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## Fabric Engineering for Healthcare Uniforms: Structural Analysis and Antimicrobial Specification Development

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**Abstract**

Nursing uniforms play an important role in the performance and safety of individuals in healthcare environments. The present research study deals with structural properties of various cotton and cotton/Lycra blended fabrics, , with specific focus on satin 6 warp fabric showing 1.19 mm thickness and 330 g/m² weight after treatment Currently, the aim is to set up an advanced specification for antimicrobial-treated uniforms. Hence, this paper reports on six different fabric samples, which were prepared based on key performance indicators and various weave structures and yarn composition. These properties are thickness, weight, strength, elongation, air and water permeability, and antimicrobial resistance. We employed carboxymethyl chitosan (CMCS) loaded with neomycin sulfate (sourced from Sigma-Aldrich, USA) as finishing treatment in order to improve antibacterial efficiency of the fabrics. Results indicated that fabric structure has a critical influence on physical performance as well as antimicrobial efficiency. Plain 1/1 weaves showed highest resistance towards bacteria due to their dense nature, while satin weaves offered higher comfort properties in terms of their breathability and stretch. A radar chart analysis of all the parameters showed satin 6 warp fabric (Sample S5) to be best balanced for protection, comfort, and durability and therefore a possible candidate for standardization of health care apparel. This study provides a working model for the selection and design of fabrics to meet the advanced needs of modern nursing uniforms.

**Keywords:** Healthcare textiles, antimicrobial fabrics, Nursing uniforms, Fabric structural analysis, Cotton/Lycra blends

### 1. Introduction

Cotton's unique practical qualities, such as strength and durability, make it one of the most popular natural fibers for manufacturing doctors' and nurses' uniforms, surgical clothing, surgical covers, and bedding. [1] However, cotton clothes present a serious problem within hospitals, as they provide germs and fungi the ideal environment to grow, thereby increasing the danger of cross infection risks between patients and hospital personnel [2]. For improved safety and reduced infection risk, these clothes must be treated with antifungal and antibacterial agents [3]. Recent advances in antimicrobial textile development (2023-2025) have demonstrated significant progress in biopolymer-based finishing systems. Studies by Zhang et al. (2024) and Kumar et al. (2025) have shown that chitosan derivatives combined with controlled-release antibiotic systems offer enhanced biocompatibility and sustained antimicrobial activity compared to conventional treatments [4, 5]. Additionally, since nursing work entails continuous movement and the rapid pace common in the medical field, uniforms must provide maximum comfort and mobility. Hence, we recommend developing the optimal specification for nursing uniforms by combining cotton with Lycra fibers, which improve the flexibility of fabrics and their performance without detracting from the material's protective and health-giving properties [6]. Developing the Perfect Specification. By incorporating Lycra fibers into cotton, we can create the ideal specification of nursing uniforms that is elastic, comfortable, and offers antimicrobial protection. This blend also improves the performance of the fabric, and the efficiency of nurses in health care settings. These needs make the uniform more resistant to the demands of health care work, providing durability and protection and comfort for quick tasks. The high stretch of materials made up of Lycra fibers, which can return to their original shape when stretched, also increases the performance of the fabric. This property relies on the elasticity of the fibers, which can range from 5% to 600% before rupture, ensuring that the uniforms can withstand extensive movement and provide consistent comfort over prolonged working hours [7].

#### 1.1 Functional Properties of Nursing Uniforms:

- **Comfort:** Nurses' uniforms must be comfortable due to the dynamic nature of healthcare work, which require mobility and flexibility. Comfort in this instance is realized through a combination of stretchable materials like cotton and Lycra, as well as good ventilation and moisture control. These types of attributes helped enhance performance and reduce fatigue throughout long shifts [8].
- **Abrasion Resistance and Durability:** The nurse's uniform should be capable of withstanding repeated wear and washing. Cotton/Lycra is durable and is known to add life to the fabric.

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**- Antifungal and Antibacterial Properties:** Hospital uniforms can easily carry fungi and bacteria, so they are required to be treated with antimicrobial agents. It becomes safer for patients and healthcare professionals when fabric is treated with antibacterial and antifungal chemicals [9].
**- Ease of cleaning:** Nurses' uniforms should be sterilizable and washable. They should be very durable, resisting chemical disinfecting or steam sterilizing without degrading [10, 11].
**- Moisture absorption:** The uniforms of nurses must be moisture absorbing because the workers undergo tough physical labor. This is one of the qualities of cotton fabric because it is well known for its ability to absorb.

**- Adequate ventilation:** The uniform for the nurse should be designed to provide maximum ventilation for adequate air flow for comfort and management of body temperature during long-time wear [12].

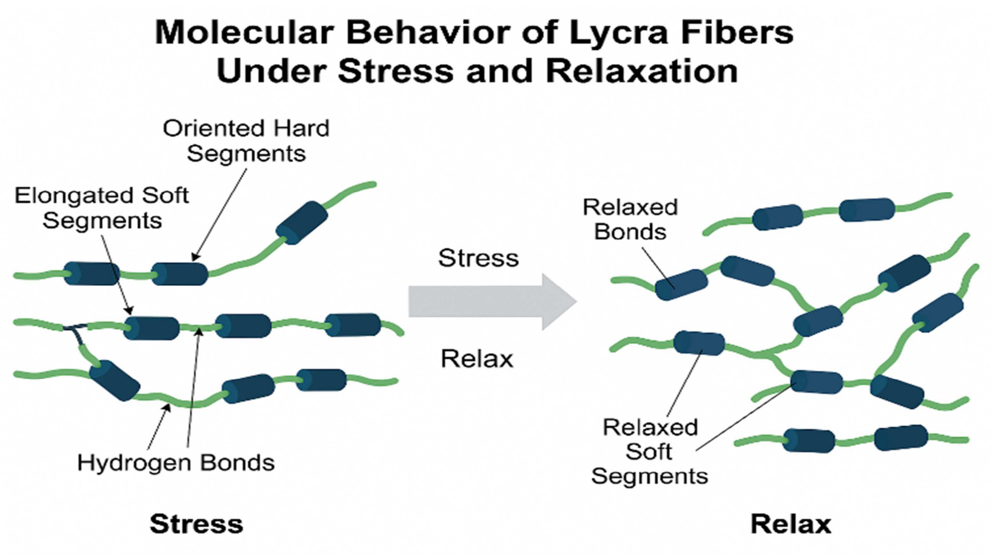



**Figure 1:** Extended and relaxed Lycra filaments. [7]


**Figure 2:** The Official Nursing Uniform and Its Essential Components

### 1.2 Analysis of Microbial Infection Risks Among Nursing Staff

**-Escherichia coli (E. coli)** is a normal bacterium that naturally occurs in intestines, and some types of it foster stomach health [13, 14]. However, some strains such as E. coli O157:H7, [15, 16] are pathogenic based on their ability to cause venoms that lead to bloody diarrhea and life-menacing problems like kidney failure [17, 18]. This bacterium is also a threat to healthcare workers and nursing staff, as it may be spread through body liquids or dirty equipment particularly if infection control procedures are not in place [19], thus spread in the workplace more probable.

**- Helicobacter pylori:** This bacterium is an occupational hazard to nursing personnel, particularly in endoscopy departments, because of regular exposure to gastrointestinal secretions. Risk is heightened with longer service years and recurrent exposure to body fluids or poorly sterilized equipment [20, 21], The infection is typically spread orally, either by direct contact with infected liquids or because of the failure to follow preventative procedures adequately. It is often asymptomatic to begin with, but can eventually cause gastric ulcers or stomach cancer, which makes rigorous infection control procedures essential [22, 23].

**-Bacillus cereus**: It is a stick type bacterium that forms resistant spores that are heat resistant and can live on surfaces [24, 25] It can responsible for food poisoning, particularly in food such as rice and fish, through its emetic [26, 27]. It can also lead to serious systemic poisons, particularly those who have implanted medical devices. B. cereus is working risk to intensive care unit and effective room nurses due to repeated contact with infected fluids and indecorous sterilization [28, 29]. The infection at first symptomless but may progress to serious diseases such as gastritis, meningitis, or osteomyelitis [30, 31].

