Antibacterial Properties of *Aloe Vera* Gel-Finished Cotton Fabric

S Wazed Ali[1], Roli Purwar[2*], M Joshi[1], S Rajendran[3]

1-Department of Textile Technology, Indian Institute of Technology, Delhi, Hauz Khas, New Delhi-110016, India
2-Department of Applied Chemistry and Polymer Technology, Delhi Technological University, Bawana Road, Delhi-110042, India, roli.purwar@dce.edu, Phone no. +91-11-27852195, Fax No. +91-11-27871023
3-Institute for Materials Research & Innovation, University of Bolton, Bolton, BL3 5AB, United Kingdom

ABSTRACT

In this study cotton fabrics were finished with *Aloe vera* gel along with 1,2,3,4-butanetetracarboxlic acid (BTCA) as crosslinking agent using pad-dry-cure method. The Finished fabrics were characterized by Fourier transform infrared spectroscopy (FTIR). The Infrared spectra confirmed that the active ingredients of *Aloe vera* gel attached with the hydroxyl groups of cotton fabric via carboxylic acid cross-linking agent. The antibacterial activity of *Aloe vera* finished fabrics were qualitatively evaluated by AATCC-147 method and scanning electron microscope (SEM) technique. It was observed that *Aloe vera* gel finished fabric has much less bacterial adhesion. The *Aloe vera* gel finished (concentration ≥3 % (w/v)) cotton fabric inhibited the growth of both Gram-positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli*) bacteria. The mechanism of cell death by *Aloe vera* gel was evaluated using transmission electron microscopy (TEM). TEM photographs suggested that the cell death is due to the destruction of bacterial cell wall. The finished fabric was also evaluated for its performance properties such as tensile strength, crease recovery angle, bending length, etc.

Keywords: *Aloe vera*; cotton fabric; antibacterial activity; performance properties

INTRODUCTION

Increased global competition in developing advanced textile based medical products has created many challenges for textile researchers and industrialists. The rapid growth in medical and wellness textiles has evolved many opportunities for the application of

innovative functional finishes. Antimicrobial finished textiles with improved functionality find a variety of applications such as infection control, other health and hygiene applications (Purwar and Joshi 2004).

In the last few decades, research has been carried out in developing novel technologies to produce enhanced antimicrobial activity on textiles by using different synthetic antimicrobial agents such as triclosan, metal and their salts, organometallics, phenols and quaternary ammonium compounds (Windler *et* al. 2013). Although the synthetic antimicrobial agents are very effective against a range of microbes and provide a durable effect on textiles, they are a cause of concern due to the associated side effects and ecological problems such as water pollution. Hence, there is a need and demand for antimicrobial textiles based on eco-friendly agents which not only help to reduce the ill effects associated due to microbial growth on textile materials but also comply with the statutory requirements imposed by the regulating agencies. There is a vast resource of natural products with active antimicrobial ingredients amongst which the plant based products cover a major range (Joshi *et.* al. 2009). Healing power of some of the plant materials has been well-known and used since ancient times worldwide. Although there are many natural products rich in antimicrobial agents, only chitosan (Zhang *et* al. 2003; Hsieh *et* al. 2004; Aly *et* al. 2004; Shanmugasundaram *et* al. 2006; Tavaria *et* al. 2012; Teli *et* al. 2013) and natural dyes (Gupta *et* al. 2004; Gupta *et* al. 2005; Han and Yang 2005; Gupta and Laha 2007; Prabhu *et* al. 2011; Rajendran *et* al.2013) have been widely used as potential antimicrobial agents for textile application. A systematic study on integrating neem seed and bark extracts to cotton (Purwar *et* al. 2008) and cotton/polyester blend (Joshi *et* al. 2007) has been reported. The major challenges in the application of natural products for textile application are most of these plant materials are complex mixtures of several compounds and also the composition varies in different species of the same plant. The durability, shelf life and antimicrobial efficiency of natural products

are other issues of concern. To address these issues further research should be carried out in the area of bioactive textiles made from natural products, to make it a viable alternative to synthetic product based antimicrobial textiles.

