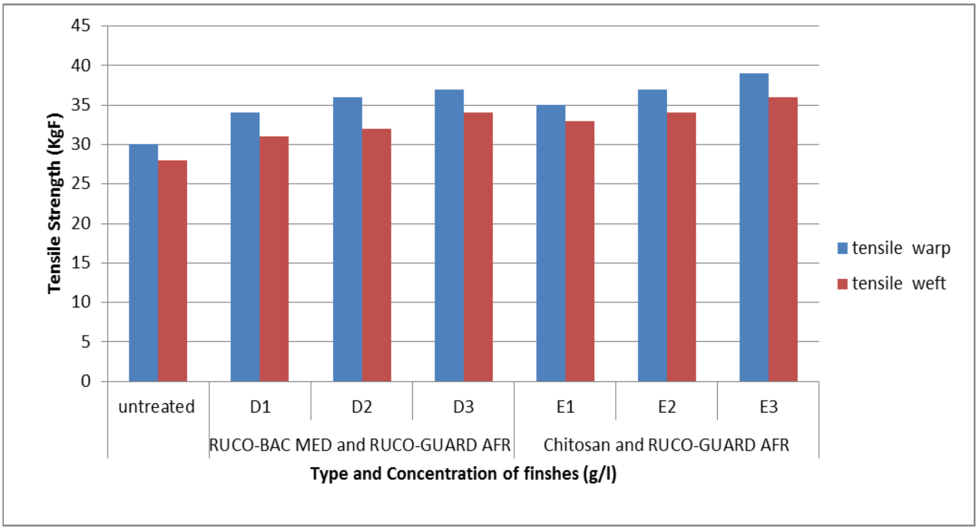

FIGURE 16. Warp and Weft Tensile strength of sample D and E

IV. CONCLUSION

Pad dry-cure method was implemented for the application of antibacterial and fluid repellent finishes for achieving the bacteriostatic and repellent effects onto the cotton fabric. Although chitosan and RUCO-BAC MED exhibited great antibacterial activity, but the antibacterial efficiency of Chitosan treated cotton fabric was found to be much better, since it is a natural antimicrobial substance that exhibits multiple functionalities along with more antibacterial activity. Another finish RUCO-GUARD AFR provided excellent repellency by avoiding the penetration of liquid substances. Either in combination or separately, the finishes maintain their functionality and do not have any drastic effect on the physical properties of the cotton fabric. The treated cotton fabric could be used for developing eco-friendly surgical gowns that would facilitate the medical staff greatly and keep the bacteria and unfavorable impurities away from them, resulting in a hygienic and comfortable environment.

Author Contribution

Faiza Anwar: conceptualization, data curation, formal analysis. **Ahmad Faraz:** software, writing – review & editing.

Conflict of Interest

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

Data Availability Statement

Data supporting the findings of this study will be made available by the corresponding author upon request.

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Generative AI Disclosure Statement

The authors did not use any type of generative artificial intelligence software for this research.

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