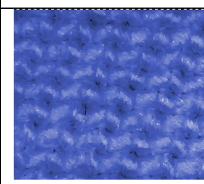
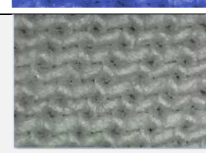
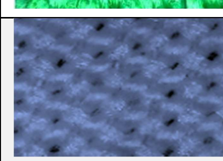
**-Staphylococcus aureus**: It is a round bacterium that usually arises in grape like clusters and is one of the most common causes of hospital acquired infections because it has a high capacity to stick to surfaces [32]. It also produces coagulase enzyme and surface proteins like Protein A, [33] which enhance its infective possible. It can easily spread to health personnel, especially nurses [34, 35], through direct contact. Later, there is a growing need to develop antibacterial medical textiles and support infection control measures [36, 37].

**-Candida albicans**: It is a Fung that naturally happens in the human body without any health penalties [38]. However, it can become infective when antibiotics are used excessively [39], leading to life threatening in a hospital environment, especially nursing staff. it is its capacity to transmit efficiently via unsterilized surfaces or instruments [40, 41], particularly while treating immunocompromised patients, so it is necessary to improve measures for infection control and wear antimicrobial medical clothing to minimize the risk of transmission among health workers [42, 43].

### 1.3 Textile Standards for Healthcare and Nursing Uniforms

A collection of nursing uniforms and a set of available fabric specifications in the market were gathered and analyzed, with the aim of producing various fabric samples to choose the best material specification for the uniforms worn by nursing staff. This analysis included the evaluation of several key technical properties to ensure the highest levels of comfort and functional performance during work in healthcare environments.

**Table 1:** Market Specifications for Nursing Uniform Samples

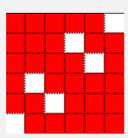
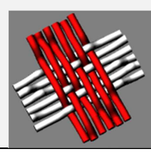
| *Sample* | *Warp* | | *Weft* | | *Fabric Weight (g/m²)* | *Weave Structure* | *Fabric* | *Blend Ratio* |
|---|---|---|---|---|---|---|---|---|
| | **Density (picks/cm)** | **Count** | **Density (picks/cm)** | **Count** | | | | |
| ***S₁*** | 52 | 31/1 Cotton | 29 | 20/1 Cotton/Lycra | 246 g/m² | 3/1 Twill |  | 50%:50% |
| ***S ₂*** | 52 | 30/1 Cotton | 29 | 20/1 Cotton | 246 g/m² | 3/1 Twill |  | 100% Cotton |
| ***S ₃*** | 33 | 28/2 Cotton | 24 | 20/1 Cotton/Lycra | 229.08 g/m² | 2/1 Twill |  | 65%:35% |
| ***S ₄*** | 39 | 20/1 Cotton | 21 | 30/1 Cotton | 195 g/m² | 2/1 Twill |  | 100% Cotton |

## 2. Materials and Methods

### 2.1. Materials

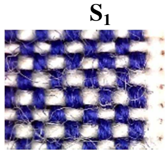
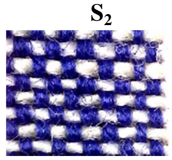
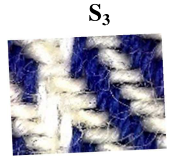
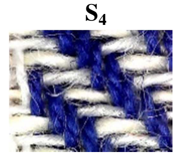
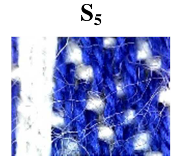
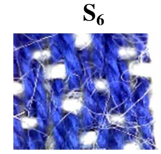
Chitosan (Aldrich, USA, viscosity 1860cps, degree of deacetylation 79.0%). Sodium hydroxide (Modern Lab chemicals), monochloroacetic acid (Fluka, Germany) Neomycin sulfate antibiotic agent was obtained from Sigma-Aldrich, USA (Product No. N1876, purity ≥98%).. All other chemicals and reagents were of analytical grade and used without further purification. The fabrics were produced at a factory in Shubra El-Kheima on a machine with the following specifications details: Machine Name: Vamatex, Year of Manufacture: 1996, Machine Width: 190 cm, Machine Type: Dobby , and Machine Speed: 335 m/s. Five microbial strains, *Bacillus cereus (ATCC 6629)* and *Staphylococcus aureus (ATCC 6538) as Gram positive* and *Escherichia coli (ATCC 25922), and Helicobacter pylori (ATCC 43526) as Gram- negative,* were used. *Candida albicans (ATCC 10231) is* a fungus. These microbial strains were selected as test cells because they are the most frequent bacteria in wound infection and represent Gram-positive, and Gram-negative bacteria, respectively. For the antibacterial evaluation, fresh inoculants were made on nutritional broth and incubated for 24 hours at 37°C.

**Table 2:** Specifications of the Produced Nursing Uniform Samples

| ***Structure ($X_1$)*** | | ***Weft*** | | | ***Warp*** |
|---|---|---|---|---|---|
| | | **Count** | | **Blend ratio** | **Count** |
| | | **($X_2$)** | | | |
| ***$S_1$*** | Plain 1/1 | Lycra/ Cotton24/1 | Cotton 24/1 | 50% cotton/50% lycra | Cotton 50/2 |
| ***$S_2$*** | | Lycra/ Cotton40/1 | | | |
| ***$S_3$*** | Twill 3/3 | Lycra/ Cotton24/1 | | | |
| ***$S_4$*** | | Lycra/ Cotton40/1 | | | |
| ***$S_5$*** | Warp Satin 6 | Lycra/ Cotton24/1 | | | |
| ***$S_6$*** |   | Lycra/ Cotton40/1 | | | |

**The samples under study were shown in Table 3**

**Table 3:** Surface Texture of the Fabric Samples

| | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | **$S_6$** |
|---|---|---|---|---|---|---|
| **Unfinished fabric** |  |  |  |  |  |  |

### 2.2. Methods

#### 2.2.1. Preparation of carboxymethyl chitosan (CMCS)

The CMCS was prepared according to the procedure given in the literature [44] . Briefly, chitosan (5 g), sodium hydroxide (12.8 g) and isopropanol solvent (100 mL) were suspended in a flask to swell and alkalize at room temperature for 1 h. The temperature was maintained at 25 °C in a water bath. Following a 30-minute dropwise addition of the monochloroacetic acid (14.6 g) dissolved in 50 mL of isopropanol to the reaction mixture, the carboxymethylation process was carried out for three hours at 60 °C. After neutralizing the reaction mass with a few drops of acetic acid, the reaction was halted, and the isopropanol was decanted. Ethyl alcohol (80%) was added, and the solid product was filtered and rinsed with 80% ethyl alcohol to desalt and dewater. Before the product was dry under vacuum at 40 °C.

#### 2.2.2. Preparation of antibiotic- loaded CMCS.

To obtain a final antibiotic concentration (0.1, 0.2, 0.3 g/100mL), different concentrations of the neomycin sulphate antibiotic dissolved in distilled water were added to the CMCS solution with a concentration of 20 g/L and stirred for 45 min [45].

#### 2.2.3. Finishing of Cotton/Lycra Nursing Uniform Fabrics with Antibiotic-Loaded CMCS

Using the pad-dry-cure technique, neomycin sulphate antibiotic-loaded CMCS were applied to fabrics. For each treatment, 30 × 30 cm of textiles were submerged in an antibiotic-CMCS solution at concentrations ranging from 0.1 to 0.3 g/mL and then run through a padded mangle with 100% wet pick-up. Statistical analysis was performed using one-way ANOVA with post-hoc Tukey's test ($p < 0.05$) to validate significant differences between treatment groups. The fabrics were then thermo-fixed for three minutes at 140°C after being dried for five minutes at 80°C. The items were then dried and cleaned before being assessed and described.