Aloe vera has been used as a skin care product for more than 2000 years. There are more than 350 *Aloe vera* species of genus *Aloe* family which are available at various parts of the globe. Some of the important *Aloe vera* species are *Aloe arborescens, Aloe aristata, Aloe dichotoma, Aloe ngobitensis, Aloe variegate, Aloe wildii, Aloe barbadensis Miller, etc.* Among all these varieties *Aloe barbadensis Miller* is mostly used because of its excellent medicinal properties (George *et* al. 2009). In a study it was found that the *Aloe* leaf contains over 75 nutrients and 200 active compounds, including 20 minerals, 18 amino acids and 12 vitamins (Agarry *et* al. 2005). The main components of these constituents are glycoprotein, barbaloin, aloe-emodin, emodin, mannose-6-phosphate, polysaccharides, acemanan, aloesin, etc. The active ingredients of *Aloe vera* gel have wide range of activities such as moisturizing, anti-inflammatory, antibacterial, antifungal, antiviral agent, antiodor, etc. (Krinsky 2003; Lee *et* al. 2009). They also possess UV protective, antiprotozoal and wound healing properties (Reynolds *et* al. 1999). Wound healing property of *Aloe vera* has been extensively studied. Glycoprotein and mannose-6-phosphate present in *Aloe vera* have good wound healing property (Choi and Chung 2003). Polysaccharides and barbaloin in *Aloe* gel are mainly responsible for their antimicrobial activity (Krinsky *et* al. 2003; Ramachandra and Rao 2008).

The antifungal and antibacterial properties of *Aloe vera* can be exploited for medical textile applications, such as wound dressing, suture and other bioactive textiles. The combined activities of *Aloe vera*, chitosan and curcumin on cotton, wool and rabbit hair with their different concentrations by exhaust method have been studied (Ammayappan and Moses 2009).

In the present work an attempt has been made to finish the cotton textiles with *Aloe vera* gel along with BTCA cross-linking agent. The finished fabric was characterized by Fourier transform infrared spectroscopy (FTIR) to understand the mechanism of attachment of *Aloe vera* gel with cotton substrate in presence of BTCA cross-linking agent. The antibacterial property of *Aloe vera* gel finished fabric was evaluated against both Gram-positive and Gram-negative bacteria. The mechanism of destruction of both Gram-positive and Gram-negative bacteria by *Aloe vera* gel has also been established.

EXPERIMENTAL

Materials

A plain weave cotton fabric (100 ends × 80 picks) weighing 80 g/m^2 was used throughout the study. Commercial *Aloe vera* gel from Fruit of the Earth, Inc, USA without any modification was used as an antibacterial agent. 1, 2, 3, 4-butanetetracarboxlic acid (BTCA) (Qualigens) was used as cross-linking agents. Sodium hypophosphite (NaH_2PO_2, H_2O, Lobal Chemie) was used as a catalyst for carboxylic acids. All the chemicals used were of reagent grade.

Methods

Finishing treatment

Pad-dry-cure method

Cotton fabric was treated with different concentration of *Aleo vera* gel ranging from 1, 3, 5 and 7 w/v along with BTCA (6% w/v) as cross-linking agent & sodium hypophosphite (4.1% w/v) as catalyst through a two bowl horizontal laboratory padder (pressure 2 kg/cm^{2,} LabIndia, New Delhi) with two dip and two nip process to give a wet pick up of 100%. After padding the treated fabric samples were dried at 85°C for 5 min and cured at 150°C for 2 min in a laboratory stenter.

Wash fastness

The *Aloe vera* gel treated fabrics were washed in a Launder-o-meter using 5g/l non-ionic detergent, Lissapol N (Purwar *et. al.* 2008) at 50^0 C for 45 min keeping M:L ratio 1:40.

Fourier transforms infrared spectroscopy (FTIR)

The infrared spectra of the *Aloe vera* treated and untreated cotton fabric samples were recorded between 400–4500 cm^{-1} on a Perkin-Elmer Spectrum-BX FTIR system (Massachusetts, USA) using KBr pellet technique. The KBr pellets were prepared by grounding 1 part of the sample with 9 part of spectral grade KBr and pressed in an evacuated die under suitable pressure to get pellets.

Antibacterial activity

The Antibacterial activity of *Aleo vera* treated fabric samples (washed and unwashed) was evaluated qualitatively and quantitatively by using AATCC-147 and AATCC-100 method, respectively, using *Staphylococcus aureus* (Gram-positive) and *Escherichia coli* (Gram-negative) bacteria. The Stock solution of bacteria culture was prepared in Nutrient Broth (Hi media) solution with count of 1.0×10^6 CFU/ml. In parallel streak method, four streaks of bacterial culture one cm apart were inoculated on the Agar plate surface with the help of wire loop. The fabric swatch (5 cm × 2.5 cm) was pressed on the streak inoculums. After incubation at 37 °C for 24 hrs, the presence of bacteria was observed underneath as well as around the fabric.

