



Antimicrobial, UV Resistant and Thermal Comfort Properties of Chitosan- and *Aloe vera*-Modified Cotton Woven Fabric

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Abstract

Health and hygiene are the primary obligations for human beings to live comfortably and work with maximum safety. The aim of the present work is to develop environmentally friendly protective textiles. *Aloe vera* extract and chitosan on bleached cotton woven fabrics for medical and health care apparel. The modified fabric was tested for its resistance to the growth of gram-positive *Staphylococcus aureus* bacteria. The *A. vera* extract and chitosan were applied, alone or together, on cotton samples by the pad-dry-cure method, using critic acid as the cross-linking agent. The applications of 2 g/l chitosan and 2 g/l *A. vera* combinations on cotton fabric showed excellent antimicrobial resistance against gram-positive *S. aureus* bacteria. Bacteria were reduced by 81%, which was greater than the 6 g/l individually-treated result. After treatment, the tensile strength and whiteness index were tested. Thickness and crease recovery angle were increased. Soil degradation tests proved the bio-compatibility of the treated sample. The incorporation of chitosan and *A. vera* on the surface of the cotton fabric was investigated by FTIR, XRD and thermal analysis. The surface morphology of treated and untreated fabrics was evaluated using high resolution scanning electron microscopy. Air permeability, water vapour permeability and thermal conductivity indicate thermal comfort that was not significantly affected by finishing treatment. Finished cotton fabric also showed a significant improvement in UV-protection.

Keywords *Aloe vera* · Chitosan · Cotton fabric · Antimicrobial · Thermal comfort · Protective textiles

Introduction

Various types of pathogenic and non-pathogenic bacteria are present in the environment. Such bacteria attack both the human body and its apparel. Although non-pathogenic bacteria are not harmful for human beings, they still create staining, discoloration and degradation of textile apparel. Non-pathogenic bacteria can also generate bad odours.

An ideal antimicrobial finish must control, destroy or suppress the growth of microorganisms. Only this can prevent their negative effects, such as odour, staining and deterioration. A common hazard in hospitals and other health care centres is bacterial contamination of textile fabric surfaces. Fabric contamination can lead to infection and cross-infections. So, it is very important to reduce the migration of

pathogenic bacteria between people and clothing, by using antimicrobial finished textiles, in health care sectors [1, 2].

Nosocomial, or iatrogenic, infections are still clinically-significant problems despite advancements in the medical sector. A nosocomial infection is defined as an infection which commences within 72 h after admission to the hospital.

Staphylococcus aureus is one type of bacteria that may be responsible for nosocomial infection. *S. aureus* is also responsible for 19% of total surgical infections in the hospital. This organism can cause boils, skin infections, pneumonia, and meningitis [3–6]. This explains the selection of gram-positive bacteria (like *S. aureus*) as the focus for testing fabric resistance in this study.

Cotton fabric was chosen for testing in this research since cotton fabric is most suitable for medical textiles and apparel. Cotton is a most favourable environment for bacterial growth due to its hydrophilic nature. So the antimicrobial treatment of cotton fabric is the most suitable way to prevent the harmful activities of bacteria in medical facilities [7–9].

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On the other hand, ultraviolet radiation, up to 60 times as strong as the sun's rays, is harmful for human skin and also responsible for skin cancer. So, the ultraviolet protection factor (UPF) of clothing is now a serious issue in public health. To avoid this problem, most people now use sunscreens on the parts of the body that are exposed to the sun in developed countries. But sunscreens are not a complete solution to UV radiation, because ultraviolet radiation also enters the human body through the person's apparel. Again, a small amount of UV radiation is absorbed by colored fabric [10, 11]. UV protection finishing on textiles could be a practical solution to avoid the penetration of UVR through clothing and into the skin.

Aloe vera (*Aloe barbadensis* Miller) belong to the *Liliaceae* family. *A. vera* gel consists of about 99% water and the remaining 1% solid material consists of a range of compounds. Solids in *A. vera* gel include water-soluble and fat-soluble vitamins, minerals, polysaccharides, enzymes, phenolic compounds and organic acids [12, 13]. Among the ingredients, acemannan is the main functional component of *A. vera*. Acemannan is a long-chain polymer consisting of randomly-acetylated linear D-mannopyranosyl units. Acemannan has immuno-modulation, anti-bacterial, anti-fungal, and antitumor-formation properties. The structure of acemannan is shown in Fig. 1a [14–17]. Botanical research shows that *A. vera* exhibits antifungal properties as well as antibacterial and antiviral properties of its constituent acemannan [18–21]. Different extraction methods were examined in these cases, to compare the impact of extraction method on the antibacterial activity of *A. vera* thus extracted. Methanol, chloroform, petroleum ether and aqueous extraction were compared. Methanol extraction produced the best antibacterial activity, compared to the other extracts. The methanol extract of *A. vera* at the different concentration showed different zones of inhibition against *E. coli*, *B. subtilis*, *B. cereus* and *S. aureus* [22].

Chitosan is a natural polysaccharide, which is composed of randomly distributed β -(1 \rightarrow 4)-linked D-glucosamine (deacetylated unit) and N-acetyl-D-glucosamine (acetylated unit). It is obtained by alkaline deacetylation

of the chitin derived from shrimp shells and its structure is shown in Fig. 1b [23, 24]. The efficacy of chitosan for use as an antimicrobial finishing agent has been confirmed in several studies [23–26].

Thus, when any natural plant extract or natural polymer or chemical is applied on fabric, the application changes the fabric's surface properties as well as its comfort properties [27–30]. Comfort is a complex phenomenon that is very difficult to define, but discomfort can be easily described in such terms as prickly, itchy, hot and cold feelings [31]. Finally, a widely-accepted definition of comfort is 'A state of physical ease and freedom from pain and discomfort' [32]. Comfort is also defined as 'a enjoyable state of physiological, psychological, and physical harmony between a human being and the environment' [33].

Clothing comfort can be divided into three main categories: tactile comfort, thermal comfort, and psychological comfort [34]. Thermal comfort can be assessed by the air permeability of fabric, as well as its permeability to water and heat [35]. When the body temperature exceeds the standard temperature of 37 °C (98 °F), then perspiration is produced. This perspiration must be able to evaporate through the garments to allow the passage of sweat from body to atmosphere. If sweat is not evaporated properly, more sweat is secreted. When that happens, dehydration can occur, which will make a person more liable to accident or illness [36]. When moderate work is performed, metabolic heat, generated by the resulting body temperature rise, is 3 °C for 30 min. If heavy work is being done and impermeable clothing is worn, this rise could be achieved in 10 min [37].

