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Preparation of Durable Antibacterial Polyester Fabrics by Grafting with the Natural Quaternary Ammonium Compound Betaine

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Abstract

Recently, the textile industry has increasingly advocated for natural resource-based healthcare textiles. This research presents a facile and eco-friendly approach to developing durable antibacterial polyester fabrics. Polyester fabric was first subjected to an alkaline hydrolysis to impart hydroxyl groups on the fiber surface. A natural antibacterial agent, betaine, was then covalently bonded to the hydrolyzed polyester fiber surface through esterification. XPS, Raman, SEM, and Wicking measurements were carried out to verify the esterification reaction. Antibacterial tests confirmed that betaine treatment grafted polyester fabrics revealed a remarkable antibacterial effect with inhibition rates > 99.9% against both *E. coli* and *S. aureus* and still remained inhibition rates of up to 91.5% against both bacteria after home washing for 20 cycles. Moreover, the modification significantly increased the capillary effect of polyester fabric but did not cause apparent adverse effects on the fabric's hand or tensile strength. Overall, this grafting strategy for durable, antibacterial polyester fabric represents a significant practicality in the textile industry.

Keywords

Polyester Fabric, Betaine, Antibacterial, Durability, Capillary

1. Introduction

Polyethylene terephthalate (PET), or polyester fabric, is a synthetic fabric. Polyester fabrics have been used for many years. The most commonly used polymers are those made from synthetic fibers. Polyester fabrics are made from ethylene glycol and terephthalic acid. Each repeating unit consists of a repeating ethylene glycol molecule ($HO(CH_2CH_2O)$ nH) and a terephthalic acid molecule ($HOOC-C_6H_4-COOH$) linked by an ester bond (-OCO-). Polyester fabrics are characterized by high strength, abrasion resistance, chemical resistance, elasticity, shrinkage, and crease resistance [1]. Polyester fabrics are used in many areas, e.g., in industry, medicine, and as clothing for human use. Polyester fabrics absorb very little water, as the ester bonds and non-polar groups in polyester fabrics have a very low affinity for water. Polyester fabrics have a low moisture content and are susceptible to generating static electricity [2]. The aim of this research was to make polyester fabrics resistant to bacteria by treating them with an antibacterial agent. It is now known that polyester fabrics are highly valued for their versatile functionality, and demand is increasing. Especially in the health and care sector. Antibacterial coatings are frequently discussed and used in this context. This is because it is able to inhibit the ability of other pathogenic microorganisms, such as algae, fungi, and bacteria, to launch an attack [3]. Bacterial invasion is a major threat to health and can even lead to death. Among these health risks, nosocomial infections are the most dangerous. The risk of infection in hospitals and other healthcare facilities is high [4]. Most bacteria exist in the form of a biofilm and are diverse microbial communities that rely on extracellular production of extracellular products.

According to the extracellular polymeric substance (EPS), bacteria adhere to a solid surface and make it irreversible. Once the bacteria are immobilized, they inhibit the synthesis of the bacterial flagellum, leading to the formation of a mature biofilm. The bacteria then become resistant to the antibiotic, making it more likely that they will become chronic [5]. There are various methods to create a bond with antibacterial agents on the surface of polyester fabrics, such as grafting chemical initiators [6]. Grafting is done by electron beam irradiation [7]. Graft copolymerisation [8] Plasma treatment [9] In addition to the above methods, antibacterial activity is also achieved by some other methods. For this research, polyester fabrics were antibacterially treated using the pad dry cure method by esterifying the fabrics with betaine. The properties of polyester fabrics were changed by the alkaline process at high temperatures. Sodium hydroxide is a strong alkaline agent used to modify polyester fabrics. As a result, the strength, wettability, and aesthetic properties of polyester fabrics have changed [10]. Sodium hydroxide breaks the ester bonds on the surface of polyester fabrics and increases the polarity by reducing the non-polar groups, thereby increasing the hydroxyl ions and increasing the water absorption capacity [11]. In this study, betaine was used for the antibacterial finishing of polyester fabrics. Betaine is a naturally occurring compound found in various organisms, including plants, animals, and microorganisms. Chemically, it is a zwitterionic compound. This means that it contains both positive and negative functional groups in the same molecule [12]. Betaine is a quaternary ammonium compound (QAS) that makes polyester fabrics antibacterial, and treatment with Na_2HPO_4 increases the antibacterial effectiveness of polyester fabrics [13]. In fact, this compound is used in some medical applications. It can be consumed by humans, and a person can consume 400 mg per day [14]. Some reports claim that betaine is non-toxic to bacteria, while others show that this compound exerts a bacteriostatic effect in high concentrations [15]. Several betaine analogues have already been developed and proposed for use as antibacterial agents· [16] (QAS) Betaine forms amino groups on the surface of polyester fabrics, which inhibits bacterial growth and increases tissue performance. It increases the positive ions on the surface of the substance [17]. (QAS) is widely used because N atoms have a cationic charge and attract the surface of the cell membrane through ionic interaction, which destroys the surface, leading to leakage of intracellular components and cell collapse [18]. However, the analysis showed that the toxicity of these compounds increased their antibacterial activity [19]. (QAS) betaine has good results against the bacteria *E. coli* and *S. aureus* and was observed by XPS, SEM, Raman, and antibacterial assays [12]. In this study, we present a new, safe, and sustainable technology for the production of antibacterial agents using betaine as a grafting reagent. Experimental data showed that finishing with betaine has better antibacterial properties on the surface of polyester fabrics. Together with the simple process, which can be easily scaled up to industrial finishing production, this approach enables the development of environmentally friendly finishing technologies for the textile industry.

2. Experimental Section

2.1. Materials

Betaine ($C_5H_{11}NO_2$), sodium hydrophosphate (Na_2HPO_4), and methyl orange were purchased from Shanghai Macklin Biochemical Technology Company Limited, 169 Chugond Road, Shanghai Chemical Industrial Park, China. 100% polyester woven fabric was obtained from Suzhou Ke Chuan Textile Company Limited, China. Sodium hydroxide (NaOH), acetic acid, ethanol, and glutaraldehyde were purchased from Gaojing Fine Chemical Industry Company Limited, China.

2.2. Method

First, the polyester fabrics were cleaned with deionized water and dried. Next, a 4% solution of sodium hydroxide (NaOH) was prepared by mixing 100 ml of water with NaOH and treated at 80˚C for 30 minutes. The solution was then cooled to room temperature, and the fabrics were washed with deionized water. The pH was neutralized using acetic acid, and the fabrics were dried in an oven. The weight of the sodium hydroxide-modified fabrics was then recorded.

Subsequently, a solution of Na_2HPO_4 (5%) and betaine (10%) was prepared, and the pH of the solution was adjusted to 3. The alkali-treated fabric was immersed in the solution, and after 10 minutes, the fabric was removed. Excess chemicals were removed using a padding machine. The fabric was then weighed again, and the pickup percentage was determined. Next, the fabric was dried and cured at 160˚C for 3 minutes to fix the chemicals onto the fabric. Finally, it was washed three times with deionized water and dried in an oven.