The antibacterial activity of the *Aloe vera* treated fabrics was quantitatively evaluated by shake flask method. This method is specially designed for specimens treated with non releasing antibacterial agents under dynamic contact conditions. In this test, the fabric sample (2.5 cm × 2.5 cm) was dipped into a flask containing nutrient broth bacterial culture solution with a cell concentration of 1×10^6 CFU/ml. The flask was then shaken at 200 rpm for 24 hrs. at 37 °C. After 24 hrs. incubation, serial dilution of the liquid was made in sterilized distilled water. Dilution of 10^{-4} and 10^{-5} were used for colony counting. 10 µl were spread on to the

Agar plate and plates were incubated at 37 °C for 24 hr. After incubation bacterial colonies were counted. The antibacterial activity was determined as follows:

Antibacterial activity (%) = (A - B) /A ×100

Where, 'A' is the bacteria colonies of untreated cotton fabric and 'B' is the bacteria colonies of the *Aloe vera* treated fabric.

Scanning electron microscopy (SEM)

A ZEISS (Model: Evo 50) SEM was used in this study to observe the adhesion of microbes on the *Aloe vera* treated fabric and compared to the untreated 'control' sample. To fix the cells, fabrics were first immersed in glutaraldehyde under refrigeration for one hour. The glutaraldehyde was then washed off with phosphate buffer (pH = 7.0) and water. Water in the specimens was removed by replacing it with ethanol through a series of ethanol aqueous solutions ranging from 10% to 100%. Ethanol was then replaced with amyl acetate following the same sequence of steps. The specimens were then freeze dried and mounted on stubs, to be observed under SEM.

Transmission electron microscopy (TEM)

Transmission Electron Microscopy (TEM) of *Aloe vera* treated bacteria (both Gram-positive and Gram-negative) was carried out to find out the destruction mechanism of the bacterial cell. Morgagni 268 D TEM was used for taking the images. 1 ml of Gram-positive bacteria (*Staphylococcus aureus*) from 10^6 CFU/ml bacteria culture was inoculated in 100 ml liquid culture containing $3/4^{th}$ of the MIC value (i.e. 0.0075 mg/ml for *Staphylococcus aureus* and 0.00075 mg/ml for *Escherichia coli* bacteria) of *Aloe vera* gel. The samples were kept in an incubator shaker at 37 ^{0}C for 6 hrs. After that the samples were centrifuged at 5000 rpm for 20 min at 4 ^{0}C to discard the supernatant. The bacterial cells were washed with phosphate buffer. The washed samples were fixed with 2% glutaraldehyde. After making the block the samples were fixed on a grid and examined through transmission electron microscopy. One

control sample i.e. bacteria without *Aloe vera* was also examined. The same preparation was carried out for Gram-negative bacteria (*Escherichia coli*).

Performance Properties of Finished Fabrics

Fabric was conditioned in the standard atmosphere (25 ^{o}C, 65% RH) for 24 hrs. The tensile testing of fabric samples in warp direction were carried out by using ASTM D 5035-90 using Instron 4202 machine. Standard ASTM D 1269 test method was used to determine the crease recovery angle (CRA) using Shirley Crease Recovery tester. For each sample, 10 specimens were tested and the average value is reported. Bending length measurement was carried out in both warp and weft direction of the treated and untreated samples using Eureka Bending Length tester according to ASTM D 1388-08 test standard. The whiteness on the finished fabric samples was measured by Gretag Macbeth, Color Eye-7000-A using Color-eye Control software.

RESULTS AND DISCUSSION

FTIR spectroscopy of untreated and *Aloe vera* treated cotton fabric

FTIR spectra of untreated (Fig. 1a), BTCA treated (Fig. 1b) and *Aloe vera* along with BTCA finished cotton fabric (Fig. 1c) are shown in Figure 1. The FTIR spectra of the BTCA treated fabric (Fig. 1b) showed an additional peak at around 1732 cm^{-1} for ester group. This shows that the carboxylic acid (BTCA) chemically reacts with the functional group of cotton and formed an ester linkage. Sauperl *et.* al (2003) treated cotton fabric with BTCA in presence of sodium dihydrogen phosphate(I) monohydrate as catalyst. FTIR spectra of treated fabric showed band at the wavelength 1725 cm^{-1} which represents the ester carbonyl group confirms the covalent bond between the cellulose and BTCA. The intensity of this band is a measure of total quantity of ester group created in the finished cotton fabrics. The FTIR spectrum (Fig. 1c) of *Aloe vera* treated fabric showed a little shift of ester peak from 1731.54 cm^{-1} to 1724.35 cm^{-1} and also the intensity of this peak is lowered as compared to that of only