Many researchers have worked on synthetic antimicrobial agents which are applied on cotton fabric with different binders. Many have gotten excellent antimicrobial results and wash durability. But they did not give any information about toxicity or the environment-friendliness of synthetic antimicrobial agents and binders [38–44]. Applications of natural antimicrobial agents have gained considerable attention in the fields of medical and health care textiles. They have built a reputation of being environment-friendly, skin-friendly, safe

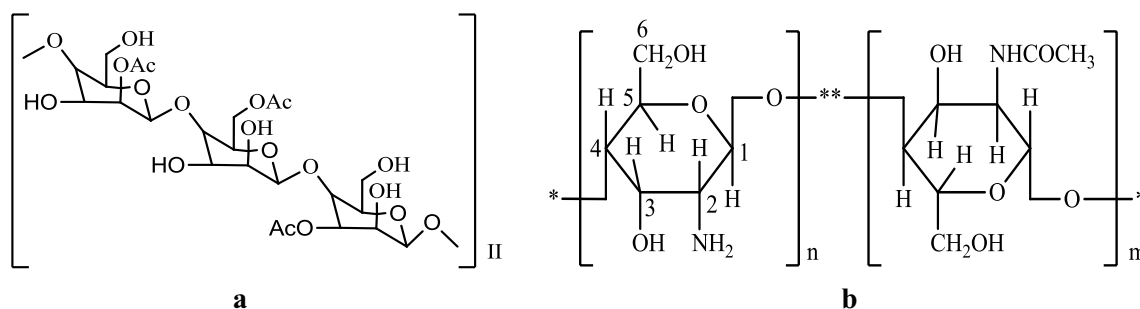


Fig. 1 Chemical structure of: **a** acemannan of *A. vera* and **b** chitosan derived from chitin

and non-toxic, when compared to synthetic anti-microbial agents [1].

For example, many researchers have experimented with the use of metals, such as silver [38–40, 43, 44], copper [41], triclosan and silver [45], silver and zinc oxide nano particle [46]. However, the use of metals raises significant health risks for wearers and significantly raises the cost for garment producers in developing countries. The metals are also not biodegradable, so they add to soil and possibly water pollution eventually. Organic, biodegradable products like chitosan and *A. vera* are absolutely harmless to humans and to the Earth. They are cheap and plentiful in developing countries. Chitosan is made from chitin, which is now a waste problem in shrimp production areas, it is so plentiful!

Chitosan and *A. vera* are a better solution than metals: for human health, for the Earth, and for keeping production costs and prices down in poor countries. Furthermore, as explained in the following paragraph, these metal studies are usually uni- or bi-dimensional, only considering the anti-microbial properties and sometimes wash durability of the resulting fabric. They do not consider other important issues for a human garment, like comfort, biodegradability, ultraviolet protection, etc. as we do.

Many researchers have worked with natural and synthetic antimicrobial agents, even *A. vera* and chitosan, on cotton fabric and observed antimicrobial and other properties. But they did not work through issues of thermal comfort properties, biodegradable attributes and the UV-protection factor.

The important difference in this study is that natural antimicrobial agents, which are available, cheap, biodegradable, non-toxic and safe for human health were tested for not only their antimicrobial properties but also their comfort, biodegradability and UV protection. This appears to be the first time that the whole range of human-suitability variables has been tested. All of these tests were done by statistically-valid means. Commercial use of materials which may be antimicrobial but not comfortable or biodegradable or UV-safe would be a public health, as well as a financial, nightmare.

The aim of the present work is to develop the range of medical and health care textiles, using natural, ecofriendly antimicrobial agents which are fully suitable for human clothing in every way. Thus, the present study is devoted to the combined effect of chitosan and *A. vera* on bleached cotton fabric. In this research, 100% cotton bleached woven fabric is defined as “untreated fabric”. This will be a novel method to produce bio-compatible protective textiles as well as to enhance other properties for human clothing suitability.

Experimental

Materials

100% cotton-bleached poplin fabric was collected from Akij Textile Ltd, Bangladesh. Fabric dimensions were 40 × 40/133 × 72. *A. vera* and chitosan were used as natural antimicrobial agents. *A. vera* leaves were collected from the local market in Rajshahi, Bangladesh. Citric acid was used as a cross-linking agent. Chitosan was produced from shrimp (or prawn) waste in our laboratory by Li et al. method [24]. Its molecular weight and degree of deacetylation were 138 kDa and 80%, respectively. Methanol was used to extract the *A. vera*. Acetic acid was used to dissolve the chitosan. All chemicals were purchased from Merck (Germany) and used without further purification.

Methods

Extraction of *Aloe Vera*

At first, the *A. vera* leaves were washed with distilled water. The *A. vera* gel was taken out from the leaves and dried in an oven at 60 °C until it was completely dry. The dried *A. vera* gel was ground by ceramic mortar pestle. Then the powder was soaked in methanol for a week. During this time, the bottles were covered with aluminum foil and kept in a dark room. After 1 week, the solutions were filtered using Whatmann filter paper. Then the solvent (methanol) was separated, using a rotary evaporator [47].

Modification of Bleached Cotton Woven Fabric with *Aloe vera* and Chitosan

Application of antimicrobial agents to cotton woven fabric was done according to the Buşilă method with little change. The required amounts of chitosan and *A. vera* extract were applied to the fabric by pad-dry-cure method with a padding machine, with two bars of pressure, at a material-to-liquor ratio of 1:15. After padding, the fabric was dried at 80 °C for 3 min and cured at 150 °C for 2 min. Then the fabric was conditioned for 4 h, in 27 °C temperature, at 65% relative humidity [46].

Determination of Different Properties of Finished Fabric

Weight Add-On Percentage

Chitosan and *A. vera* were applied to the fabric. As a result, the weight of the fabric increased. The weight add-on was calculated according to the formula [48].

$$\text{Weight add on (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \quad (1)$$

where W_1 and W_2 are the weight of untreated and treated fabrics.

Fabric Weight

Fabric weight per unit area was measured as per Standard ASTM-D 3776-96 [49].

Fabric Thickness

The principle of measurement of fabric thickness is expressed in B.S. 2544:1954 by James Heal's thickness gauge [50].

Tensile Test

Tensile strength of the samples was measured according to Grab test [51]. The test sample was cut into 4 in. × 6 in. swatches in warp direction. Samples were clamped in top and bottom jaw. After optimized the pretention, the machine was started. Its cell load was 3000 N and the machine worked at a constant rate of extension (CRE) of 100 mm/min, and after a certain time it was break.

Whiteness Index

The CIE whiteness index value was evaluated for the treated and untreated samples by the AATCC test method [52]. The whiteness index was measured by Data Color spectrophotometer (Model No. TM 650, USA).

Absorbency Test

The absorbency of chitosan and *A. vera*-treated fabric was observed by the wicking method. Wicking was done by dispersing liquid through a material vertically or horizontally with the capillary action of the liquid [53].

Crease Recovery

The fabric crease or wrinkle recovery angle was determined according to the procedure described in AATCC 66-2010, using a Shirley crease recovery tester [54].

Abrasion Resistance

The abrasion resistance was tested in accordance with ASTM D 4966-98 by using a Martindale Abrasion Tester [55].

Quantitative Antibacterial Test

Antibacterial activity against Gram-positive bacteria (*S. aureus*) was tested. The bacterial population (total colony-forming units) of treated and untreated samples was determined by AATCC-100 standard [56]. As per the standard, a test sample of 2" × 2" was cut and put into five 50 ml conical flasks, each containing 20 ml of the nutrient broth and 20 μl of microbial culture was added. All the flasks were kept in a shaker incubator with 200 rpm at 37 °C for 24 h. The incubated test culture in the nutrient broth was diluted five times with sterilized distilled water. 20 μl of each dilution was spread in a nutrient agar petri dish. All the inoculated plates (untreated and treated samples) were incubated at 37 °C for 24 h. After 24 h, the surviving cells were counted. The percentage reduction was calculated using the following equation:

$$\text{Bacterial colony reduction (\%)} = \frac{(B - A)}{B} \times 100 \quad (2)$$

where A is the number of surviving cells (CFU/ml) for the flasks containing the treated samples and B is the number of surviving cells (CFU/ml) for the flasks containing the untreated sample.