2.3. Characterizations

To verify the chemical state of the elements on the surface of the samples, multifunctional X-ray photoelectron spectroscopy (XPS) was performed on a (ULTRA DLD, Shimadzu Ltd., Japan) at 450 W power. ATR-FTIR spectra were recorded on a spectrometer (Nicolet 5700, Thermo Electron Co, USA) in the scanning range of 4000 - 400 cm^{-1}. A Raman analyzer (Reni Shaw model, UK) was used to investigate the functional groups of the material. Both the unmodified and the modified PET tissue were subjected to Raman analysis. The samples were irradiated with 785 nm laser light to analyze them in the wavelength range of 200 - 3000 cm^{-1}. The surface morphology of the PET fibers in the selected tissues was analyzed by microscopic images from a scanning electron microscope (SEM) (Gemini SEM 500, UK) and an energy dispersive X-ray spectrometer (EDS). The adsorption of methyl orange was tested using a UV-Vis spectrophotometer (UV-2550, SHIMADZU) to estimate how much betaine molecule was grafted onto PET fabric. *Escherichia coli* (*E. coli*, ATCC 1555) and *Staphylococcus aureus* (*S. aureus*, ATCC 547) were used as test microorganisms to analyze and measure the bacteria of unmodified and modified PET tissue against the bacteria. The hand feel value was analyzed using the PhabrOmeter instrument (Nu Cybertec, Inc. USA) according to the AATCC test method. For the purpose of discussion, the hand feel index is defined as the sum of elasticity, softness and smoothness. The level of wicking of fabrics was determined in accordance with the standard FZ/T 01071-2008 "Capillary effect test method for textile fabrics". To analyse the water absorption capacity of the PET fabric grafted before and after the betaine. The tensile strength of the fabric samples before and after betaine grafting was measured using the electronic strength tester (Electronic Strength Tester, China) according to the American Society for Testing and Materials (ASTM) standard D2261. Six samples (200 mm × 50 mm) were measured for each sample.

2.4. Quantitative Estimation of Betaine Moieties Grafted on Polyester Fabrics

The approximate amount of grafting of betaine molecules with polyester fabrics depends on the concentration reduction of the methyl orange solution. Because the polyester fabrics have to determine the amount of solution absorbed. Modified and unmodified polyester fabrics (5 × 5 cm) were cut and immersed in methyl orange solution (30 mL, 0.011 mmol/L) for 10 minutes. After 10 minutes the fabrics were removed from the solution and the concentration of methyl orange was determined used UV-Vis Spectrophotometry machine whose solution absorbance value was 460 nm. This test was carried out 3 times and the amount of Betaine was determined with the help of the following formula.

$$m = \frac{\mathrm{C} \times \mathrm{V}}{\mathrm{M}} \quad (1)$$

Where C (mmol/L) is the concentration decrease, V (L) is the solution volume, M (g) is the quality of the fabrics, and *m* (mmol/g) is the Betaine quantity adsorbed by the polyester fabric. The quantity of Betaine moieties grafted on the polyester fabric is its difference from the original polyester fabric.

Pickup%: Pickup% is the ability of polyester fabrics or any other fabrics to absorb water. At first, weigh a dry fabric, then immerse the fabric in a chemical solution at room temperature or in solution for a specific period of time. Then the fabric was dewatered by a padding machine. By passing the fabrics through the rollers of the padding machine, the excess solution in the fabrics is removed. Another major reason for this process is that the fabric is subjected to a chemical treatment and then passed through the roller, which puts a lot of stress on the fabric. As a result, the chemicals in the solution can easily penetrate the surface of the fabric. After removing the excess solution with a padding machine, the fabric has to be reweighed. This weight shows how much water or solvent the fabric has absorbed. The rate at which fabrics absorb this water or solute is called *pickup*%. It's expressed by the formula below.

$$Pick\,Up\% = \frac{Wet\,Weight - Dry\,Weight}{Dry\,Weight} \times 100 \quad (2)$$

Through this research, the pickup of polyester fabrics after processing in chemical solutions has been calculated to be 77% ± 2%. This formula has provided a percentage representing the increase in weight of the fabric due to the absorption of water or solvent during the immersion process.

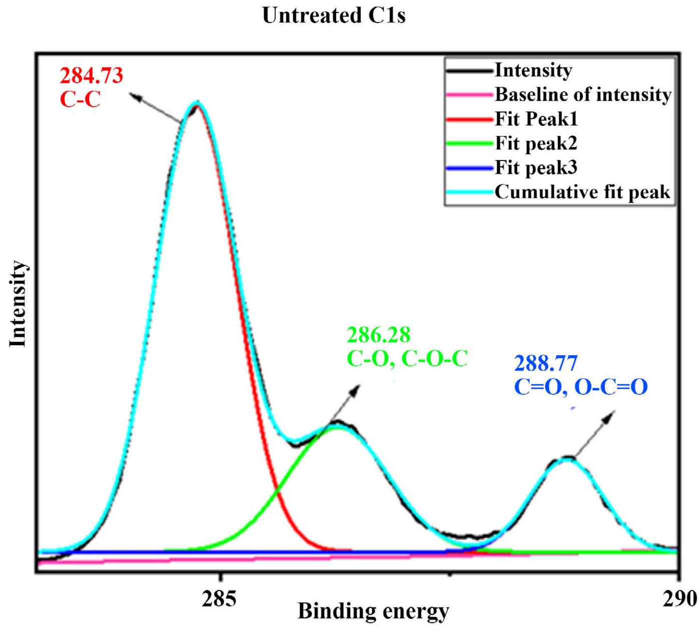
2.5. Preparation of Antibacterial Polyester Fabrics Finished with Betaine

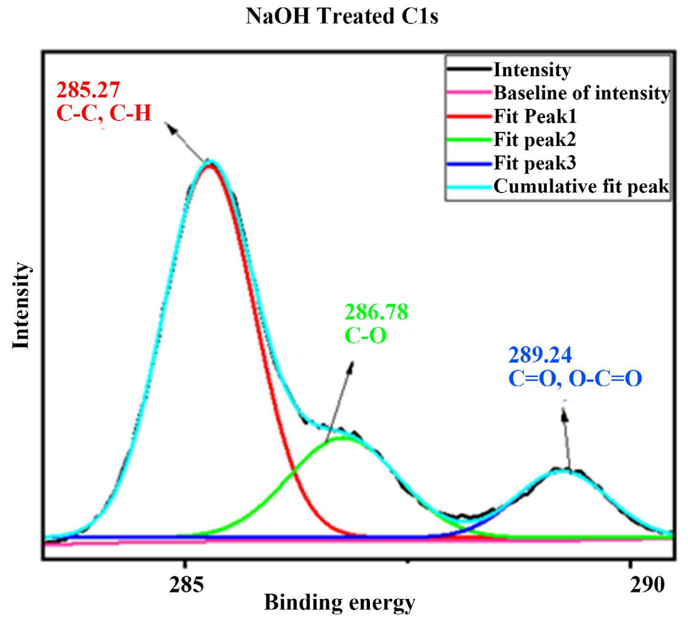
For antibacterial testing, polyester fabrics are suitable for testing after treatment with an antibacterial agent or quaternary ammonium salt. Then the test is done in the following way: *Escherichia coli* (*E. coli*, ATCC 1555) and *Staphylococcus aureus* (*S. aureus*, ATCC 547) were used as test microorganisms. Before the tests, the bacteria were incubated with Letheen broth fluid nutrient medium for 24 hours in a constant-temperature incubator. The polyester fabric (0.24 g) was cut into pieces, added into the castrated centrifuge tube with the actuated bacteria of *E. coli* or *S. aureus* (10 IL, 106 CFU/mL) and the castrated Letheen broth fluid nutrient medium (4 mL), and shaken at 25℃ for 18 h. The supernatant was adulterated to an applicable amount, dispersed onto LB agar, and incubated at 37˚C for 24 h. The bacteria reduction rate (BR) was calculated using this formula,