BTCA treated fabric (Fig. 1b). This indicates a decrease in the average number of ester groups formed in presence of *Aloe vera.* The lower intensity peak of *Aloe vera* with cross-linking agent treated cotton is due to the interaction of *Aloe vera* active compounds with some of the hydroxyl (-OH) groups of the cotton and also interaction with the free –COOH groups of carboxylic acid molecules which are supposed to form ester linkage with cotton in absence of *Aloe vera* compounds. Hence, the extent of degree of direct chemical cross-linking between cotton and carboxylic acids via ester linkage is effectively less in *Aloe vera* treated samples as some of the –OH groups of cotton are actively occupied by some of the –OH groups (as shown in Fig. 2) of *Aloe vera* ingredients. Thus active ingredients of *Aloe vera* containing –OH groups in their chemical structure can easily form H-bonding with the either –OH groups of cellulose backbone or chemically react with the carboxylic acid during curing process. In some cases the carboxylic acid may act as a bridge between the active ingredients of *Aloe vera* and cotton molecules. Similar results obtained when cotton fabric was finished with neem active ingredients along with glyoxa/glycol cross-linking agent (Purwar *et* al. 2008).

Antibacterial activity of the *Aloe vera* treated fabric

Qualitative analysis

Antibacterial activity of *Aloe vera* finished cotton fabric after (1^{st} washed sample) was evaluated qualitatively by Parallel Streak Method (AATCC 147-1998) against both Gram-positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli*) bacteria. The results of qualitative test are shown in Fig. 3. It was observed that there is no visible growth of bacteria (*both Staphylococcus aureus* and *Escherichia coli*) on the cotton fabric treated with 3% (w/v) *Aloe vera* concentration. However, there is no clear zone of inhibition found around the treated fabric. The non-leaching phenomenon of *Aloe vera* from the cotton substrate substantiate that the active ingredients of *Aloe vera* gel is physically as well as chemically

bonded with the cotton structure. Further the bacterial adherence on the fabric surface was further examined by scanning electron microscopy. SEM Photographs of untreated and treated fabric are shown in Fig. 4. The intensive growth of bacteria namely *Staphylococcus aureus* (Fig. 4a) and *E. coli* (Fig. 4c) was observed *on* the surface of the untreated cotton. The SEM Photograph (Fig. 4b and Fig. 4d) of *Aloe vera* treated fabric showed tremendous reduction in bacterial adhesion. The active ingredients of *Aloe vera* gel act as an effective bactericidal agent on to the fabric and inhibits the growth of both *Staphylococcus aureus* (Gram-positive) and *Escherichia coli* (Gram-negative) bacteria.

The antibacterial activity of the treated samples with different concentration of *Aloe vera* (1%, 3%, 5% and 7% w/v) was evaluated quantitatively using dynamic shake flask method (AATCC 100-1999) against both Gram-positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli*) bacteria. The percent antibacterial activity was calculated and the result obtained are summarized in Table 1. Two control samples were tested along with the *Aloe vera* treated samples. Untreated fabric was taken as control-I and only BTCA treated fabric sample was taken as control-II. It was found that with increase in concentration of *Aloe vera* gel in finishing bath and subsequently on treated fabric, the antibacterial activity of the treated fabric increases. 3% *Aloe vera* gel treated fabric showed more than 90% antibacterial activity against both types of bacteria.With increase in concentration of *Aloe vera* (up to 7%) the bacterial reduction increased up to 99%. This may be due to the enhanced weight add-on% of the aloe active ingredients on the fabric with increasing *Aloe vera* concentration. It was also observed that only BTCA treated fabric showed bacteria retention of around 70%.

The durability of the antibacterial activity of the *Aloe vera* treated cross-linked fabric was evaluated after repeated washing and results obtained are presented in Fig. 5. It was found that the antibacterial activity retains more than 70% up to 5 machine washes and more than 50% even after 8 machine washes although there is a sharp reduction in antibacterial activity

after 10 machine washes. This may be due to significant loss of active ingredient of *Aloe vera* after 10 machine washes. In other words, the covalent bonds formed during cross-linking are deteriorated paving the way for the active ingredients to leach out from the fabric during washing.