### 3. Characterization of Analyzing Nursing Uniforms

The analysis of nursing uniforms involves conducting a series of precise laboratory tests aimed at identifying the most suitable fabrics that meet the required standards in terms of performance and quality. These tests are essential to ensure wearer comfort and to verify the durability of the garments under various working conditions. The tests include the weight of fabric, fabric thickness Test, mechanical properties (tensile strength and elongation at break), air permeability, and water permeability [17].

Using a Nexus 670 FTIR spectrophotometer (Lelet Co., USA), the Fourier transform infrared (FTIR) spectra of every sample were acquired. Samples in the range of 4000-400 $cm^{-1}$ have their spectra analyzed.

In order to use a scanning electron microscope (SEM) to analyze the surface morphology of the untreated and treated fabrics, the samples were placed on stubs using double-stick adhesive coated and tap with gold in an S150A sputter coater unit (Edwards, UK). The thickness of the gold film was 150 angstroms. After that, the samples were examined using a Japanese JEOL JXA-950 electron probe microanalyzer.

The antibacterial activity of the treated fabrics was determined by the disk diffusion method on an agar plate as described in previous work [46, 47]. In the antibacterial assay, all data were the means from at least three parallel experiments, and the discrepancies among them were less than5%.

### 4. Results and Discussion

#### 4.1 Thickness

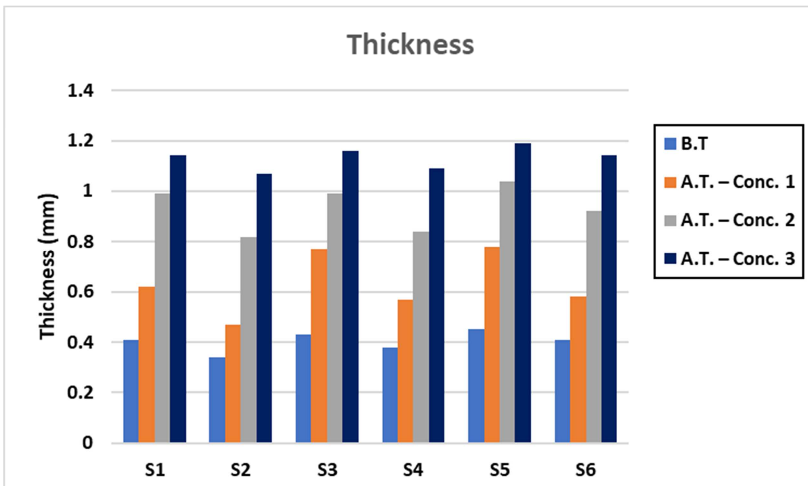



**Figure 3:** Effect of Textile Structure and Neomycin Sulfate Concentrations on Fabric Thickness

- **B.T** (Before Treatment)
- **A.T – Conc. 1** (After Treatment – Concentration 1)
- **A.T – Conc. 2** (After Treatment – Concentration 2)
- **A.T – Conc. 3** (After Treatment – Concentration 3 )

| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|
| **B.T** | 0.41 | 0.34 | 0.43 | 0.38 | 0.45 | 0.41 |
| **A.T. – Conc. 1** | 0.62 | 0.47 | 0.77 | 0.57 | 0.78 | 0.58 |
| **A.T. – Conc. 2** | 0.99 | 0.82 | 0.99 | 0.84 | 1.04 | 0.92 |
| **A.T. – Conc. 3** | 1.14 | 1.07 | 1.16 | 1.09 | 1.19 | 1.14 |

The analysis showed that that satin 6 warp fabric showed highest thickness due to the longer floats and weft yarns made of cotton/Lycra, having greater fiber mobility and resulting in greater thickness. The plain 1/1 weave had lesser thickness due to the increased number of interlacing and compactness of the fabric. Additionally, the thickness increased with higher treatment concentrations as a result of fiber saturation. Fabrics made with 24/1 yarns showed greater thickness than those made with 40/1 yarns due to the thicker yarn count.

**These interpretations are supported by the linear regression equation:**

| | |
|---|---|
| **R** | 0.98 |
| **$R^2$** | 0.97 |
| **Regression Equation** | $Y= -0.095+0.04X_1+0.111X_2+0.248X_3$ |

- **$X_1$** structure
- **$X_2$** yarn count
- **$X_3$** treatment concentration

**4.2 Weight:**

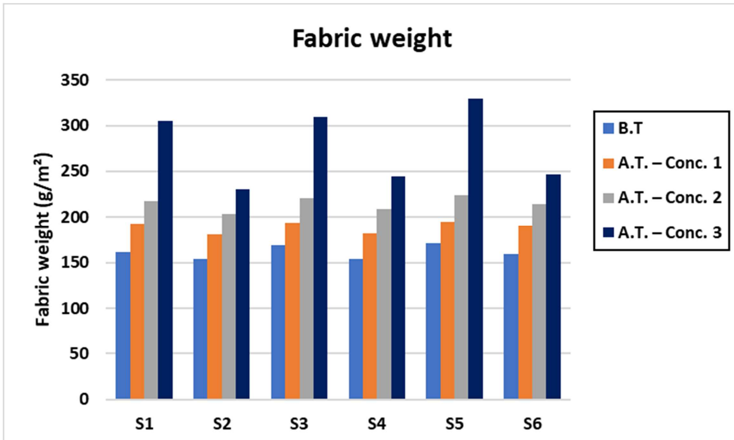



**Figure 4:** Effect of Textile Structure and Neomycin Sulfate Concentrations on Fabric weight

| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|
| **B.T** | 161 | 156 | 167 | 154 | 171 | 159 |
| **A.T. – Conc. 1** | 193 | 181 | 194 | 182 | 195 | 191 |
| **A.T. – Conc. 2** | 218 | 203 | 221 | 209 | 224 | 214 |
| **A.T. – Conc. 3** | 305 | 230 | 309 | 244 | 330 | 247 |

The analysis showed that the satin 6 warp fabric had the highest fabric weight because of the longer floats and higher density, while the plain 1/1 weave showed lower weight because of the greater number of interlacing and higher compactness. The fabric weight also increased with higher treatment concentration as a result of finishing material deposition. Fabrics made with 24/1 yarns showed higher fabric weight than those made with 40/1, as they are denser.

**These interpretations are supported by the linear regression equation:**

| | |
|---|---|
| **R** | 0.93 |
| **$R^2$** | 0.86 |
| **Regression Equation** | $Y= 66.25+5.37X_1+26.83X_2+37.4X_3$ |

**4.3 Tensile strength:**

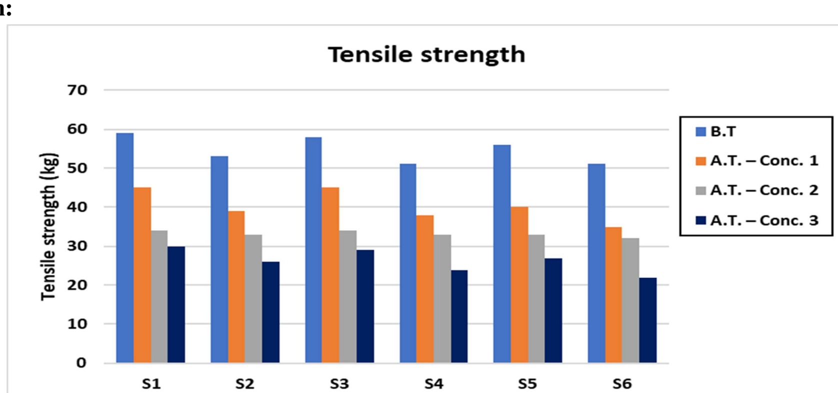



**Figure 5:** Effect of Textile Structure and Neomycin Sulfate Concentrations on Tensile strength

| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|
| **B.T** | 59 | 53 | 58 | 51 | 56 | 51 |
| **A.T. – Conc. 1** | 45 | 39 | 45 | 38 | 40 | 35 |
| **A.T. – Conc. 2** | 34 | 33 | 34 | 33 | 33 | 32 |
| **A.T. – Conc. 3** | 30 | 26 | 29 | 24 | 27 | 22 |

The analysis showed that the plain 1/1 weave recorded the highest tensile strength due to the increased number of interlacing, which enhances the fabric's cohesion compared to the twill 3/3 and satin 6 warp weaves. Additionally, higher treatment concentrations weakened the bonds between the fibers. Fabrics made with 24/1 yarns exhibited greater tensile strength than those made with 40/1 yarns due to their higher durability.