Qualitative Antibacterial Test

The inhibition zones of treated and untreated samples were determined, according to AATCC-147 standard using the parallel streak method [57]. The zone of inhibition was calculated as per the following equation:

$$W = \frac{T - D}{2} \quad (3)$$

where W is the width of the clear zone of inhibition in mm, T is the total diameter of test specimen and clear zone of inhibition in mm, and D is the diameter of the test specimen in mm.

Wash Durability Test

The treated fabric was subjected to washing by industrial machine and the antibacterial activity of the washed sample was evaluated by the AATCC-100 and AATCC 124 test standards respectively [56, 58].

Measurement of UV Protection Factor

The UPF was measured by UV spectrophotometer (Shimadzu 1650, Japan). The UPF was calculated according to the AATCC test method [59] by the following equation:

$$\text{UPF} = \frac{\sum_{280}^{400} E_{\lambda} \times S_{\lambda} \times \Delta_{\lambda}}{\sum_{280}^{400} E_{\lambda} \times S_{\lambda} \times \Delta_{\lambda} \times T} \quad (4)$$

where E_{λ} is erythemal spectral effectiveness, S_{λ} is solar spectral irradiancies, λ is the wavelength in nm, T_{λ} is the spectral transmission of the fabric and Δ_{λ} is the measured wavelength intervals in nm.

Thermal Conductivity

Thermal conductivity (K) is the ability of the material to conduct heat. Thermal conductivity was measured with a Lee disc Apparatus [60] by the following formula:

$$\text{Thermal conductivity, } K = \frac{msd \times \frac{d\theta}{dt}}{A(T_1 - T_2)} \quad (5)$$

where K is thermal conductivity of the sample, m is the mass of the brass disc, S is the specific heat of the material of the disc; d is the thickness of the specimen in mm; $\frac{d\theta}{dt}$ is rate of cooling, A is the area of cross-section of the specimen; T_1 is the highest steady temperature and T_2 is the lowest steady temperature.

Thermal Resistance

Thermal resistance means resistance to heat flow. Thermal resistance is inversely proportional to thermal conductivity. It was calculated according to the BS 4745 test [61] by the following equation:

$$\text{Thermal resistance, } R = \frac{h}{\lambda} \quad (6)$$

where h is thickness of the sample and λ is thermal conductivity.

Water Vapor Permeability

Water vapor permeability was assessed according to the BS 7209 test [62] by the following formula:

$$\text{Water vapor permeability} = \frac{24M}{At} \text{ gm/m}^2/\text{day} \quad (7)$$

where M is loss of mass in grams, A is the area of the exposed test specimen in m^2 and t is the time between successive weighing of the assembly in hours.

Air Permeability

The air permeability of a fabric is the volume of air, measured in cubic centimeter passed per second through one square centimeter of the fabric at a pressure of 1 cm of water. Air permeability was evaluated by air flow method [63]. Three samples were tested in each group and expressed as $\text{cm}^3/\text{cm}^2/\text{s}$. Sample size was $4 \times 4 \text{ cm}^2$.

Soil Degradation Test

The soil degradation test was carried out according to the Swain method with some modification. Treated and untreated samples were kept under soil six inches deep in four pots filled with approximately 750 g soil and 250 g cow dung each. Sparkling 100 ml water was added to the pots at regular time intervals. The degradation of the samples was determined by weight loss after 30 days. The samples were carefully removed from the soil and washed with water gently, then dried in the sunlight. The weight loss was determined by the following equation [64].

$$\text{Weight loss (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad (8)$$

where W_1 is the initial weight and W_2 is the after-burial weight.

Fourier Transform Infrared Spectrophotometer (FTIR)

All samples and potassium bromide (KBr) were dried at $105 \text{ }^\circ\text{C}$ for 10 h. The samples were mixed with KBr, using mortar and pestle, to make a powder in the mass ratio 1:100 (1 mg sample and 100 mg KBr). Again, mixed samples were dried at $105 \text{ }^\circ\text{C}$ for 10 h [65]. Then the sample was analyzed with a FTIR spectrophotometer (Spectrum-100, Perkin Elmer, USA) using the scanning range of $400\text{--}4000 \text{ cm}^{-1}$.

Scanning Electron Microscopy (SEM)

SEM (Model- Phenom G2 pro, Netherland) was performed to investigate the surface morphology and thus to confirm the binding to the fabric of antibacterial agents and their alignment on the fabric sample. Samples were tested at a magnification of $\times 5100$ and were scanned at 5 kV.

X-Ray Diffraction (XRD) Analysis

The XRD patterns were recorded, using dry powdered samples, on a PAN Analytical X Pert PRO X-ray diffractometer, using Cu K α radiation of wavelength 1.5406 Å, as the X-ray source. The measurements were carried out at a scanning rate of 5°/min in a range of 10°–60°. The peak width at half maximum in the XRD has been used to determine the crystal diameter as per the following Debye–Scherrer formula [66].

$$D = \frac{K\lambda}{\beta \cos \theta} \quad (9)$$

where $K (=0.9)$ is the Scherrer constant, $\lambda = 1.5406 \text{ \AA}$ is the X-ray wave length, β is the peak width of half maximum and θ is the Braggs diffraction angle.

Thermal Properties

The thermal stability of the untreated and treated samples was studied by a simultaneous TGA, DSC thermal analyzer

(Jupiter, Germany). The temperature range 20–600 °C was used for analysis at a heating rate of 10 °C/min, in a nitrogen atmosphere. The weight loss of the sample was continuously recorded as a function of temperature.

Statistical Analysis

Correlation coefficients were calculated according to the Karl Pearson's formulae [67]. The test of hypothesis was carried out by Chi square method at 5% level of significance [68].

Results and Discussions

In this investigation, 100% cotton-bleached poplin fabric was finished with chitosan and *A. vera* in the presence of citric acid as cross-linking agent. Chitosan and *A. vera* were also applied together on cotton fabric.

From Table 1, it can be seen that weight add-on percentage increased with increase of antimicrobial agent concentration, since more extract attached to the fabric during finishing. As a result, the GSM of treated fabric also increased. These findings are in accordance with Puwar's [69] report that weight add-on percentage increased with increase in concentration of neem bark extract. The add-on percent of chitosan-treated fabric was higher than that of *A. vera*-treated fabric, in the same concentration, due to the high degree of affinity of chitosan to cotton fabric. That is why

Table 1 Weight add-on (%), thickness, GSM and absorbency of chitosan and *A. vera* treated fabric

Observation	Weight add-on (%)	Fabric weight (g/m ²)	Fabric thickness (cm)	Absorbency height (cm)	Tensile strength (N)
Untreated	–	122	0.021	4.8	1148
2 g/l chitosan	2.8	125	0.025	5.0	820
4 g/l chitosan	4.2	127	0.027	6.2	795
6 g/l chitosan	5.4	129	0.029	7.6	750
2 g/l <i>A. vera</i>	1.6	123	0.022	4.0	920
4 g/l <i>A. vera</i>	2.2	124	0.023	3.4	890
6 g/l <i>A. vera</i>	2.7	125	0.024	3.0	858
Combined ^a	3.9	126	0.025	4.7	940

^aCombined means 2 g/l *A. vera* and 2 g/l chitosan

Table 2 Abrasion resistance and soil degradation test result (sample buried for 30 days) of treated and untreated samples fabric

Observation	No. of rub cycles	Abrasion resistance	After soil degradation weight loss (%)
Untreated fabric	10,000 cycles	No thread breakage	71
4 g/l Chitosan-treated	10,000 cycles	No thread breakage	38
4 g/l <i>Aloe vera</i> -treated	10,000 cycles	No thread breakage	50
Combined treated fabric	10,000 cycles	No thread breakage	41

chitosan-treated fabric became higher in GSM weight and also thicker.