This observation was further reaffirmed by evaluating the crease recovery angle (CRA) of only BTCA treated fabric with repeated laundering. The results are shown in Table 2. The crease recovery angle has also decreased with repeated laundering. With repeated machine washing, crease recovery angle of the BTCA finished cotton fabric decreases. This is due to opening of the bonds between BTCA and cotton. As active ingredients of *Aloe vera* gel also contain –OH groups like cellulosic molecules, and also forms same types of bonds among BTCA and cotton structure, they are going to lose during washing. Thus antibacterial activity is going down due to removal of active ingredients along with the removal of BTCA. This also confirms that the active ingredients of *Aloe vera* gel are chemically / physically linked with the BTCA. Similar results were obtained when cotton fabric was finished with neem extract along with Glyoxal/glycol cross-linking agent. The crease recovery angle as well as antimicrobial activity of the finished fabric deceases with repeated laundering (Purwar *et*.al. 2008).

Mode of action of *Aloe vera* on tested bacteria

Transmission Electron Microscopy (TEM) has been used to study the mode of action of *Aloe vera* on both the Gram-positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli*) bacteria. The healthy cells of bacteria and *Aloe vera* treated bacterial cell were observed under TEM and are shown in Fig. 6. It was observed that untreated bacteria showed distinct cell wall (Fig. 6a and 6c). The shape of the cells treated with *Aloe vera* gel has become larger as compared to original cell. The broken cell wall was observed in *Aloe vera* treated cells. The active ingredients of *Aloe vera* destroyed the cell wall of both the bacteria. Thus, the

cytoplasmic content is leaked out from the cell inhibiting the multiplication for bacterial growth further.

Performance properties of *Aloe vera* treated fabric

The *Aloe vera* gel treated samples were tested for various fabric properties such as appearance, tensile strength, crease recovery angle and bending length. The results are summarised in Table 3. The *Aloe vera* finished fabric has higher crease recovery angle, higher bending length and decrease in whiteness index as compared to the untreated fabric. This is due to presence of BTCA cross-linking agent. The decrease in whiteness index of the carboxylic acid treated cotton is due to the formation of alkene double bond on cotton fabric with carboxylic acid under high temperature curing. There was a slight change in bending length of the treated fabric as compared to the untreated one and the bending length is directly related to the flexural rigidity of the fabric. Thus flexibility of fabric is not changed too much even after the finishing treatment although the tensile strength loss was 44% after the treatment process. The loss of strength is mainly due to the stiffening of the molecular backbone after cross-link formation (Yang *et.* al. 1997). Such strength loss of carboxylic acid treated cotton is also attributed to acid catalyzed depolymerisation of cellulose molecules (Kang *et.* al. 1998).

CONCLUSIONS

Aloe vera gel has been used as an effective eco-friendly bioactive agent for imparting durable antibacterial finish to the cotton substrates. Minimum 3% (w/v) *Aloe vera* gel was found to be effective to obtain good antibacterial efficacy against both Gram-positive and Gram-negative bacteria. FTIR spectra confirm the attachment of active compounds of *Aloe vera* gel with the cotton structure via physical as well as chemical bonding. Active ingredients of *Aloe vera* gel act as an effective bactericidal agent against both Gram-positive and Gram-negative bacteria where cytoplasmic material is leaked out due to deterioration of bacterial cell wall. The

antibacterial activity of the *Aloe vera* finished cotton fabric is retained up to eight machine washes. The treated fabric showed increased crease recovery angle. However, the tensile strength and whiteness index of the fabric had to be compromised as compared to untreated one to ripen this novel functionality for its usage as a health and hygiene product for a range of niche applications.

References

Agarry OO, Olaleye MT, Michael COB (2005) Comparative antimicrobial activities of aloe vera gel and leaf. African J Biotech 4 (12): 1413 - 1414.

Aly AS, Hashem A, Hussein SS (2004) Utilization of chitosan citrate as crease-resistant and antimicrobial finishing agent for cotton fabric. Indian J Fibre Text Res 29 (2): 218 - 222.

Ammayappam L, Moses JJ (2009) Study of antimicrobial activity of *aloe vera*, chitosan and curcumin on cotton, wool and rabbit hair. Fibres and Polymers 10 (2): 161 - 166.

Borris RP (1996) Natural products research: perspectives from a major pharmaceutical company. J Ethnopharmacol 51: 29 - 38.

Choi S, Chung MH (2003) A review on the relationship between *aloe vera* components and their biologic effects. Seminars in Integrative Medicine 1 (1): 53 - 62.

Chung YS, Lee KK, Kim JW (1998) Durable press and antimicrobial finishing of cotton fabrics with a citric acid and chitosan treatment. Text Res J 68 (10): 772 - 775.