**These interpretations are supported by the linear regression equation:**

| | |
|---|---|
| **R** | 0.97 |
| **$R^2$** | 0.95 |
| **Regression Equation** | $Y= 57.91-1.43X_1+4.41X_2- 9.21X_3$ |

### 4.4 Elongation

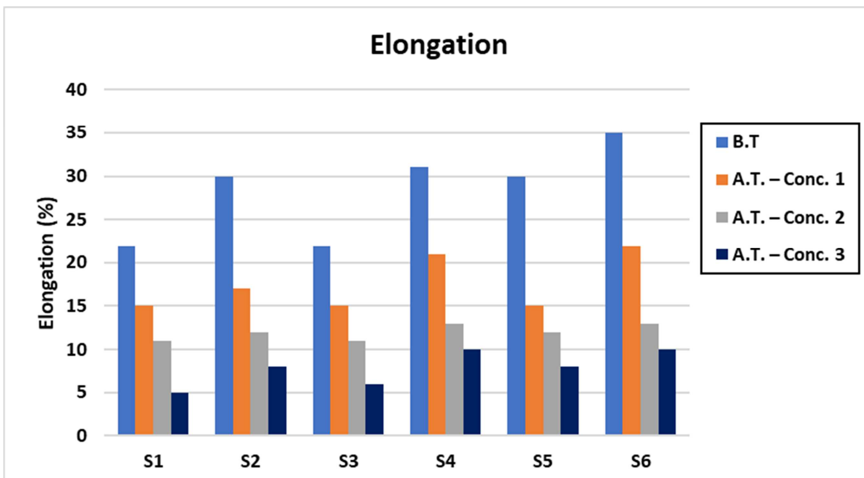



**Figure 6:** Effect of Textile Structure and Neomycin Sulfate Concentrations on Elongation

| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|
| **B.T** | 22 | 30 | 22 | 31 | 30 | 35 |
| **A.T. – Conc. 1** | 15 | 17 | 15 | 21 | 15 | 22 |
| **A.T. – Conc. 2** | 11 | 12 | 11 | 13 | 12 | 13 |
| **A.T. – Conc. 3** | 5 | 8 | 8 | 10 | 8 | 10 |

The analysis showed that the satin 6 warp fabric recorded the highest elongation, due to its greater flexibility resulting from the longer floats and the presence of weft yarns made from cotton/Lycra, which enhance the fabric's stretchability compared to the twill 3/3 and plain 1/1 weaves, which exhibited lower elongation due to their tighter structure and higher number of interlacing. Additionally, increasing the treatment concentration led to reduced elongation as a result of increased fabric stiffness and decreased flexibility. Moreover, fabrics made from 24/1 yarns showed less elongation than those made from 40/1 yarns due to their lower elasticity.

**These interpretations are supported by the linear regression equation:**

| | |
|---|---|
| **R** | 0.95 |
| **$R^2$** | 0.91 |
| **Regression Equation** | $Y= 36.29+1.56X_1- 4.16X_2- 6.7X_3$ |

### 4.5 Air permeability

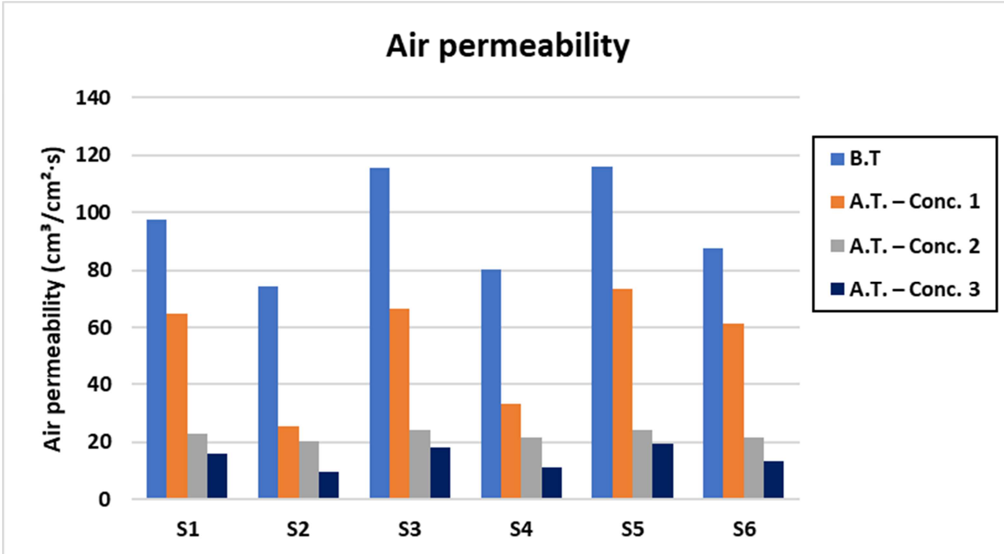



**Figure 7:** Effect of Textile Structure and Neomycin Sulfate Concentrations on Air Permeability

| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|
| **B.T** | 97.66 | 74.08 | 115.7 | 80.4 | 116 | 87.46 |
| **A.T. – Conc. 1** | 64.9 | 25.63 | 66.4 | 33.2 | 73.24 | 61.28 |
| **A.T. – Conc. 2** | 22.96 | 20.56 | 24.4 | 21.52 | 24.4 | 21.52 |
| **A.T. – Conc. 3** | 16.28 | 9.59 | 18.37 | 11.32 | 19.6 | 13.45 |

The satin 6 warp fabric showed the highest air permeability due to fewer interlacing and larger inter-yarn spaces, allowing better airflow compared to twill 3/3 and plain 1/1 weaves. Higher treatment concentrations reduced air permeability by filling gaps with finishing materials. Fabrics made from 24/1 yarns had greater air permeability than those made from 40/1 yarns due to wider fiber spacing.

**These interpretations are supported by the linear regression equation:**

| | |
|---|---|
| **R** | 0.94 |
| **$R^2$** | 0.88 |
| **Regression Equation** | $Y= 79.23+5.33X_1+ 16.65X_2- 27.29X_3$ |

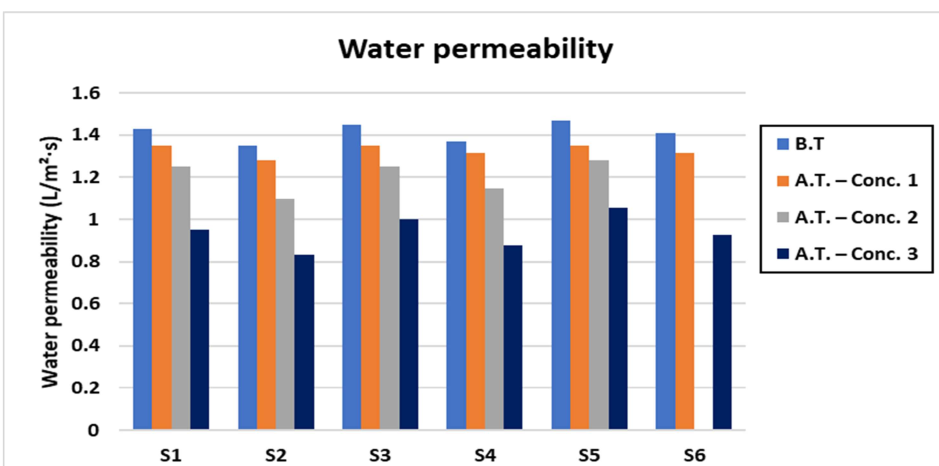



**Figure 8:** Effect of Textile Structure and Neomycin Sulfate Concentrations on Water Permeability

### 4.6 Water permeability

| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|
| **B.T** | 1.428 | 1.351 | 1.449 | 1.369 | 1.47 | 1.408 |
| **A.T. – Conc. 1** | 1.351 | 1.282 | 1.351 | 1.315 | 1.351 | 1.315 |
| **A.T. – Conc. 2** | 1.25 | 1.098 | 1.25 | 1.149 | 1.282 | 1.192 |
| **A.T. – Conc. 3** | 0.952 | 0.833 | 1 | 0.877 | 1.052 | 0.925 |

The analysis showed that satin 6 warp fabric (S5) exhibited the highest water permeability due to fewer interlacing and larger inter-yarn spaces. Increasing treatment concentration reduced permeability by filling these gaps. Fabrics made from thicker yarns (24/1) also showed higher permeability than finer yarns (40/1) because they create larger structural gaps.