From the wicking test, it was found that absorbency sharply increased with increase of chitosan concentration but decreased with increase of concentration of *A. vera* extract. The combined antimicrobial agent (2 g/l chitosan and 2 g/l *A. vera*) treated fabric absorbency was 4.7, which is higher than 4 g/l *A. vera*-treated fabric and lower than 4 g/l chitosan-treated fabric. These results indicate that chitosan exhibited more absorbency.

Conversely, it can be also seen from Table 1 that, with the increase of finishing agent concentration, the tensile strength of the treated fabric decreased in all cases. The strength loss of combined-treated fabric was minimal. Maximum strength loss happened in the 6 g/l chitosan-treated sample. This was probably the result of hydrolysis of cotton cellulose macromolecules during treatment, in the presence of citric acid. The results of other publications support this finding [70–72].

Thread breakage was not seen at 10,000 rubs per cycle (Table 2) in chitosan- and *A. vera*-treated samples. Thus, antimicrobial finish did not influence the abrasion resistance of cotton fabric. Perhaps the reason for this is that the antimicrobial finish did not have any detrimental effect on the chemical structure of cellulose in the fabric. Bonin's results also were similar to these findings [73].

The maximum weight loss as a result of soil degradation was that of the untreated sample. Microorganisms in the soil attacked the untreated fabric quickly, in the absence of any treatment to inhibit them. According to Table 2, the least degradation (38%) occurred in the 4 g/l chitosan-treated sample, which proves the strong antimicrobial activity of chitosan. The soil degradation of *A. vera*-and chitosan-(combined) treated sample was next least, with 41% weight loss. On the other hand, weight loss was 50%, for only *A. vera*-treated samples. Thus, chitosan had the strongest antimicrobial effect underground in every test. The soil

degradation results prove that treated samples are still biodegradable and, thus, environmentally-friendly, although the treated samples resist soil degradation moderately.

Table 3 shows that whiteness decreased about 15% with 4 g/l chitosan treatment, 30% with chitosan–*A. vera* combination treatment and 47% with 4 g/l concentrated *A. vera* treatment. Thus, chitosan-only treatment is best to preserve fabric whiteness, noting that some deterioration of whiteness is inevitable with anti-microbial treatment. EI-Thalaway et al. and Dhiman et al. studied whiteness index of chitosan-treated fabric and also got lower WI values compared to untreated samples [45, 70].

Table 3 also shows that the treated cotton fabric showed greater crease recovery as compared to the untreated cotton fabric. This is because the thickness of treated fabric is greater than in untreated fabric. Among the treated fabrics, the largest crease recovery angle was found in 6 g/l chitosan-treated cotton fabric. The average transmittance value of combined-treated fabric is least. The average transmittance value slowly decreased as *A. vera* and chitosan concentration increased. Untreated fabric was shown to have the greatest average transmittance value. More UV transmittance value indicates a greater health risk.

Generally, UV rays are absorbed by the ozone layer. But, at present, UV rays come to earth easily due to climate changes as well as depletion of the ozone layer. UV rays cause skin damage such as sunburn, premature skin ageing, allergies and skin cancer.

Figure 2 shows the highest UPF in the combined treated sample. It is ten times higher than that of the untreated sample. Because polyphenols in *A. vera* may help to block the UV rays and flavonoids, sinapate esters in methanolic extracts of *A. vera* can absorb UV rays [74, 75]. In addition, chitosan contains two chromophoric groups,

Table 3 Whiteness index (WI), average UV transmittance value and crease recovery angle (CRA) of treated and untreated fabrics

Observation	Whiteness index	Average UV transmittance value	Crease recovery angle (°)
Untreated	64	2.79	120
2 g/l chitosan	59	0.57	125
4 g/l chitosan	55	0.53	132
6 g/l chitosan	52	0.51	140
2 g/l <i>A. vera</i>	39	0.54	124
4 g/l <i>A. vera</i>	34	0.50	130
6 g/l <i>A. vera</i>	28	0.48	135
Combined ^a	45	0.28	126

^aCombined means 2 g/l *A. vera* and 2 g/l chitosan

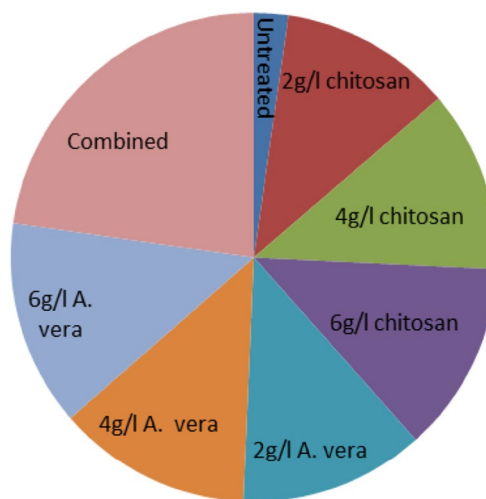


Fig. 2 UV protection factor (UPF) of treated and untreated fabrics

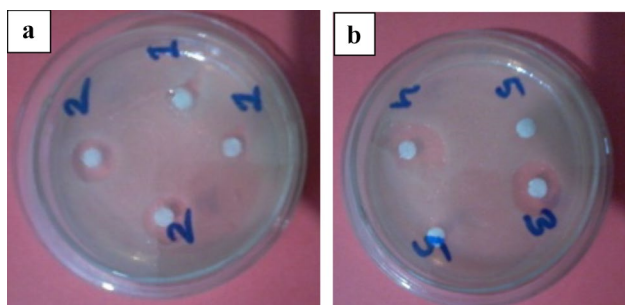


Fig. 3 Antimicrobial activity of *A. vera* extract (a) and chitosan (b) solution against *S. aureus* gram-positive bacteria

N-acetylglucosamine and glucosamine. These are obtained through partial deacetylation of chitin [76]. These chromophoric groups assist in UV resistance. Thus, *A. vera* and chitosan together have the strongest UV resistance, as they both absorb UV range light. The UV protection factor of the *A. vera* treated sample, alone, was just above that of the chitosan-treated sample.