George D, Bhat SS, Antony B (2009) Comparative evaluation of the antimicrobial efficacy of aloe vera tooth gel and two popular commercial toothpastes: An in vitro study. General Dentistry 57 (3): 238 - 241.

Gupta D, Khare SK, Laha A (2004) Antimicrobial properties of natural dyes against Gram-negative bacteria. Coloration Tech 120 (4): 167 - 171.

Gupta D, Laha A (2007) Antimicrobial activity of cotton fabric treated with Quercus infectoria extract. Indian J Fibre Text Res 32 (1): 88 - 92.

303 Gupta D, Singh R, Jain A, Panwar S, Khare SK (2005) Antimicrobial activity of some natural
304 dyes. Dyes Pigments 66: 99 - 102.
305 Han S, Yang Y (2005) Antimicrobial activity of wool fabric treated with curcumin. Dyes
306 Pigments 64: 157 - 161.
307 Hsieh SH, Haung ZK, Haung ZZ, Tseng ZS (2004) Antimicrobial and physical properties of
308 woolen fabrics cured with citric acid and chitosan. J Appl Polym Sci 94 (5): 1999 - 2007.
309 Joshi M, Ali SW, Purwar R, Rajendran S (2009) Ecofriendly antimicrobial finishing of
310 textiles using bioactive agents based on natural products. Indian J Fibre Text Res 34(9):
311 295 - 304.
312 Joshi M, Ali SW, Rajendran S (2007) Antibacterial finishing of polyester/cotton blend fabrics
313 using neem (Azadirachta indica): A natural bioactive agent. J Appl Polym Sci 106: 793 -
314 800.
315 Kang IS, Yang CQ, Wei W (1998) Mechanical strength of durable press finished cotton
316 fabrics: effects of acid degradation and crosslinking of cellulose by polycarboxylic acids.
317 Tex Res J 68 (11): 865 - 870.
318 Krinsky DL, Hawkins EB, Pelton R, Willis NA, Lavalle JB (2003) Natural Therapeutics
319 Pocket Guide, ed. 2. Cleveland: Lexi-Comp, Inc., pp 379.
320 Lee G, Anand SC, Rajendran S (2009) Are biopolymers potential deodourising agents in
321 wound management? J Wound Care 18 (7): 290 - 295.
322 Lu Y, Yang CQ (1999) Fabric yellowing caused by citric acid as a cross linking agent for
323 cotton. Text Res J 69 (9): 685 -690.
324 Mathur JP, Mehta A, Karnawat R, Bhandari CS (2003) Use of neem bark as wool colourant-
325 optimum conditions of wool dyeing. Indian J Fibre Text Res 28 (1): 94 - 99.
326 Moerman DE (1996) An analysis of the food plants and drug plants of native North America.
327 J Ethnopharmacol 52: 1 - 22.

328 Nam CW, Kim YH, Ko SW (1999) Modification of polyacrylonitrile (PAN) fiber by
329 blending with N-(2-hydroxy)propyl-3-trimethylammonium chitosan chloride. J Appl
330 Polym Sci 74 (9): 2258 - 2265.
331 Purwar R, Mishra P, Joshi M (2008) Antibacterial finishing of cotton textiles using neem
332 extract. AATCC Rev 8 (2): 36 - 43.
333 Purwar R, Joshi M (2004) Recent developments in antimicrobial finishing of textiles—a
334 review. AATCC Rev 4 (3): 22 - 26.
335 Ramachandra CT, Rao PS (2008) Processing of *aloe vera* leaf gel: a review. American J
336 Agricultural and Biological Sci 3 (2): 502 - 510.
337 Rajendran R, Radhai R, Kotresh TM, Csiszar E (2013) Development of antimicrobial cotton
338 fabrics using herb loaded nanoparticles. Carbohydrate Polymers 9 (2):613–617
339 Reynolds T, Dweck AG (1999) *Aloe vera* gel leaf: a review update. J Ethnopharmacol 68: 3 -
340 37.
341 Rodriguez DJ, Castillo DH, Garcia RR, Sánchez JLA (2005) Antifungal activity in vitro of
342 Aloe vera pulp and liquid fraction against plant pathogenic fungi. Indust Crops and
343 Products 21 (1): 81 - 87.
344 Sauperl O, S-Kleinschek K, Voncina B, S-Smole m, Marechal AML (2003) Application of
345 spectrophotometric methods in Assessing the influence of alkaline treatment on the
346 degree of crosslinking of cotton cellulose with BTCA, Croatica Chemica Acta 76(4):293-
347 298.
348 Schultes RE (1978) The Kingdom of plants In: Thomson WA R (ed.), Medicines from the
349 earth, McGraw-Hill Book Co., New York, pp 208.
350 Seong HS, Kim JP, Ko SW (1999) Preparing chito-oligosaccharides as antimicrobial agents
351 for cotton. Text Res J 69 (7): 483 - 488.