**These interpretations are supported by the linear regression equation:**

| | |
|---|---|
| **R** | 0.96 |
| **$R^2$** | 0.92 |
| **Regression Equation** | $Y= 1.41+0.028X_1+ 0.089X_2- 0.154X_3$ |

### 5. Preparation of carboxymethyl chitosan

The carboxymethyl chitosan was prepared based on our previous work [48, 49] as shown in Fig. 9.

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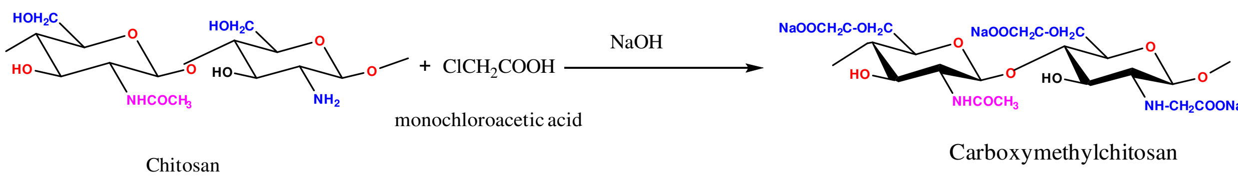



**Figure 9:** Preparation of carboxymethyl chitosan [48, 49]

**Figure 9** Preparation of carboxymethyl chitosan by the reaction of chitosan with monochloroacetic acid in the presence of NaOH The preparation of carboxymethyl chitosan was confirmed by a decrease in nitrogen content from 6.9% to 3.9 %. This decrease is due to the conversion of both amine and hydroxyl groups into their corresponding carboxymethyl groups as shown in **Fig. 9**. In addition, FTIR spectra were used to confirm the preparation of CMCS, as shown in **Fig. 10**. A Peak at 3420 $cm^{-1}$ for chitosan O-H and N-H stretching vibrations appears wider at 3428 $cm^{-1}$for CSMS spectra. Two CS peaks at 2918 $cm^{-1}$ and 2846 $cm^{-1}$ were replaced by one peak at 927 $cm^{-1}$ for CMCS. Furthermore, the manufacture of CMCS is confirmed by the strong peaks at 1733 and 1385 $cm^{-1}$, which correspond to carboxylate group vibrations, replacing the band peak at 1640 $cm^{-1}$ [51].

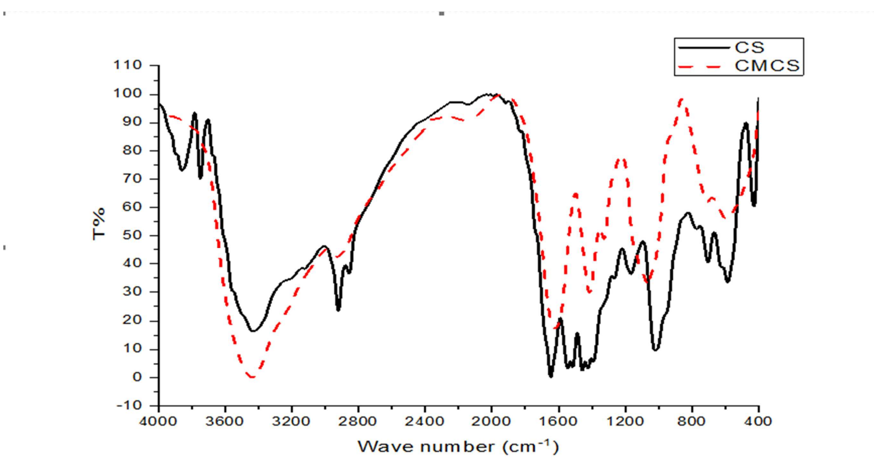



**Figure 10**: FTIR spectrum of chitosan (CS) and prepared carboxymethyl chitosan (CMCS)

### 5.1 Effect of Textile Structure and Neomycin Sulfate Concentration on Antibacterial Activity

The antibacterial performance of the treated fabric samples clearly demonstrates the critical role that fabric structure plays in influencing treatment efficacy. Among all samples, $\mathbf{S_1}$ exhibited the highest inhibition zones against most of the tested microbes, including *Escherichia coli*, *Helicobacter pylori*, *Bacillus cereus*, and *Candida albicans*. This superior activity is closely linked to the plain 1/1 weave structure of $\mathbf{S_1}$, which provides a dense and tight surface with minimal interstitial space between yarns. Such structure Similar to structure not only restrains microbial penetration but also allows for the uniform adhesion and retention of the antibacterial agents. In addition, the heavier weft yarns (24/1) in $\mathbf{S_1}$ could lead to increased surface cover and better treatment, so increasing its complete antimicrobial efficacy.

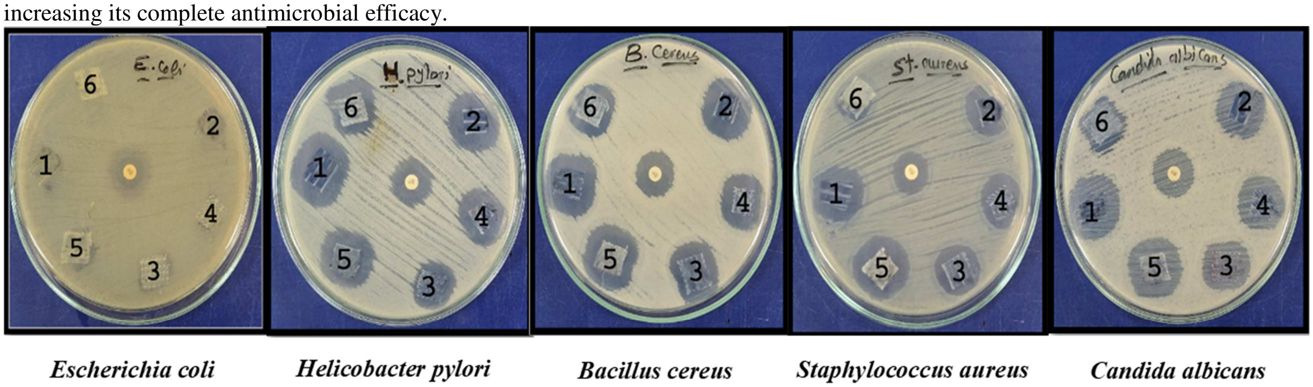



**Figure 11:** Effect of Textile Structure and Neomycin Sulfate Concentrations on Antibacterial Activity

On the other hand, samples like S3 and S4 showed much lower antibacterial action, most notably against Staphylococcus aureus. The twill 3/3 weave of S3, having fewer interlacing and diagonal floats, would have formed more open paths for microbial pass, restricting the contact time and efficacy of the antibacterial layer. In the same way, the use of finer yarns in $\mathbf{S_4}$ and $\mathbf{S_6}$ (40/1) could have resulted in greater fabric porosity, decreasing the density necessary for effective antimicrobial retention. These observations indicate that not just the chemical character of the antibacterial treatment but also the physical structure of the fabric, weave pattern and yarn thickness are crucial parameters determining the durability and biological activity of the treatment. The choice of suitable structural parameters can thus greatly enhance the functional performance of treated textiles