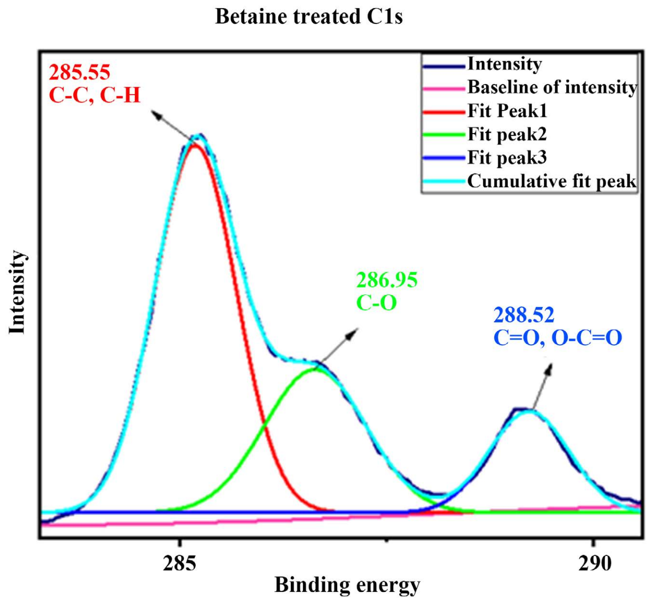
$$Reduction\,rate\% = \frac{A - B}{B} \times 100 \quad (3)$$

Where A and B are the number of colony-forming units (CFU) of the surviving microorganisms for the treated polyester fabric and the control sample (original polyester fabric) independently. Bacterial adhesion property of the Betaine-treated polyester fabrics. The fabric (one piece, 5 cm × 5 cm) was immersed in 20 mL of a bacterial result (*S. aureus* or *E. coli*, attention, 107 CFU/mL), incubated at 37℃ for 2 h, held vertically for 3 min to remove the redundant bacterial result, put into a fresh nutrient broth (20 mL), and incubated at 37℃ for 24 h with vibration at 120 rpm. The sample was washed using sterile water (50 mL × 3 times) and sterile PBS (50 mL × 3 times) to remove the free bacteria and treated with 2.5 wt% glutaraldehyde waterless result for 1 h to fix the bacteria remained. Washed using PBS (50 mL 3 times) and distilled water (50 mL 3 times). The fixed bacteria were dehydrated using a series of canted 50 mL ethanol results (50, 65, 85, and 100 wt, for 15 min each), dried in a dessicator overnight.

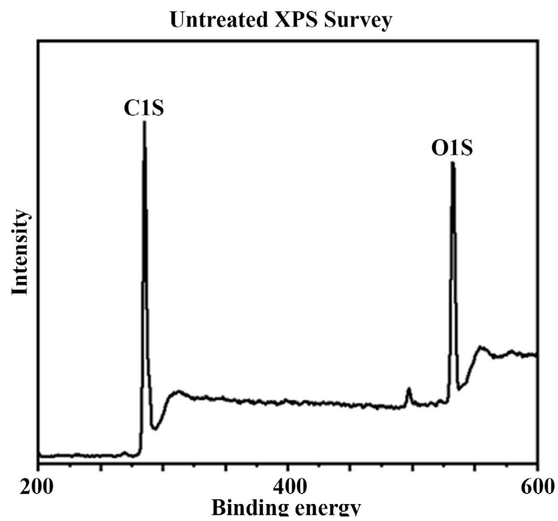
3. Results and Discussion

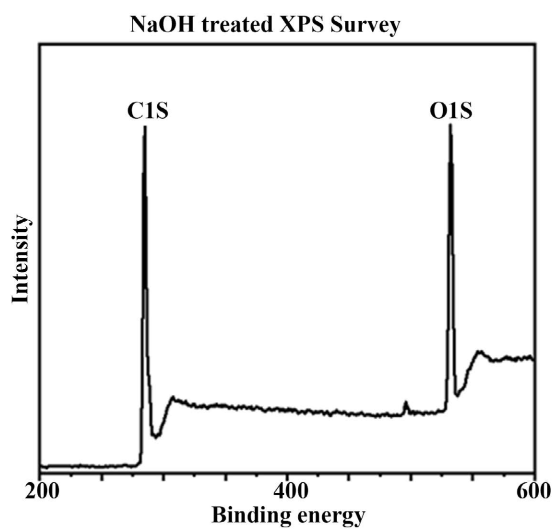


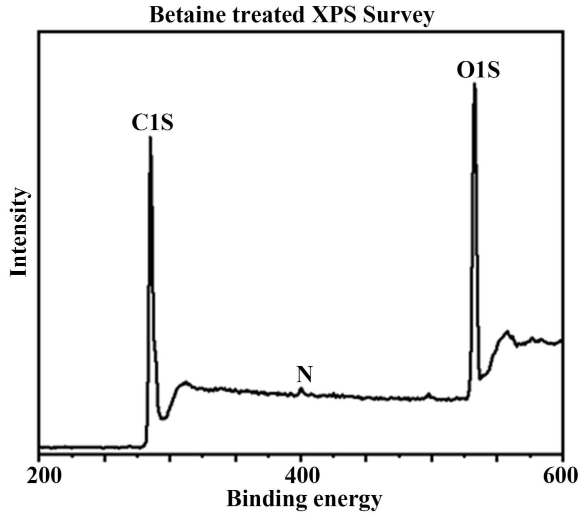



Betaine treated C1s
285.55
C-C, C-H
286.95
C-O
288.52
C=O, O-C=O
Intensity
Baseline of intensity
Fit Peak1
Fit peak2
Fit peak3
Cumulative fit peak
Intensity
285
290
Binding energy

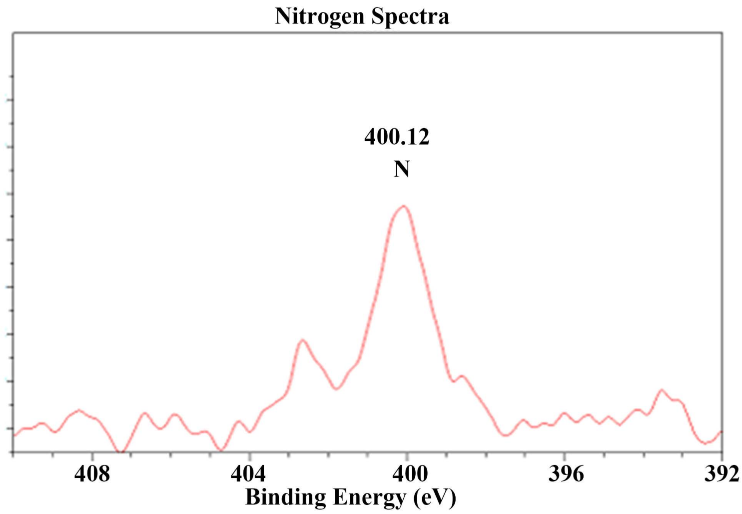
(a)