Chitosan may create a transparent film on the cotton fabric which allows UV rays through the fabric [77]. In addition, UPF rating increases by increasing the concentration of chitosan and *A. vera* from 2 to 6 g/l. Chitosan- and *A. vera*- treated fabrics have a lower transmittance value than untreated fabric (Table 3). This means that the chitosan and *A. vera* help to absorb more UV rays and protect the human body. Ktob et al. worked on cotton fabric modification by chitosan and other UV protective agents [77]. They found a UPF rating of 12 for 20 g/l chitosan-treated fabric a UPF rating of untreated cotton fabric of 5. Singh studied cotton fabric modification by *A. vera* and reactive dye, and found improved UPF value after treating the *A. vera* on reactive dyed cotton fabric [78].

Figure 3a shows 2 g/l and 4 g/l *A. vera* solution (numbers 1 and 2, respectively). On the other hand, Fig. 3b shows 2 g/l and 4 g/l chitosan solution (numbers 3 and 4, respectively). The number 5 indicates the untreated sample that did not

show any zone of inhibition. Numbers 1, 2, 3, and 4 each showed a clear zone of inhibition. Chitosan solution had a better zone of inhibition than did *A. vera* extract solution.

In the colony count test, Table 4 shows that the bacterial reduction rate increased with the increase of concentration of chitosan and *A. vera*. Bacterial reduction rates of 2 g/l, 4 g/l and 6 g/l for chitosan-treated fabric against *S. aureus* reached 56%, 66% and 76%, respectively. Bacterial reduction rates for 2 g/l, 4 g/l and 6 g/l *A. vera*-treated fabric reached 40%, 50% and 58%, respectively. The bacteria reduction rate of combined antimicrobial agent (2 g/l chitosan and 2 g/l *A. vera*) treated fabric was 81%. But the bacteria reduction rate of each individual chitosan and *A. vera*- treated fabric, at a concentration of 4 g/l, was lower than that with combined-treated fabric, amounting to 66% and 50%, respectively. Other studies have shown that *A. vera* and neem hybrid combination also showed the highest level of antibacterial activity as compared to *A. vera* or neem separately [79]. The reason behind these findings is that, when one antimicrobial agent is applied on a textile surface, less functional groups are created. Conversely, two antimicrobial agents form more functional groups on the textile surface and thus show a synergistic effect. As a result, the greater number of new functional groups present in antimicrobial-treated textiles attack the cell walls of the bacteria and inhibit their growth greatly. So, it can be said that combined antimicrobial agents illustrate more biocidal activity compared to that of single antimicrobial agents [48].

The durability of antibacterial activity, after repeated washing, was also assessed. The results clearly indicate the decrease in bacterial reduction with subsequent washing. The bacterial reduction in case of *S. aureus* was from 76 to 53% for 6 g/l chitosan-treated fabric and 58–38% for 6 g/l *A. vera*-treated fabric after 10 washes. It was observed that all the treated fabric samples retained 60–70% antimicrobial activity up to ten washing cycles. This lesser degree of antimicrobial activity was owing to hydrogen bonds and weak van der Waal's forces existing between the cellulose and anti- bacterial agents [79]. Sathianarayanan also found

Table 4 The antibacterial activity of bleached cotton fabric treated by chitosan and *A. vera* against *S. aureus*

Observation	No of colonies	Bacterial reduction (%)	Bacterial reduction (%) after five washes	Bacterial reduction (%) after ten washes	Inhibition zone in mm
Untreated	824	00	00	00	00
2 g/l chitosan	360	56	40	30	1.4
4 g/l chitosan	280	66	50	42	1.7
6 g/l chitosan	202	76	65	53	2.1
2 g/l <i>Aloe vera</i>	492	40	32	25	1.0
4 g/l <i>Aloe vera</i>	410	50	40	32	1.2
6 g/l <i>Aloe vera</i>	350	58	50	38	1.5
Combined	160	81	70	58	2.3

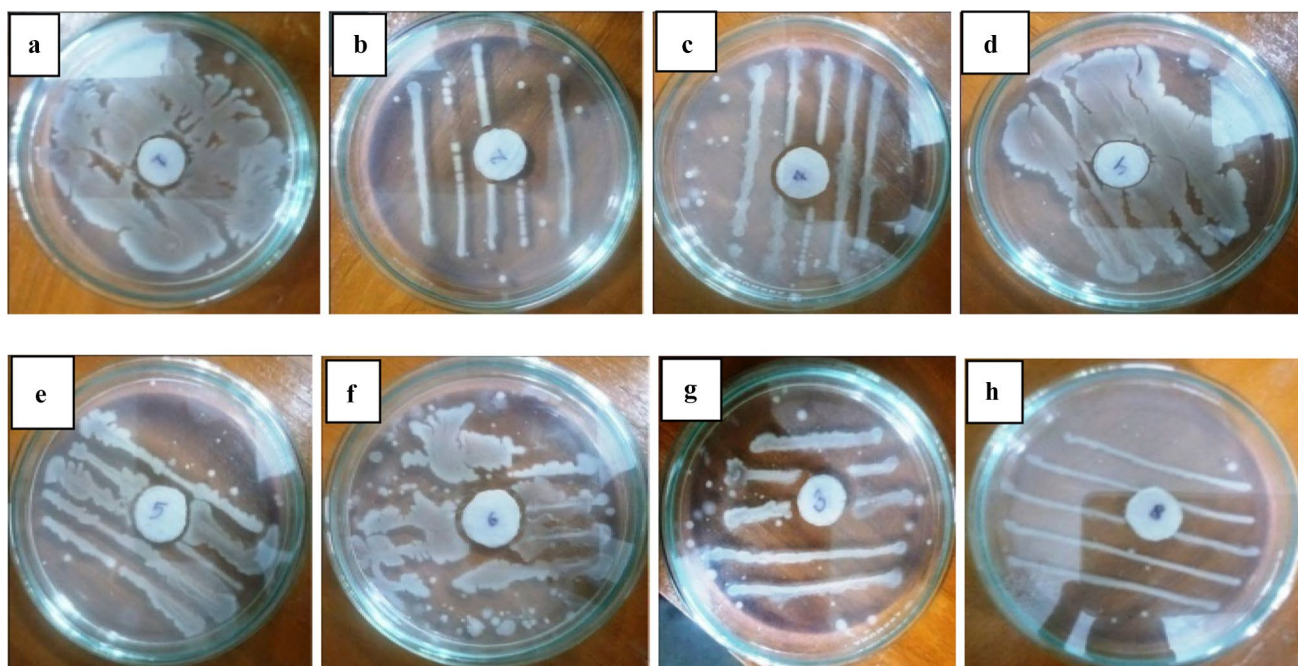


Fig. 4 Photographs showing zone of inhibition of treated and untreated sample examined by qualitative method (a 2 g/l chitosan, b 4 g/l chitosan, c 6 g/l chitosan, d 2 g/l *A. vera*, e 4 g/l *A. vera*, f 6 g/l *A. vera*, g 4 g/l combined, h untreated)

60–70% antimicrobial activity of tulsi- and pomegranate-treated cotton fabric after ten washing cycles [80]. Overall, 50–70% antibacterial activity continued in the natural antimicrobial agent-treated cotton fabric after ten washing cycles. Therefore, the antimicrobial durability of the cotton treated with chitosan and *A. vera* was at least as good as that of fibers treated with neem and *A. vera* or with tulsi and pomegranate. Active ingredients of chitosan and *A. vera* on fabric surface are diminished gradually by repeated laundering cycles. This could be due to removal of a superficial layer of chitosan and *A. vera* from the fabric surface. Most probably *A. vera* and chitosan form weak binding like H-bonds and van der Waal's forces with cellulose and loss of its cationic nature under alkaline conditions during laundering.