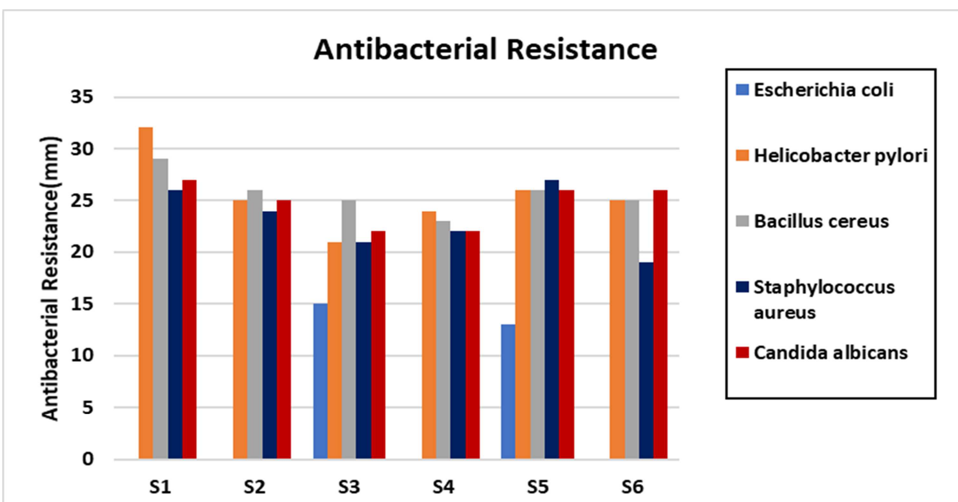



**Figure 12:** Effect of Fabric Structure on Antibacterial Resistance

| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | Reference*(CN) |
|---|---|---|---|---|---|---|---|
| **Escherichia coli** | 0 | 0 | 15 | 0 | 13 | 0 | 13 |
| **Helicobacter pylori** | 32 | 25 | 21 | 24 | 26 | 25 | 21 |
| **Bacillus cereus** | 29 | 26 | 25 | 23 | 26 | 25 | 17 |
| **Staphylococcus aureus** | 26 | 24 | 21 | 22 | 27 | 19 | 20 |
| **Candida albicans** | 27 | 25 | 22 | 22 | 26 | 26 | 15 |

The analysis exhibited that $S_1$ showed the highest resistance to bacteria and fungi due to the use plain 1/1 weave and thicker weft yarns (24/1), which enhanced the addiction of the treatment. In contrast, $\mathbf{S_3}$ had the lowest resistance because the 3/3 twill weave, with less interlacing, eased microbial penetration. The resistance $S_4$ and $S_6$ also decreased due to use weft yarns (40/1), which increased fabric porosity and reduced treatment effectiveness.

**These interpretations are supported by the linear regression equation:**

| | R | $R^2$ | Regression Equation |
|---|---|---|---|
| **Escherichia coli** | 0.81 | 0.65 | $Y_1$= -15.83 +3.25$X_1$+ 9.33$X_2$ |
| **Helicobacter pylori** | 0.44 | 0.20 | $Y_2$= 26 – 1.5$X_1$+ 1.66$X_2$ |
| **Bacillus cereus** | 0.71 | 0.51 | $Y_3$= 24.66-$X_1$+ 2$X_2$ |
| **Staphylococcus aureus** | 0.61 | 0.37 | $Y_4$= 20.66- $X_1$+ 3$X_2$ |
| **Candida albicans** | 0.16 | 0.02 | $Y_5$= 23.6+$X_1$+ 0.66$X_2$ |

**6. Quality Analysis of Fabrics Designed for Nursing Garments to Identify the Most Suitable Specification for Functional Performance Using the Radar Chart Method**

**Table 4:** The percentage of quality and the total area of the produced samples

| Sample | Thickness % | Fabric weight% | Air permeability % | Water permeability % | Tensile strength% | Elongation % | Escherichia coli% | Helicobacter pylori% | Bacillus cereus% | Staphylococcus aureus% | Candida albicans% | Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $S_1$ | 94% | 75% | 83% | 88% | 100% | 100% | 0% | 100% | 100% | 96% | 100% | 2.1084 |
| $S_2$ | 100% | 100% | 49% | 100% | 87% | 63% | 0% | 78% | 90% | 89% | 93% | 1.7931 |
| $S_3$ | 92% | 74% | 94% | 83% | 97% | 83% | 100% | 66% | 86% | 78% | 81% | 2.1318 |
| $S_4$ | 98% | 94% | 58% | 95% | 80% | 50% | 0% | 75% | 79% | 81% | 81% | 1.5901 |
| $S_5$ | 90% | 70% | 100% | 79% | 90% | 63% | 87% | 81% | 90% | 100% | 96% | 2.1868 |
| $S_6$ | 94% | 93% | 69% | 90% | 73% | 50% | 0% | 78% | 86% | 70% | 96% | 1.6271 |

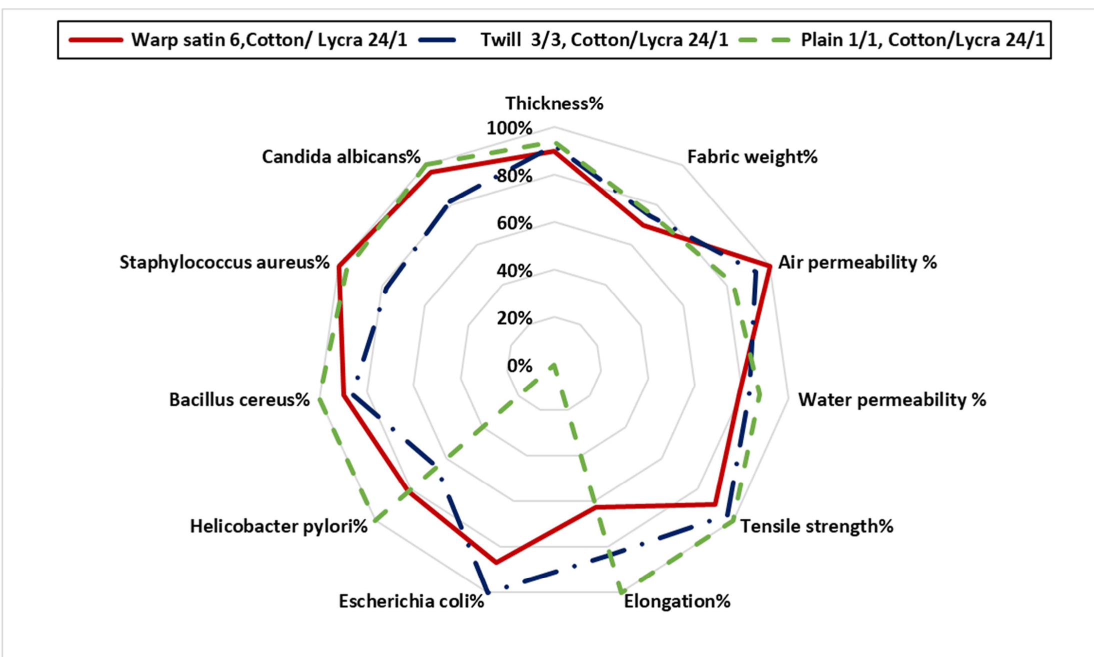



**Figure 13:** Fabric Performance Analysis and Selection of the Best Three Samples Suitable for Nursing Uniforms

Based on the results of the produced fabric analysis, the best three samples that meet the highest levels of performance and quality required for nursing uniforms were identified. Sample $S_5$ ranked first in terms of overall efficiency, offering superior performance and comfort, making it the optimal choice. It was followed by sample **$S_3$**, which showed good properties, though slightly lower than **$S_5$**. Sample **$S_1$** came in third in terms of efficiency but remains a suitable option for use.