Untreated XPS Survey
C1S
O1S
Intensity
200
400
600
Binding energy


NaOH treated XPS Survey
C1S
O1S
Intensity
200
400
600
Binding energy



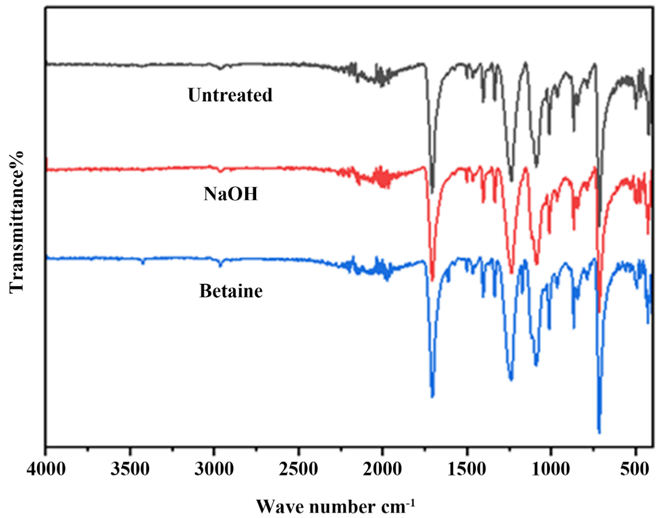
(b)



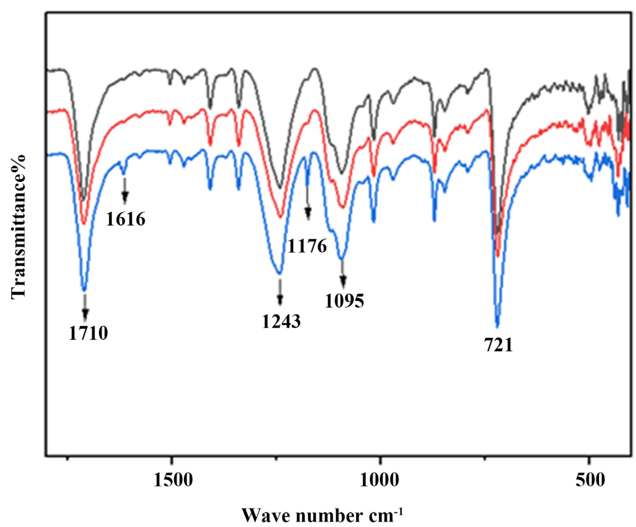
(c)

Figure 1. XPS Deconvoluted Cls XPS spectra of (a) original PET, alkali modified Pet, Betaine modified PET (b) XPS survey spectra of original PET, alkali modified Pet, Betaine modified PET, (c) Nitrogen spectra.

We look for or acknowledge the presence of C-C bonds, C-O bonds, and C=O bonds, as these bonds represent peaks, and we compare them with standard XPS data for polyester. In our result, we discovered the untreated C1s spectrum, C-C, C-O, C-O-C, and C=O, O-C=O, at 284.73, 286.28, and 288.77 eV (**Figure 1(a)**). After re-treatment of alkali-treated polyester fabric with an antibacterial agent or the quaternary ammonium compound Betaine, it was seen that the peaks of polyester fabrics treated with Betaine were different from the peaks of polyester fabrics treated with NaOH. The C1s peaks of samples treated with NaOH were 285.27, 286.78, and 289.24 eV (**Figure 1(a)**), and the bonds were C-C, C-H, C-O, C=O, and O-C=O [20]. After treatment with Betaine and Na_2HPO_4, the peaks increased to 285.55, 286.95, and 289.52 eV (**Figure 1(a)**). Similarly, the amount of oxygen and carbon elements obtained from the XPS survey graph treated with NaOH has also changed, and some new peaks have been added. The oxygen and carbon content of the untreated sample was 42.07% and 57.92% (**Figure 1(b)**), and the oxygen and carbon content of the NaOH-treated sample was 46.12% and 53.88% (**Figure 1(b)**), respectively. But after treatment with betaine and Na2HPO4, the oxygen element of the sample increased by 52.28%, the carbon element decreased by 46.45% (**Figure 1(b)**), and new nitrogen (N) peaks of 1.27% (**Figure 1(c)**) were formed [12]. Re-treatment of alkali-treated polyester fabric with betaine increased the positive ion of the sample and formed an amino group. Treatment of polyester fabrics with NaOH breaks the ester linkages in the polyester fabrics and increases the polarity by reducing the non-polar groups and increasing the hydroxyl ions, thereby increasing the water absorption capacity of the polyester fabrics. Re-treatment with betaine and Na_2HPO_4 further increased the hydroxyl ions of the sample, resulting in decreased carbon content and an increased oxygen element in the polyester fabrics. Along with that, the water absorption capacity of the fabric has also increased.



(a)



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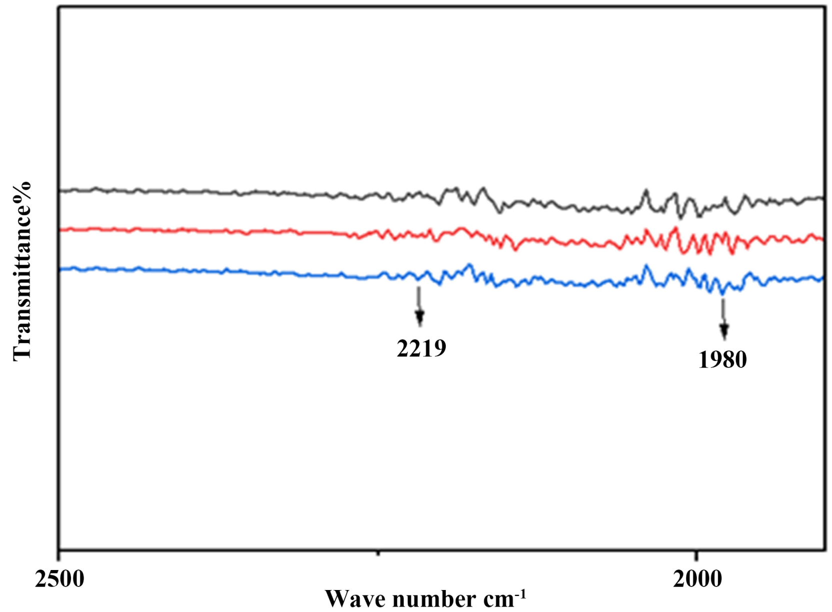
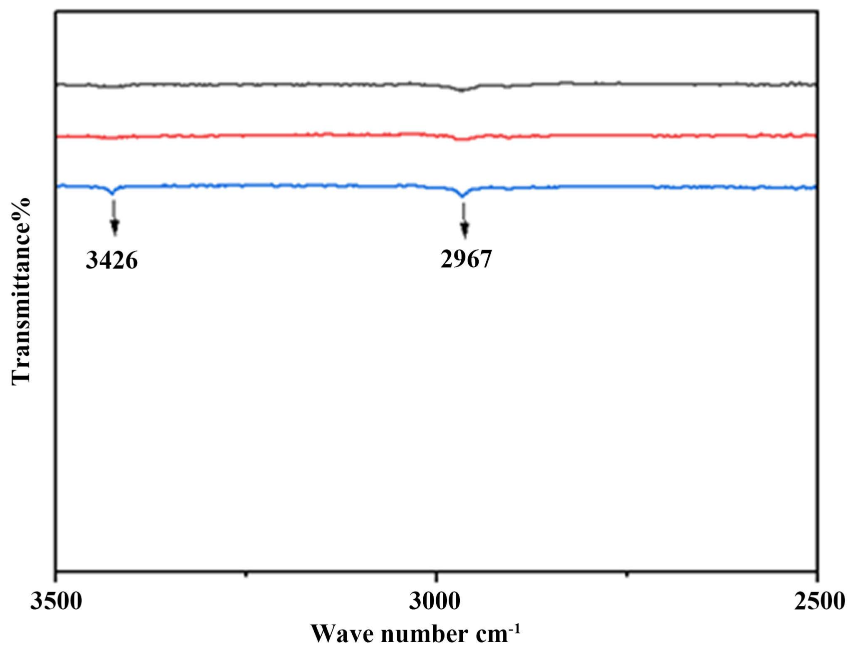


(c)



(d)

Figure 2. FTIR spectra of original PET, alkali modified PET, Betaine modified PET fabric.