Shanmugasundaram OL, Giridev VR, Neelakandan R, Madhusoothanan M, Rajkumar GS (2006) Drug release and antimicrobial studies on chitosan-coated cotton yarns. Indian J Fibre Text Res 31(4): 543 - 547.

Tavaria FK, Soares JC, Reis IL, Paulo MH, Malcata FX, Pintado ME (2012) Chitosan: antimicrobial action upon staphylococci after impregnation onto cotton fabric. J Appl Microbial 112 (3): 1034 - 1041.

Teli MD, Sheikh J, Bhavsar P (2013) Multifunctional finishing of cotton using chitosan extracted from bio-waste. Int J Biol Macromol 54:125-30

Tiwari SK, Prajapati KG, Gharia MM (2001) Pigment prints with antibacterial characteristics. Colourage 48 (9)**:** 17 - 20.

Windler L, Height M, Nowack B (2013) Comparative evaluation of antimicrobials for textile applications. Environment International. 53: 62–73

Yang CQ, Wang X, Kang IS (1997) Ester crosslinking of cotton fabric by polymeric carboxylic acids and citric acid. Text Res J 67 (5): 334 342.

Zhang Z, Chen L, Ji J, Haung Y, Chen D (2003) Antibacterial properties of cotton fabrics treated with chitosan. Text Res J 73 (12) : 1103 - 1106.

377 Table 1 Antibacterial activity of Aloe Vera-treated washed cotton fabric

378

Samples	Bacteria tested			
	Staphylococcus aureus		*Escherichia coli*	
	Colony forming unit (CFU/ml)	Antibacterial activity (%)	Colony forming (unit CFU/ml)	Antibacterial activity (%)
Original (Control-I)	209 $x10^6$	-	190 $x10^6$	-
BTCA cross-linked (Control-IIb)	155 $x10^6$	26	139 $x10^6$	27
Aloe vera (1%) treated with BTCA	86 $x10^6$	59	61 $x10^6$	68
Aloe vera (3%) treated with BTCA	17 $x10^6$	92	17 $x10^6$	91
Aloe vera (5%) treated with BTCA	3 $x10^6$	98.5	4 $x10^6$	98
Aloe vera (7%) treated with BTCA	1 $x10^6$	99.5	1 $x10^6$	99

379
380
381
382
383
384

385 Table 2 Washing durability of carboxylic acid-treated cotton

386

Sample	Washing cycle	Avg. dry CRA (W + F) (^{o})	CV % of CRA
Untreated cotton	-	150	0.69
BTCA treated cotton	Unwashed	248	0.56
	1 washed	242	0.40
	5 washed	241	0.65
	8 washed	240	0.71
	10 washed	218	0.48

387
388
389
390

391 Table 3 Physical properties of the finished cotton fabrics

392

Samples	Avg. dry CRA (W + F) (°)	CV % of dry CRA	Avg. bending length (cm)	CV% of bending length	Avg. whiteness index - CIE	Tensile strength retention (%)
Untreated cotton	156	0.69	1.8	0.65	69.08	-
Aloe vera + BTCA treated cotton (washed)	240	0.57	2.3	0.80	35.08	56

393 (N.B. CRA of only BTCA treated cotton fabric was 245° and 231° respectively)