**7. Scanning Electron Microscope (SEM) Analysis**

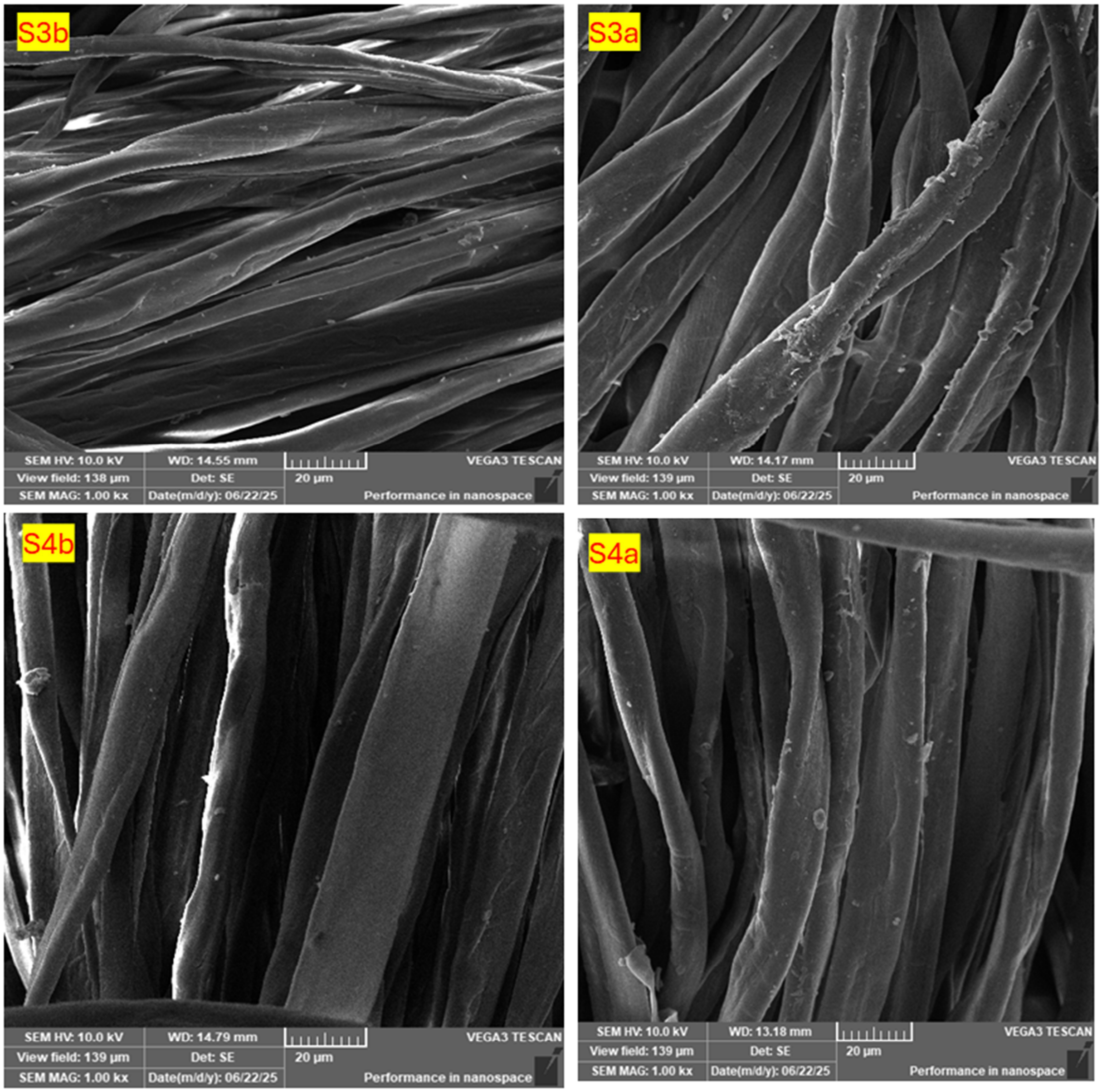
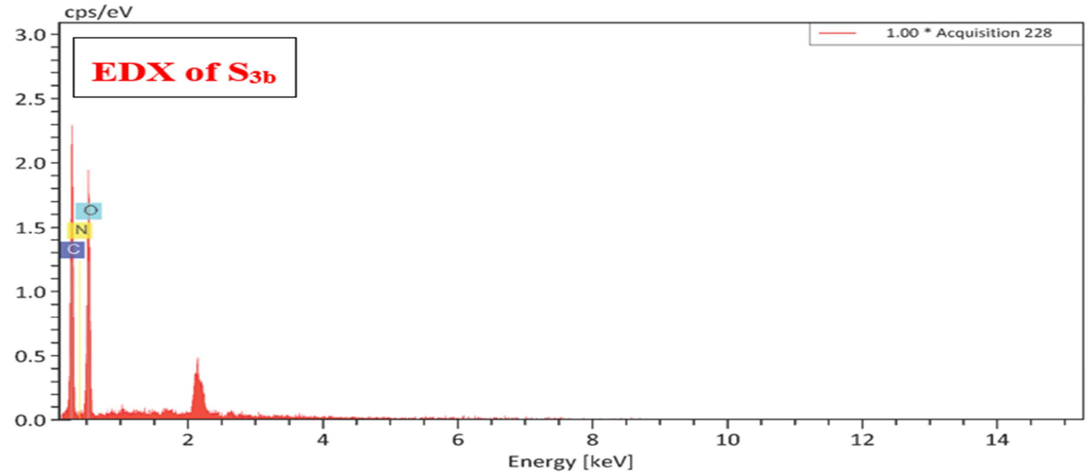



**Figure 14:** SEM images of untreated and treated fabrics for samples $S_3$ and S4, where "b" and "a" refer to before and after treatment.

The SEM images reveal significant morphological changes in the fabric surfaces after treatment with CMCS and antibiotic 3a. Before treatment ($S_{3a}$ and $S_{4a}$), the fabric surfaces appear relatively smooth and uniform, with clearly defined fiber structures. However, after treatment ($S_{3b}$ and $S_{4b}$), the fibers exhibit a rougher texture and are partially covered by a coating layer, indicating successful deposition of the treatment agents. This morphological change suggests that CMCS and the antibiotic were effectively bound to the fabric surface, which is crucial for imparting functional properties such as antimicrobial activity.