Figure 2 shows the FTIR of PET and its subsequent treated samples. The PET shows the characteristic peaks at 2967 cm^{-1} for C-H aliphatic (two strong glycol C-H stretchings). 1712 cm^{-1} C=O stretching. 1577 cm^{-1} ring C-C stretching, 1506 cm^{-1} ring C-H in-plane bending. 1471 cm^{-1} CH_2 bending, O-C-H bending. The peak at 1409 cm^{-1} corresponded to the aromatic ring, which is a stable group. It was the characteristic absorption peak of PET. 1340 cm^{-1} CH_2 wagging, O-C-H bending. 1239 cm^{-1} C(=O)-O stretching, ring ester C-C stretching, C=O in-plane bending. C-O vibrations of the ester group at 1093 cm^{-1} and 1018 cm^{-1} indicate the presence of O=C-O-C or secondary alcohol, ring C-H in-plane bending. 968 cm^{-1} O-CH_2 stretching, C(=O)-O stretching, chain folding. 871 cm^{-1} ring C-H out-of-plane bending, ring ester C-C out-of-plane bending, and C=O out-of-plane bending. 844 cm^{-1} C=O in plane bending, C-H_2 rocking. 792 cm^{-1} ring C-H out-of-plane bending, C=O rocking, and CCO bending. C-H aromatic out of plane bending vibration at 721 cm^{-1}. Similar FTIR data for aminated polyester has been reported. After hydrazine treatment, these peaks have either broadened with the appearance of new peaks due to the N-H amine at 3426 cm^{-1} and the C-O vibrations of the ester group at 1176 cm^{-1}, shoulder at nearby 1616 cm^{-1} due to the carbonyl group, or shifted with enhanced intensity as a result of band overlap for those due to ester, indicating the success of hydrazide formation (PET hydrazide). The main structure of the polyester sample was ester, alcohol, anhydride, aromatic rings, and heterocyclic aromatic rings. Alcohol was able to react with anhydride and produce ester groups. This is a reason why there are still alcohol and anhydride as residual reactants left in the polyester. However, several new features that can be assigned to the carboxylate group are evident in this spectrum. These features include a broad band centred at 3426 cm^{-1} and an intense peak at 1712 cm^{-1}. The strong peak observed at 1340 cm^{-1} for betaine samples probably corresponds to the vibration of the bond between the $-CH_2N^+(CH_{3)3}$ group of Bet and the OH- ionic. Overall, the FTIR results suggest that acidic conditions favour the transformation of the carboxylate group, thereby promoting esterification reactions on PET fabric surfaces [21].

After treatment of PET fabrics with sodium hydroxide, there were some changes, such as the 1187 cm^{-1} peak disappearing and the 1615 cm^{-1}, 1728 cm^{-1}, and 1001 cm^{-1} (**Figure 3(a)**) peaks changing in position and intensity. Again, due to treatment with the antibacterial agent Betaine, changes were observed, such as the position and intensity of peaks at 1098 cm^{-1}, 1183 cm^{-1}, 1293 cm^{-1}, 1617 cm^{-1}, and 1729 cm^{-1}. The peaks at 1419 cm^{-1}, 1676 cm^{-1}, 1787 cm^{-1}, and 1827 cm^{-1} are newly created, and the intensities of the remaining peaks are changed. Raman spectrum of polyethylene terephthalate (PET) fabric with Raman shift and intensity There are two dominant, very intense bands at 1617 cm^{-1}, which is the C-C aromatic ring, and at 1729 cm^{-1}, carbonyl C=O (**Figure 3(b)**) stretching. 1098 cm^{-1} C-O and C-C stretch, 1183 cm^{-1} C-C and 1187 cm^{-1} C-C ring stretch, 1293 cm^{-1} CO-O stretch 1676 cm^{-1} C=O stretch. The band at 1419 cm^{-1} (**Figure 3(c)**) belongs to CH_2 or CH_3 groups [22]. Exhibit new Raman peaks that are not evident in the spectrum of the original fabric. These peaks are observed at around 1729 and 1419 cm^{-1}, and they are attributed to the carboxyl (COOH) bond or carbonyl group C=O and CH_3-N+ groups, and peaks at 3203 cm^{-1} are attributed to the hydroxyl-OH group of modified polyester fabric by treatment with Betaine, respectively [23]. Overall, the Raman results suggest that acidic conditions favour the transformation of the carboxylate group, thereby promoting esterification reactions on polyester fabric.