It can be seen from Table 4 and Fig. 4 that the circular inhibition zone increases with increasing concentrations of *A. vera* and chitosan. Combined-treated fabric shows a 2.3 mm zone of inhibition against *S. aureus* bacteria. At a concentration of 4 g/l, chitosan- and *A. vera*-treated fabrics showed 2.1 mm and 1.5 mm inhibitory zones, respectively. The greater antimicrobial activity of chitosan is due to the interaction of the positively-charged chitosan with the negatively-charged residues on the cell surfaces of many fungi and bacteria, which causes extensive cell surface alteration and alters cell permeability. This causes the leakage of intracellular substances, such as electrolytes, UV absorbing materials, proteins, amino acids, glucose, and lactate

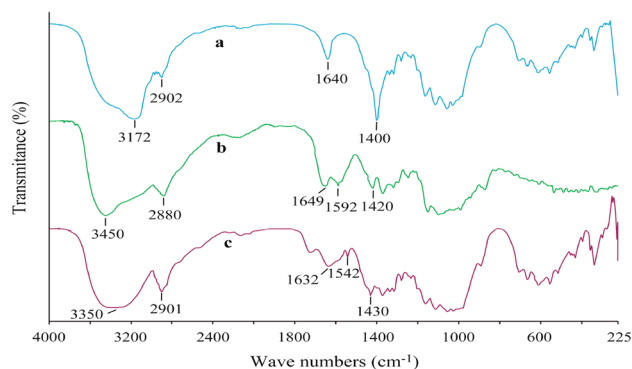


Fig. 5 FTIR spectra of: (a) cotton, (b) chitosan and (c) chitosan modified fabric

dehydrogenase. As a result, chitosan inhibits the normal metabolism of microorganisms and finally leads to the death of these cells [81]. *A. vera* contains polysaccharide acemannans, anthraquinones and tannins that have antibacterial properties. These components have the ability to inactivate enzymes, denature proteins and disrupt the membrane, to limit the growth of microbes, by disabling cell functioning or reproduction [21].

Table 4 and Fig. 4 show the anti-microbial effect of the two treatments, chitosan and *A. vera*, on cotton fabric. Again, chitosan shows its superiority over *A. vera* in every test. However, the real hero of these tests was the combination

of chitosan and *A. vera*, which outperformed either of the treatments alone. Therefore, any fabric destined for use in a health care setting should be treated in chitosan–*A. vera* combination.

FTIR Analysis

From Fig. 5a, it can be seen that the FTIR spectra of scoured bleached cotton show a broad peak at 3172 cm^{-1} , which was assigned to OH-stretching vibration of cellulose hydroxyl groups in the region of $3100\text{--}3600\text{ cm}^{-1}$. The spectra of the scoured bleached cotton fabric also showed typical characteristic peaks at 1400 cm^{-1} and 2900 cm^{-1} , which were assigned to C–H bending and stretching bands, respectively. Furthermore, the peak at 1640 cm^{-1} is attributed to the H–O–H stretching vibration of absorbed water in carbohydrate [82].

Figure 5b presents a broad peak at 3450 cm^{-1} , that indicates O–H and N–H stretching vibration of chitosan. The characteristic peaks of chitosan at 1592 cm^{-1} and 1649 cm^{-1} represent N–H bending vibration of amino groups and the C=O stretching vibration of acetyl groups, respectively [83]. After chitosan treatment, the sample showed, at 3350 cm^{-1} ,

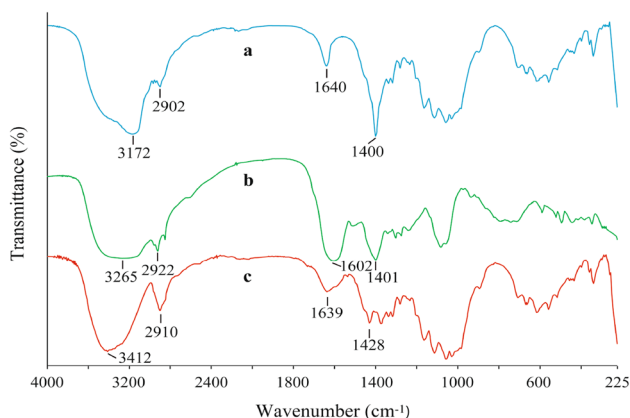


Fig. 6 FTIR spectra of: (a) cotton, (b) *A. vera* and (c) *A. vera* modified fabric

intermolecular hydrogen bonding between the cotton and chitosan. The chitosan-treated sample also peaked 1542 cm^{-1} and 1632 cm^{-1} . These peaks proved that chitosan had been incorporated in the fabric (Fig. 5c).

The spectra of *A. vera* (Fig. 6) showed different polar groups such as –OH (corresponds to 3265 cm^{-1}), CH_2 (corresponds to 2922 cm^{-1}), CO (corresponds to 1602 cm^{-1}) and COO^- (corresponds to 1401 cm^{-1}). Similar results were found by Ray [84, 85]. After treatment of cotton fabric by *A. vera*, the characteristic peak at 3412 cm^{-1} was found. This peak was assigned to the intermolecular hydrogen bonding which occurred between the untreated cotton bleached fabric and *A. vera*. The peak at 1401 cm^{-1} shifted to 1428 cm^{-1} after treatment. That also provides evidence of attachment between *A. vera* and the untreated sample.

Air permeability is an indicator of the rate of air flow through the fabric. By increasing the concentration of antimicrobial agents, from 2 to 6 g/l, applied on the fabric, the thickness of the fabric was increased. As a result, the air permeability was slightly reduced [86]. According to the test results listed in Table 5, chitosan- and *A. vera*-treated fabrics had lower air permeability than that of untreated fabrics. This occurs because chitosan and *A. vera* treatments fill the pores of the fabrics. The coating layer thickness was greater in the case of chitosan-treated fabric compared to *A. vera*-treated fabric. Thus, the air permeability of chitosan-treated fabric is lower than *A. vera*-treated fabric. When the amount of air permeability decreases then discomfort arises.

Water vapour permeability is the ability of water vapour to penetrate the apparel. When moisture vapour does not pass freely through the fabric, this leads to sweat accumulation. Then, heat cannot be dissipated. Impacted heat causes discomfort. Lower values of fabric mass per square meter and thickness, which permit the easy passage of water vapour through the fabrics, are thus preferable.