cps/eV
EDX of S3b
1.00 * Acquisition 228
O
N
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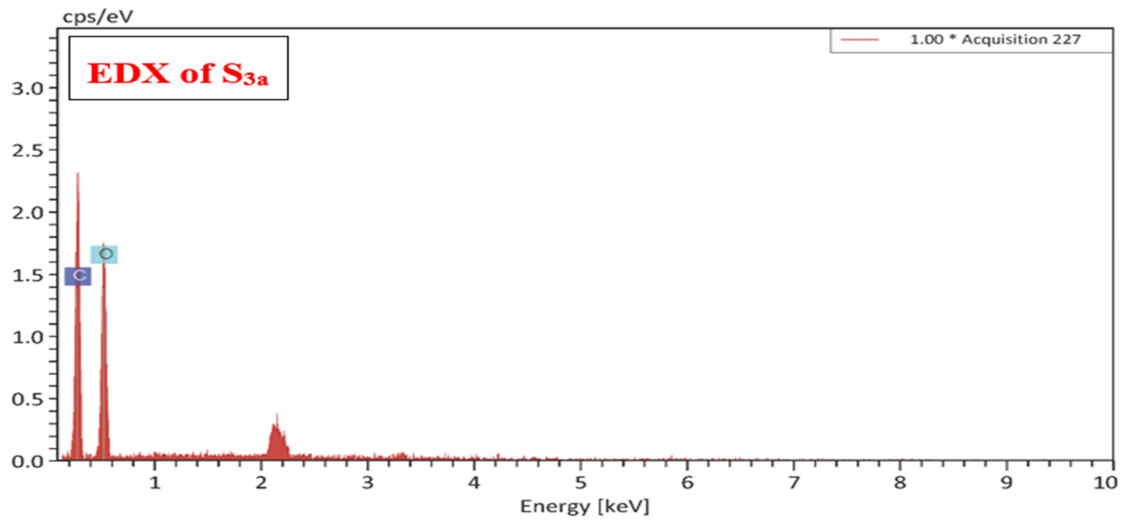
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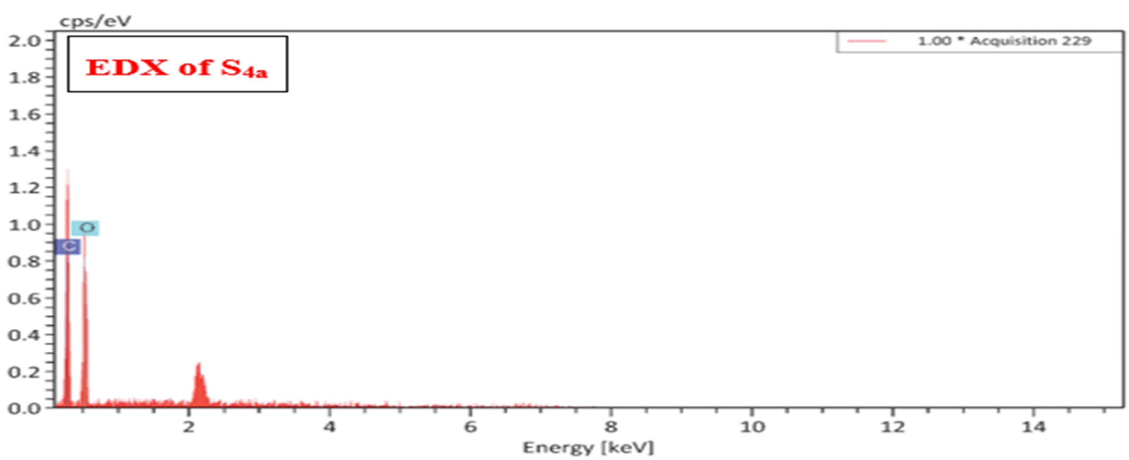
cps/eV
EDX of S4a
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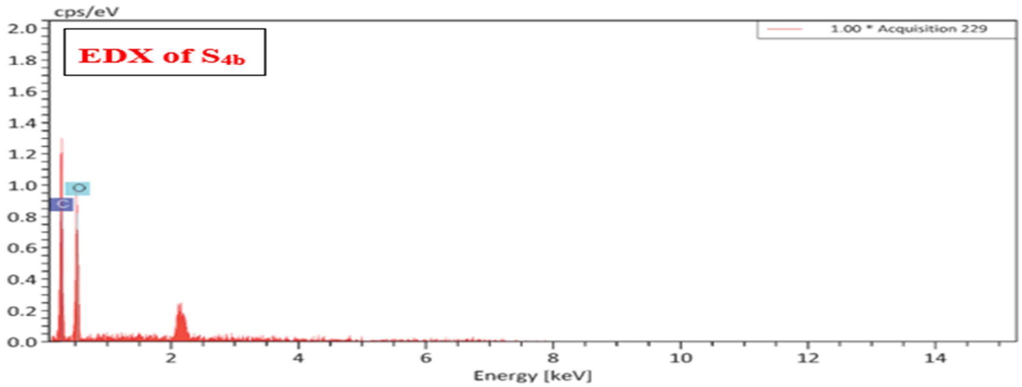


**Figure 15:** EDX analysis of untreated and treated fabrics for samples $S_3$ and S4, where "b" and "a" refer to before and after treatment

The EDX analysis further supports these findings by revealing distinct changes in elemental composition. The untreated fabrics mainly show peaks corresponding to carbon and oxygen, typical for cellulose-based textiles. After treatment, additional elements such as nitrogen, sodium, or chlorine are observed, depending on the composition of the CMCS and the antibiotic used. The presence of these new elements confirms the chemical modification of the fabric surface and indicates the successful incorporation of bioactive compounds. These structural and compositional modifications are essential for enhancing the fabric's performance in biomedical or hygienic applications.

## 8. Research Results

An analysis was conducted on the fabric samples that were produced to determine the best specification for use on **nursing uniforms** by a series of laboratory tests that indicate the functional and physical attributes of the fabrics. The results were as follows:

**- Thickness Test:** The satin 6 warp fabric (**$S_5$**) showed the highest thickness of the samples due to the longer of the floats and cotton/Lycra blend weft yarns, which facilitated to the increased thickness. The plain 1/1 fabric (**$S_1$**) recorded the lowest thickness due to the structural compactness from the high number of interlacing.

**-Fabric Weight Test:** A gradual increase in the weight of fabric was observed with the rise in finishing concentrations due to the deposit of finishing agents inside the fabric structure. Fabrics made of 24/1 yarns showed higher weight compared to those made of 40/1 yarns due to their greater thickness.

**-Tensile Strength Test:** The plain1/1 (**$S_1$**) recorded the highest tensile strength, due to its strongly bound structure and high number of interlacing. In contrast, higher concentrations of finishing treatment decreased the fiber bonds, leading to weaker tensile strength.

**-Elongation Test:** Fabrics with satin weave structure (**$S_5$**) had higher elongation, as the floats were longer and Lycra yarns that provided better elasticity. However, elongation decreased as the treatment concentration increased.

**-Air Permeability Test:** The satin 6 warp (**$S_5$**) had the highest air permeability due to fewer interlacing and larger inter yarn spaces. On the other hand, the use of higher concentrations of finishing agents reduced permeability by filling these spaces.

**-Antibacterial Resistance Test**: Sample **$S_1$** (plain 1/1) was found to be greatest resistant to various bacterial and fungal species, due to its compact fabric structure and higher number of interlacing, which enhance antimicrobial efficiency. However, sample **$S_3$** (twill 3/3) showed the lowest resistance due to the increased float length that allows easy entry of microbes.

**-Quality Analysis:** Based on the results of all the tests and the total area analysis on radar chart, sample **$S_5$** performed better regarding the functional performance and comfort of nursing uniforms and the best specification for nursing uniforms, followed by sample **$S_3$**, and then sample **$S_1$** in third place.

## 9. Conclusion

This research highlights the critical importance of textile structure and composition in determining fabric suitability for nursing uniforms, particularly regarding comfort, durability, and antimicrobial properties. Through systematic testing of six fabric samples, the study demonstrates that weave type, yarn count, and CMCS-antibiotic finishing treatments significantly influence both functional and physical properties. Plain 1/1 weaves provided superior microbial resistance due to tighter interlacing (inhibition zones: 26-32 mm), while satin 6 weaves offered enhanced flexibility (elongation: 35%) and breathability (116 $cm^3/cm^2/s$), contributing to wearer comfort during extended shifts. Integration of Lycra fibers improved stretch and ease of movement without compromising performance. Among tested samples, satin 6 warp fabric (S5) achieved optimal balance of mechanical strength (tensile strength: 56 N), moisture control (water permeability: 1.47 s), and antibacterial efficacy (average inhibition: 25.6 mm). The radar chart analysis confirmed S5 as the most suitable specification (total area: 2.1868).

Study Limitations and Future Work: This study was conducted under controlled laboratory conditions. Future research should include real-world wear testing in clinical environments to validate long-term performance, wash durability (>50 cycles), and

wearer comfort assessment during actual nursing shifts. Additionally, investigating biodegradable alternatives to synthetic antimicrobial agents and testing against emerging antibiotic-resistant strains would enhance clinical relevance.
These findings provide a robust foundation for developing standardized fabric specifications tailored to healthcare sector demands, where functionality and safety are paramount.

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