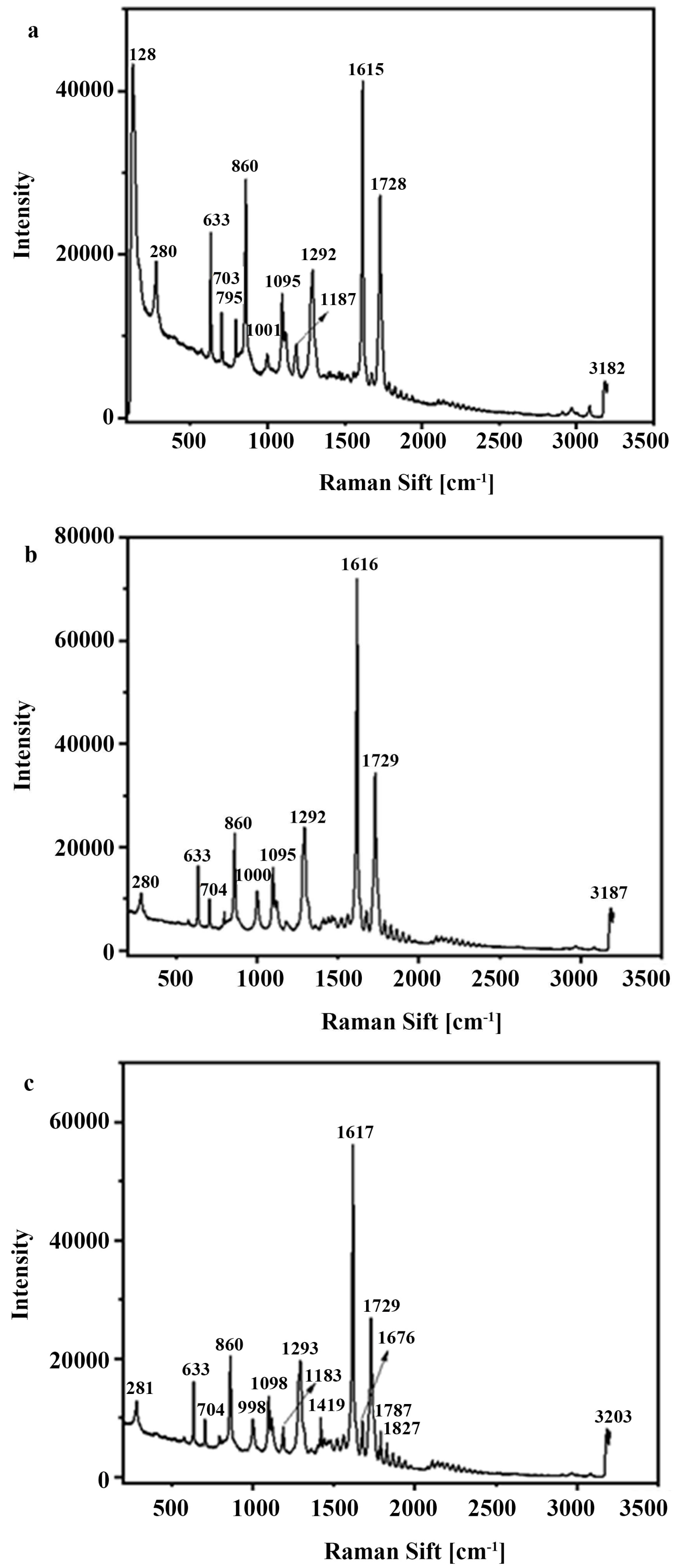


Figure 3. Raman spectra of (a) Original pet, (B) Alkali modified PET, (c) Betaine modified PET fabric.

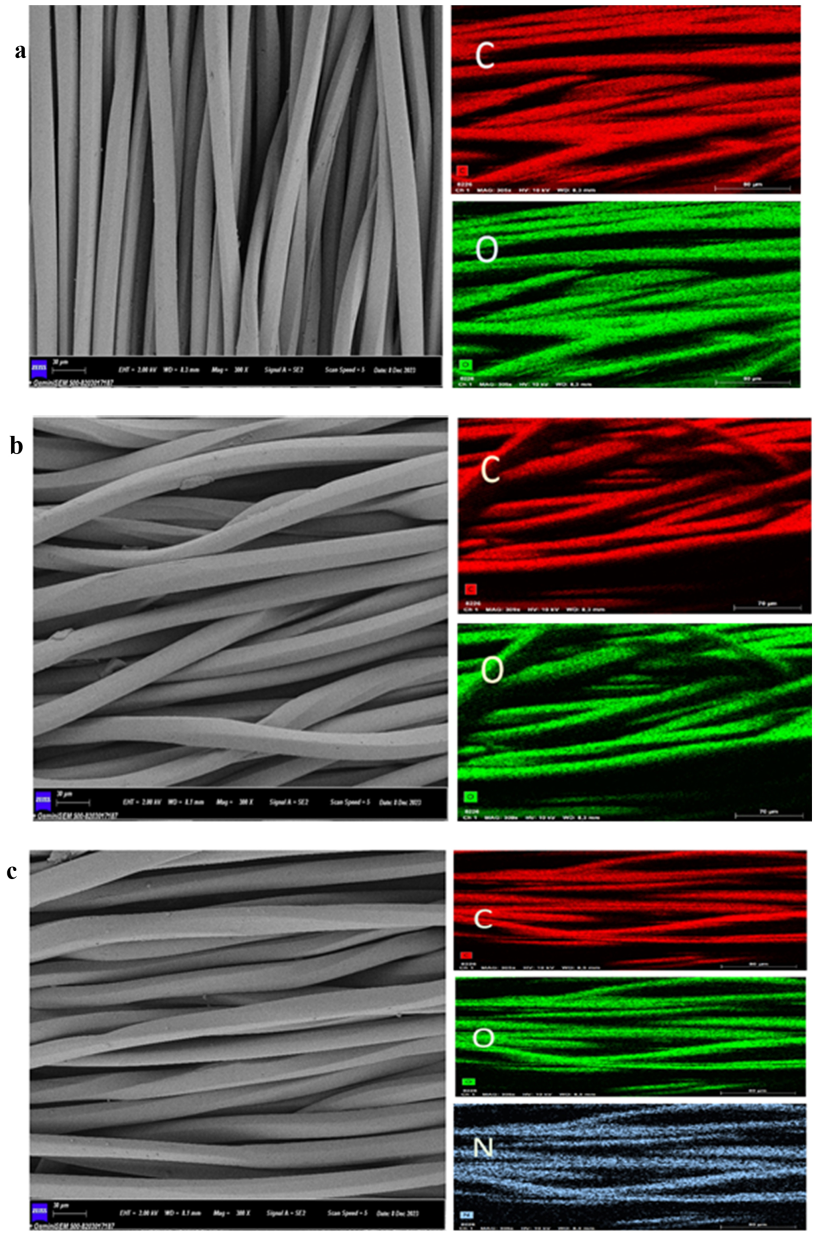
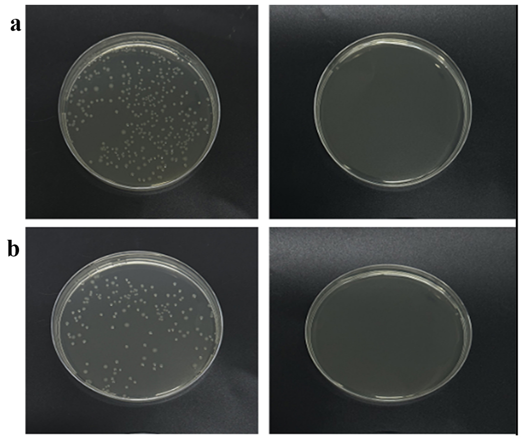


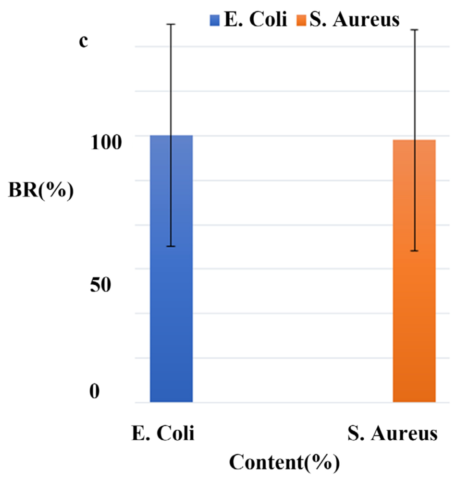
Figure 4. SEM images and elemental mapping (C, O, N) of the fiber surfaces in (a) original PET, (b) alkali modified PET, (c) Betaine modified PET fabric.