The rate of water vapour permeability increased with increasing concentration of chitosan. On the other hand, *A. vera*-treated fabric showed the opposite result. The main reason for this difference is that chitosan-treated fabric quickly absorbs water vapour, which promptly evaporates. Table 5

Table 5 The results of air permeability, water vapor permeability and thermal conductivity of treated fabrics

Observation	Air permeability (cc/cm/s ⁻¹)	Water vapour permeability (g/m ² /day)	Thermal conductivity (W/mk) × 10 ⁻³	Thermal resistance (m ² k/W) × 10 ⁻³
Untreated	129	882	6.138	3.421
2 g/l chitosan	123	887	3.990	6.265
4 g/l chitosan	122	896	3.799	7.107
6 g/l chitosan	120	899	3.624	8.002
2 g/l <i>A. vera</i>	126	870	5.428	4.053
4 g/l <i>A. vera</i>	125	861	4.551	5.053
6 g/l <i>A. vera</i>	124	850	4.384	5.474
Combined	125	881	3.914	6.387

also shows that the combined antimicrobial agents (at 2 g/l of each treatment agent) produced greater water vapour permeability (881 g/m²/day) than the 4 g/l *A. vera*-treated fabric but less than the 4 g/l chitosan-treated fabric. The water vapour permeability, with combined treatment, is not much better than not treating the fabric at all (882 g/m²/day). The best water vapour permeability result was that of 6 g/l chitosan-treated fabric.

Thermal conductivity is a measure of heat flow through a material. The rate of thermal conductivity of treated fabric decreased with increasing concentration of antimicrobial agents. Due to the greater thickness of chitosan-treated fabric, the rate of thermal conductivity is less than that of *A. vera*-treated fabric. Table 5 also shows that the combined antimicrobial agent (2 g/l chitosan and 2 g/l *A. vera*)-treated fabric's thermal conductivity result was less than that of 4 g/l *A. vera*-treated fabric and higher than that of 4 g/l chitosan-treated fabric.

Antimicrobial agents also change the surface morphology of treated fabric, which also creates barriers to thermal conductivity. The SEM results showed that the surface of treated fabric was smoother than that of untreated fabric, as the chitosan and *A. vera* filled the pores of the untreated fabric. This produces less thermal conductivity.

Thermal resistance is an assessment of the material's ability to prevent heat passing through it. Thermal resistance is a function of the thickness and thermal conductivity of a fabric. However, the results reveal that, as thermal conductivity

increases, the thermal resistance decreases, and vice versa. When fabric thickness increases, the thermal resistance also increases. 6 g/l chitosan-treated fabric showed the greatest thermal resistance, due to the higher amount of antimicrobial agent absorbed, which produced a thicker fabric. Greater absorption of antimicrobial agent thickens the fabric and increases the GSM more.

Aloe vera-treated fabric is more comfortable to wear in warmer climates, due to its lesser thermal resistance and greater thermal conductivity. Chitosan-treated fabric feels warmer to wear and will be suitable for slightly-cold weather, due to its lower thermal conductivity.

SEM Analysis

A scanning electron microscope (SEM), which produces three-dimensional images, was used to study the surface consistency of both the treated and the untreated fabrics. The scan showed that one effect of all kinds of treatment was elimination of protruding fibers. A large number of protruding fibers were observed on the surface of the untreated cotton fabric sample, as can be seen in Fig. 7a. The treated fabrics all showed zero protruding fibers. Such protruding fibres produce a rough feel in the garment [87–89].

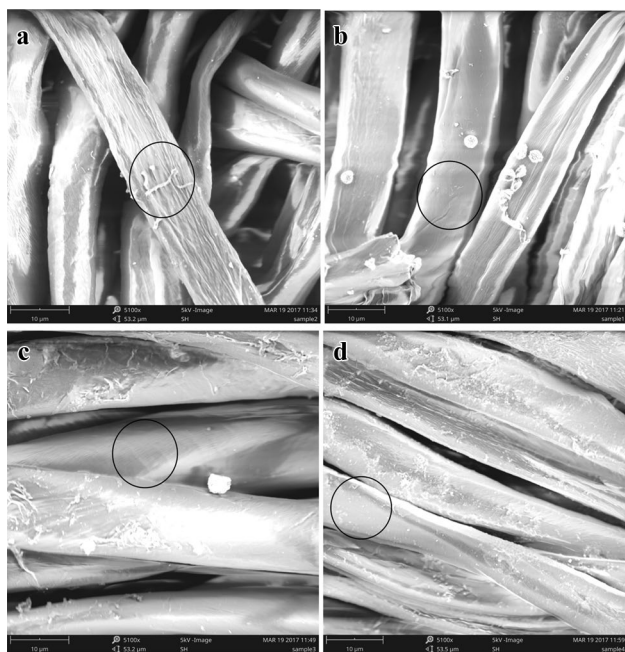


Fig. 7 SEM photograph of: **a** untreated fabric, **b** 4 g/l chitosan-treated fabric, **c** 4 g/l *A. vera*-treated fabric, and **d** 4 g/l combined treated fabric

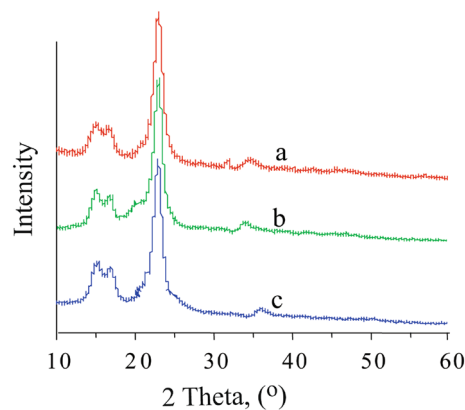


Fig. 8 XRD pattern of: (a) cotton fabric, (b) *A. vera*-treated fabric and (c) chitosan-treated fabric

Table 6 Measurement of crystal diameter of untreated and treated sample

Observation	Average FWHM (β) value (°)	Crystal diameter (D) (nm)
Cotton fabric	1.897	4.30
4 g/l <i>Aloe vera</i> -treated fabric	1.929	4.13
4 g/l Chitosan-treated fabric	1.912	4.26

FWHM Full width at half maximum in degree

Although the pores of the untreated fabrics were filled up by treatment with antibacterial agents, the surfaces of all the treated fabrics were a little irregular. Agglomerated granular was clearly visible on the treated fabric, which is evidence that the antimicrobial agents successfully attached to the untreated fabric. Granular deposits on the *A. vera*- and chitosan-combined treated fabrics was more prominent than on those fabrics treated with either of the agents alone.

XRD Analysis

From Fig. 8 and Table 6, it can be seen that the 2-theta value of the untreated sample showed three distinctive peaks at 15.78, 22.97 and 34.8, respectively. These peaks correspond to crystal planes of (101), (0 02) and (040). This result is consistent with the result found by Altınış et al. [90]. The full width at half-maximum (FWHM) values of *A. vera*- and chitosan-treated samples were only slightly higher than that of the untreated sample. The FWHM value is inversely proportional to the crystal diameter, according to the Debye–Scherrer formula (Eq. 9). The FWHM was determined with the help of Origin Pro software. The crystal diameter of the untreated sample was greater, compared

to both the chitosan- and *A. vera*-treated sample, because the FWHM of the untreated sample was least. Similarly, Xu and Chen found that the crystallinity of *A. vera* extract-modified cotton fabric was slightly less than that of the untreated sample [72]. In addition, the crystallinity of nano chitosan-treated cotton fabric was also less than that of pure cotton [91].

The XRD characteristic peaks of cotton, *A. vera*- and chitosan-treated cotton are almost the same. This indicates that the cotton fiber cellulose did not undergo any remarkable changes after *A. vera*- and chitosan- incorporation. However, the intensity of XRD peaks at $2\theta = 22.97^\circ$, for the cotton cellulose, slightly decreased after *A. vera* extract- and chitosan treatment.