The SEM mapping test was performed in three steps after careful preparation of the samples. After the completion of the SEM mapping tests, the results of the sampling were collected in three stages. The elements carbon (c) and oxygen (o) were obtained from the unmodified sample (Figure 4(a)) of the first step, and the number of elements was noted. After treatment with sodium hydroxide (NaOH) in the second step, there are no changes with respect to the peak at the tissue surface (Figure 4(b)). The treatment with NaOH breaks the ester bonds of the surface of polyester fabrics, which increases the hydrophilicity and the absorption capacity for other chemicals. No new elements are created, but the number of elements changes. In particular, the amount of oxygen has increased, as NaOH reduces the non-polar group of the polyester fabric and increases the polarity and the hydroxyl ion. In the third step, the polyester fabric is also treated with betaine and sodium hydrophosphate (Na2HPO4). After treatment with betaine, a new nitrogen peak (N) was formed (**Figure 4(c)**) [11]. The aim of this research was to see the formation of ammonium groups on the surface of polyester fabrics after treatment with betaine. These ammonium groups play an important role in the production of antibacterial fabric. Betaine is a quaternary ammonium compound and contains an amino group (N) that is both positively and negatively charged. The results of the betaine-treated samples show that this treatment led to the formation of amino groups on the surface of the material [8]. The amount of carbon (c) also decreased, and the amount of oxygen increased.

The images show the antibacterial exertion of the undressed polyester fabric and the Betaine-treated polyester fabric against *S. aureus* and *E. coli*. Meanwhile, compare the statistically calculated BR values. The results indicate that Betaine retains excellent antibacterial exertion (BR 100%) against *E. coli* (**Figure 5(a)**) and (BR 99%) against *S. aureus* (**Figure 5(b)**) compared to the original polyester fabric (control sample). Likewise, the antibacterial function of the modified fabrics is durable after 10 times washing, with *E. coli* and *S. aureus* BR (**Figure 5(c)**) values maintained above 91.5% (**Figure 5(d)**) indeed after 20 cycles of laundering [12].



(a) E.coli, (b) S.aureus



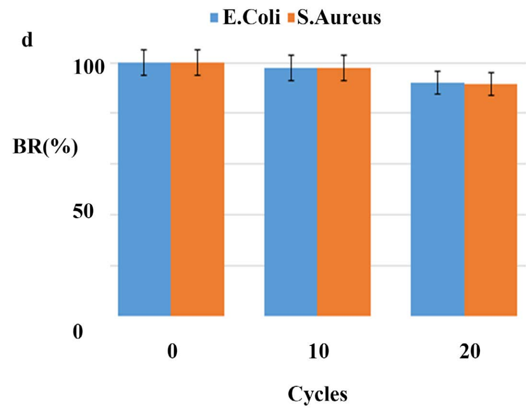


Figure 5. Optical images of the antibacterial tests against (a) *E. coli*, (b) *S. aureus*, (c) antibacterial rates of the Bet treated fabrics and (d) antibacterial durability of Betaine modified PET fabric.

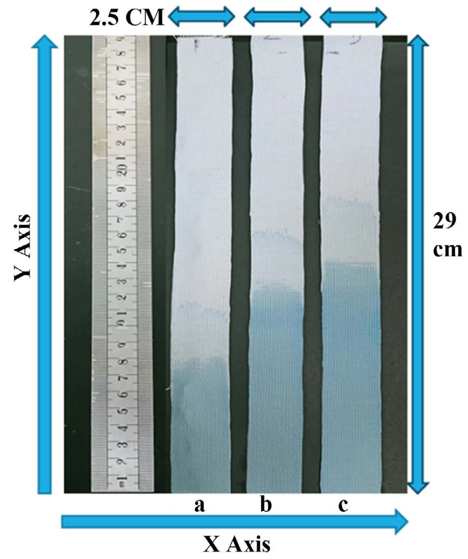
Polyester fabrics treated with betaine are tested to determine the approximate amount of betaine absorbed. The modified fabrics were immersed in a methyl orange solution, and the amount of solution absorbed by the fabrics and the amount reduced after absorption were checked by using a UV-Vis spectrophotometry machine. The results show that immersion of the modified fabrics in the solution resulted in reduced dissolution. The amount of betaine molecule grafting with polyester fabrics is determined by Equation (1).

Table 1. Results of the decrease in methyl orange concentration (MOD) and estimated beta moieties that grafted on the fabrics (BMF).

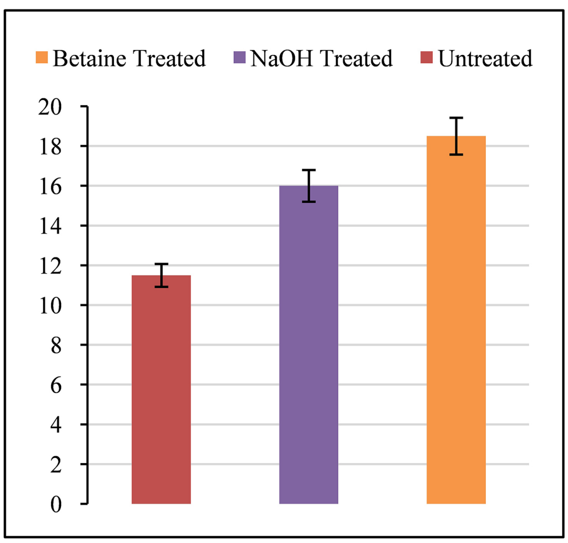
Sample	MOD[a] (mmol/L)	BMF[b] (mmol/g)
Original Polyester	18×10^{-4}	75×10^{-6}
Modified Polyester	70×10^{-4}	20×10^{-5}

This table shows the estimated quantities of Bet molecules that grafted on the polyester fabrics. (a) Decrease in methyl orange concentration (MOD); here we can see the original polyester fabric MOD is 18×10^{-4} and the modified polyester fabric MOD is 70×10^{-4}. (b) Estimated Bet moieties that grafted on the fabrics (BMF); also, here we can see the original polyester fabric BMF is 75×10^{-6} and the modified polyester fabric BMF is 20×10^{-5} (**Table 1**).

After sticking the samples to the stand according to the rules, 5 mm from the bottom of the samples were marked. This 5 mm part will be submerged in water. A clip weighing 3 grammes is attached to the lower part of the samples so that this part is well submerged in water [24]. After completing all the samples, a scale is placed next to the samples. Because it is easy to collect the results at the end of the test. Then the samples are carefully dipped together in a container of water. This test takes 30 minutes. After 30 minutes, the water container was removed, and the clips were removed from the samples. The results are then compared with the scale. When the results were collected after (**Figure 6(a)**) 30 minutes of testing, it was observed that the warp sample of untreated polyester fabric absorbed up to 9 cm of water. (**Figure 6(b)**) When the results were collected after 30 minutes of testing, it was observed that the warp sample of NaOH-treated polyester fabric absorbed up to 12.5 cm of water. When the results were collected after 30 minutes of testing, it was observed that the warp sample of Betaine and Na_2HPO_4-treated polyester fabric absorbed up to 14 cm of water. This test shows that treating untreated polyester fabric with NaOH modifies it and increases its water absorption capacity. Ester lingkase in polyester fabrics breaks down and increases hydroxyl ions, reduces non-polar groups, and increases polarity, resulting in increased water absorption capacity. Which makes it suitable for further processing and increases the water absorption capacity of Betaine and fabric, as well as making fabric with antibacterial ability.



(a)



(b)

Figure 6. Vertical wicking test of (a) unmodified PET (b) alkali modified PET.

Table 2. Hand feel results of the original PET, alkali modified PET, and betaine modified PET.

Sample	Stiffness	Softness	Smoothness	Drape
Untreated PET	54.59 ± 1.41	73.94 ± 0.35	96.94 ± 0.14	15.15 ± 1.04
NaOH treated PET	48.97 ± 0.33	76.31 ± 0.58	97.82 ± 1.05	12.83 ± 0.33
Betaine treated PET	51.65 ± 1.01	77.06 ± 0.44	94.96 ± 0.54	13.79 ± 0.93

In this table shows the results for the untreated PET, the PET treated with NaOH, and the PET treated with betaine. Here we see that the untreated PET has a stiffness of 54.59 ± 1.41, a softness of 73.94 ± 0.35, a smoothness of 96.94 ± 0.14, and a drape of 15.15 ± 1.04. The PET treated with NaOH has a stiffness of 48.97 ± 0.33, a softness of 76.31 ± 0.58, a smoothness of 97.82 ± 1.05, and a drape of 12.83 ± 0.33. PET treated with betaine has a stiffness of 51.65 ± 1.01, a softness of 77.06 ± 0.44, a smoothness of 94.96 ± 0.54, and a drape of 13.79 ± 0.93 (Table 2).

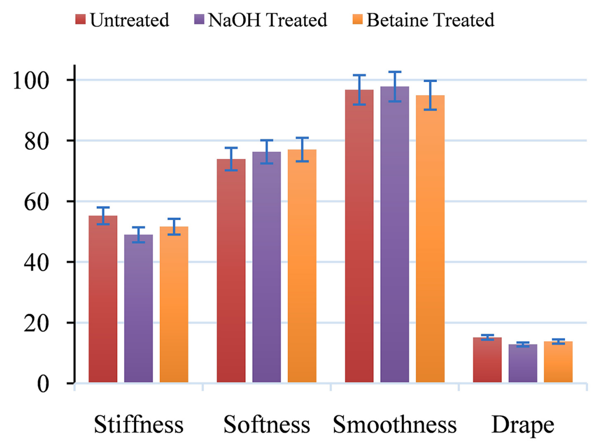


Figure 7. Hand feel.

After treatment of polyester fabrics with an antibacterial agent, the fabric is hand-felt tested. Figure 7 shows the handfeel results of the tested polyester fabrics. By observing the hand feel results, it can be seen that, compared to the original polyester fabrics, the results of the fabric treated with sodium hydroxide and the fabric treated with Betaine are slightly different. The stiffness, softness, smoothness, and drape index of polyester fabrics were tested. Here, compared to the original polyester fabrics, the fabric treated with sodium hydroxide and the fabric treated with Betaine have decreased stiffness, increased softness, and decreased smoothness and drape ability. Therefore, treatment of polyester fabrics with antibacterial agents has negative effects on the smoothness and drapeability of the fabrics. This demonstrates that antibacterial treatment has a slightly negative influence on the performance of smoothness and drapeability [25] [26].

Table 3. Tenacity results of the original PET, alkali modified PET, and betaine modified PET.

Sample	Warp	Elongation	Weft	Elongation
Untreated PET	741.67 ± 7.21	18.4 ± 0.44	2499.27 ± 18.15	46.83 ± 0.93
NaOH treated PET	721.84 ± 8.66	18.2 ± 0.26	2379.24 ± 17.81	38.54 ± 1.15
Betaine treated PET	717.44 ± 7.89	18.27 ± 0.32	2354.67 ± 16.62	37.44 ± 0.32

This table shows the results for the untreated PET, the PET treated with NaOH, and the PET treated with betaine. Here we see that the untreated PET has a warp of 741.67 ± 7.21, an elongation of 18.4 ± 0.44, a weft of 2499.27 ± 18.15, and an elongation of 46.83 ± 0.93. The PET treated with NaOH has a warp of 721.84 ± 8.66, an elongation of 18.2 ± 0.26, a weft of 2379.24 ± 17.81, and an elongation of 38.54 ± 1.15. PET treated with betaine has a warp of 717.44 ± 7.89, an elongation of 18.27 ± 0.32, a weft of 2354.67 ± 16.62, and an elongation of 37.44 ± 0.32 (Table 3).

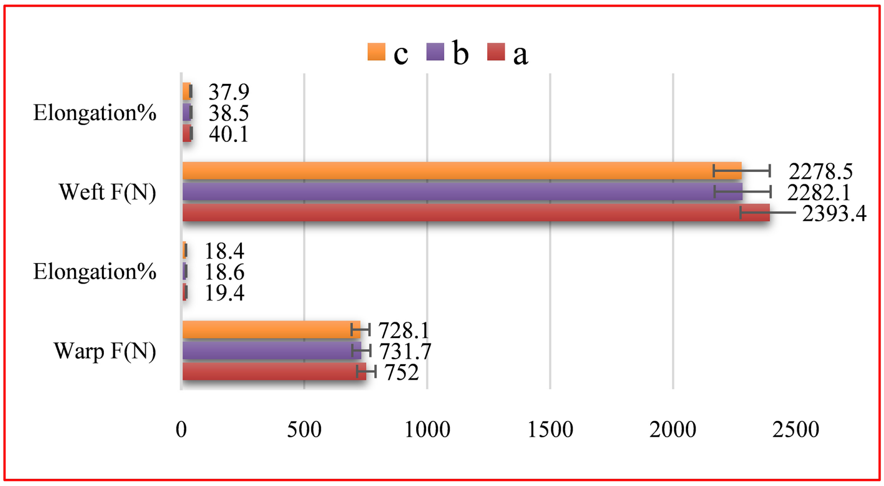


Figure 8. Tenacity.

The first sample of untreated polyester fabric in the warp direction is clamped well with the clamp of the machine so that the sample does not come out of the clamp due to tension from both sides. After setting the sample in the machine, the machine is switched on, and the amount of force and time taken to tear the sample are recorded. Thus, first, the warp and weft samples of untreated polyester fabric were tested. Samples treated successively with NaOH and lastly treated with Betaine with Na_2HPO_4 were tested, and the results were collected. Figure 8 shows the tenacity results of the tested polyester fabrics. The results observed showed that untreated polyester fabric samples took more energy and time to tear. Thus, it took slightly less energy and time to dissolve the NaOH-treated sample than the untreated sample [27]. Again, samples treated with betaine took slightly less energy and time to dissolve than samples treated with NaOH [28]. In fact, it is evident from this test that if untreated fabric is treated with different chemicals for a certain time at a certain temperature, the strength of the fabric decreases, as we have seen through this test. One thing to be careful about is that the strength of the treated fabric does not decrease too much. Then using fabric will make it unusable. As a result, treatment should be done with caution during chemical treatment.

4. Conclusion

In this research, quaternary ammonium compounds (Betaine) form covalent bonds on the surface of polyester fabrics through esterification reactions, increasing carbonyl and hydroxyl groups. Polyester fabrics produced through this process exhibit excellent antibacterial properties. These modifications do not affect the flexibility, absorbency, or tenacity of the polyester fabrics. The results of the study demonstrate that polyester fabrics surface-modified by grafting with Betaine exhibit 100% and 99% resistance against the bacteria *E. coli* and *S. aureus*, respectively, compared to untreated polyester fabrics. Even after 20 washes, the antibacterial efficiency of the modified fabrics remains above 91.5%. Betaine-modified fabrics also exhibit increased water hydrophilicity compared to the original fabrics, while tenacity remains consistent. Additionally, evidence of modification is observed through XPS, SEM, Raman, and hand-feel tests. Betaine, as a naturally occurring antibacterial agent, proves highly beneficial in the grafting process with polyester fabrics, presenting an environmentally friendly method for manufacturing antibacterial textile fabrics.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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