Thermal Analysis

From Fig. 9, mass loss of 14%, 8% and 5% of the untreated, chitosan-treated and *A. vera*-treated samples, respectively, occurred in the temperature range between 100 and 200 °C. This mass loss is due to vapourisation of moisture and the low molecular weight of both the solvent and gas. More significant mass loss occurs between 200 and 400 °C, due to decomposition of the specimen. This mass loss was 94%, 85% and 55%, of the untreated, chitosan-treated and *A. vera*-treated samples, respectively. Thereafter, with more heating, little weight is lost between 400 and 600 °C. Finally, the least ash was found in the untreated sample. The results clearly indicate that the decomposition rate of the *A. vera*-treated sample was least.

The differential scanning calorimetry (DSC) curve of untreated cotton fabric, (b) in Fig. 10 displayed a broad endothermic peak at 370 °C, which showed the maximum decomposition of cellulose. In the case of *A. vera*- and chitosan-treated fabrics, the endothermic peak occurs at a lower temperature, of nearly 350 °C. This maximum

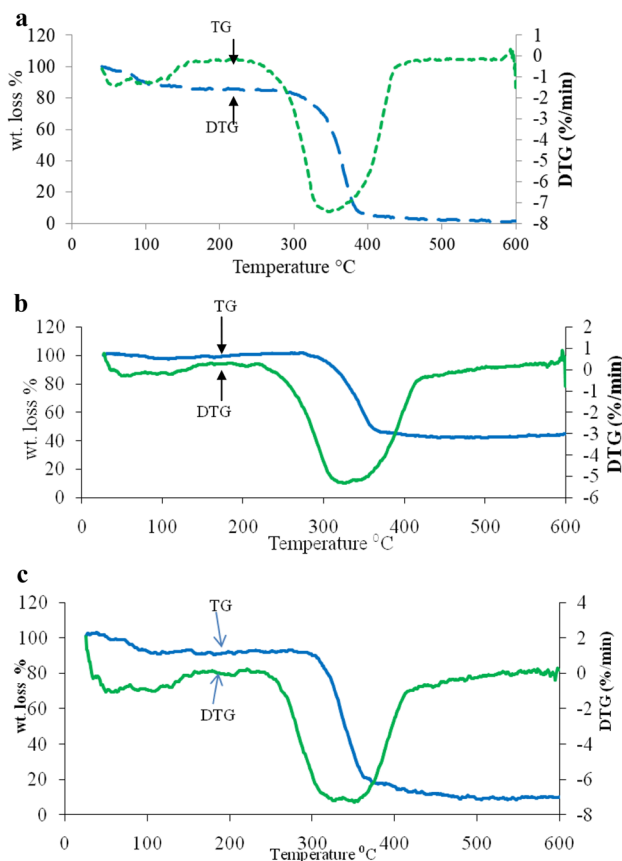


Fig. 9 TG and DTG curve of: **a** untreated, **b** *A. vera*-treated fabric and **c** chitosan-treated fabric

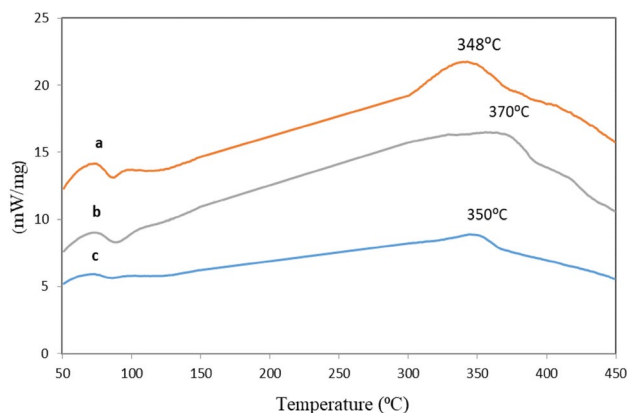


Fig. 10 DSC diagram of: (a) chitosan treated fabric, (b) untreated fabric, and (c) *A. vera* treated fabric

Table 7 Correlation coefficient of different parameters of treated sample

Observation	Correlation coefficient (r) for chitosan-treated sample	Correlation coefficient (r) for <i>Aloe vera</i> -treated sample
Air permeability verses thermal conductivity	0.9771	0.9308
Fabric thickness verses thermal conductivity	−0.9996	−0.9308
Fabric thickness verses air permeability	−0.9819	−1
Fabric absorbency verses water vapor permeability	0.9475	0.9851

- Chitosan-treated sample means 2, 4 and 6 g/l concentration
- *Aloe vera*-treated sample means 2, 4 and 6 g/l concentration

decomposition of cellulose in treated fabric at a lower temperature may be attributed to reduced intermolecular hydrogen bonding of the *A. vera*- and chitosan- treated fabric. Other studies have also shown that the decomposition temperature of chitosan-treated cotton was lower than that of untreated cotton fabric [92]. The thermal stability of modified cotton fabric was less than that of untreated fabric. It can thus be assumed that the antimicrobial agent not only cross-linked with the amorphous region but also accessed the crystalline phase of cotton cellulose. This would have caused some disruption of some intermolecular hydrogen bonding in the crystalline regions of cotton. Such disruption would then decrease the crystallinity of modified fabric. This assumption also supports the XRD analysis.

Statistical Analysis

From Table 7, the correlation coefficient values between air permeability and thermal conductivity show a perfect positive correlation, for both chitosan-and *A. vera*-treated fabrics. On the other hand, a perfect negative correlation was found between thickness and thermal conductivity. These findings indicate that thermal conductivity values decrease when the fabric thickness increases. Finally, Table 7 shows a positive correlation between fabric absorbency and water vapour permeability, for both chitosan- and *A. vera*-treated fabrics.

It is clearly seen in Table 8 that all the calculated values are lower than the tabulated values at a 5% level of significance. The results indicate that there is no significant difference between treated fabrics' and untreated fabrics' thermal comfort properties. Therefore, the thermal comfort

of bleached cotton woven fabric was not influenced by *A. vera* or chitosan treatments.

Conclusion

Chitosan and *A. vera* were successfully attached to cotton woven fabric by the pad-dry-cure method. Their presence on the surface of the cotton fabric has been confirmed by both FTIR and SEM inspection. Antimicrobial effect has been proven to result from both chitosan and *A. vera* treatment of fabrics. In the presence of chitosan, the water absorbency of treated fabric was shown to be better than that of fabrics in the presence of *A. vera*. Chitosan-treated textiles may produce a better moisture balance between fabric and skin. Air permeability, water vapour permeability and thermal conductivity are the main responsible factors for thermal comfort in wearing textiles. The comfort properties of treated fabric were not significantly changed by treatment with *A. vera* or chitosan.

The results of this study can be helpful in the development of eco-friendly UV-protective and bacteria-resistant textile products. Treatment with chitosan and *A. vera*, common substances in developing countries, can improve the qualities needed for apparel and textiles for medical use, without making them less comfortable.

Table 8 Chi-square (χ^2) hypothesis test observation

Observation	Calculated value	Tabulated value	Degree of freedom	Level of significance
Thermal conductivity of treated and untreated fabric	4.4721	12.59	6	5%
Air permeability of treated and untreated fabric	3.3488	12.59		
Water vapour of permeability of treated and untreated fabric	2.4034	12.59		

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