394

395

396

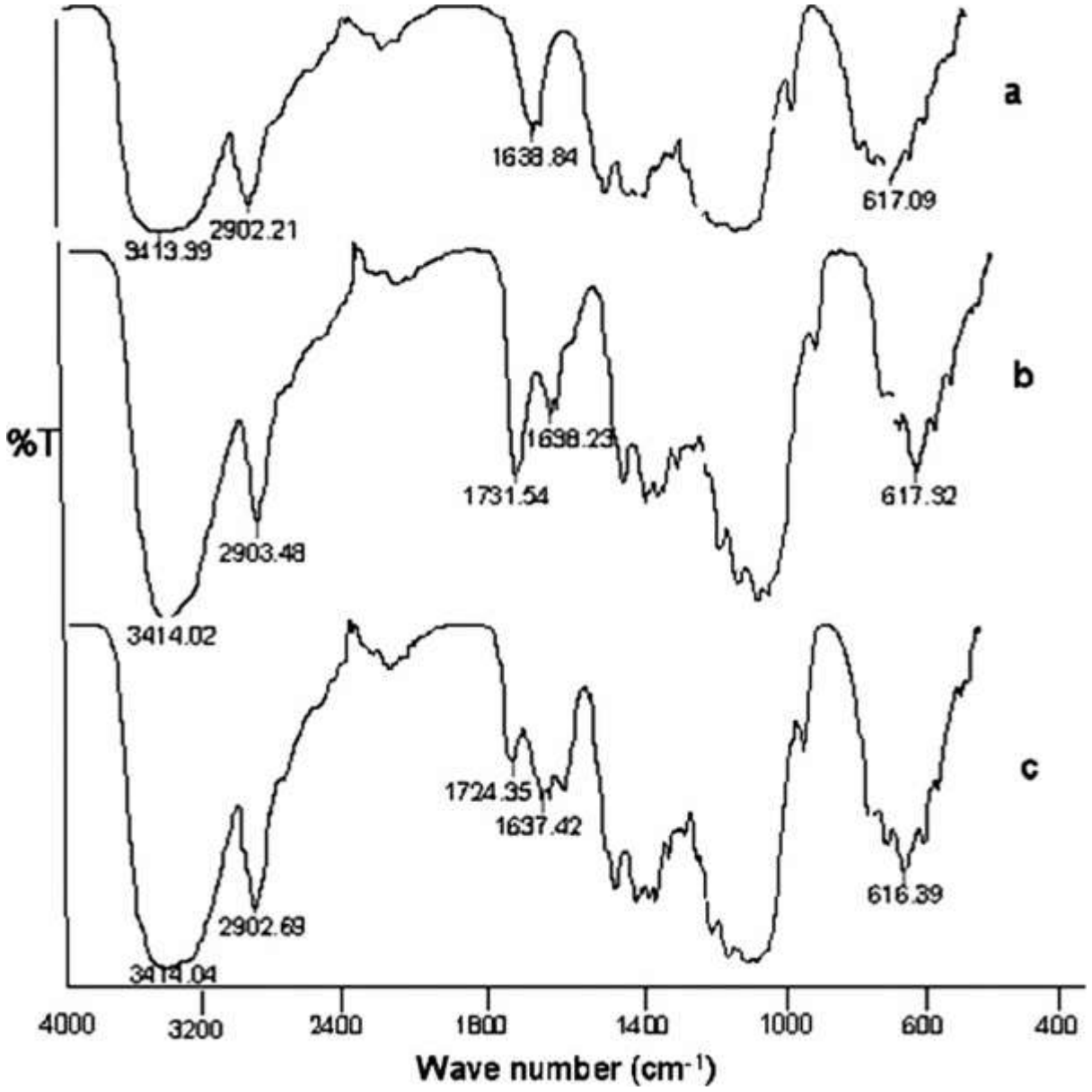
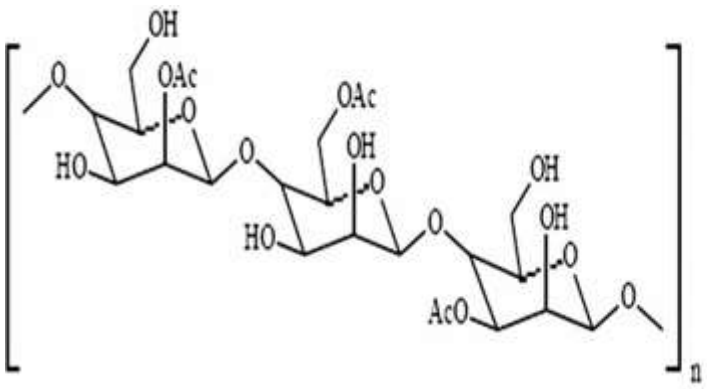
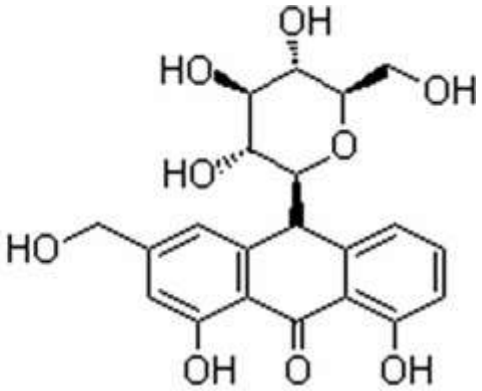


Fig. 1 FTIR spectra of a untreated cotton b BTCAtreated cotton. c Aloe vera and BTCA-treated cotton



Polysaccharide acemannan

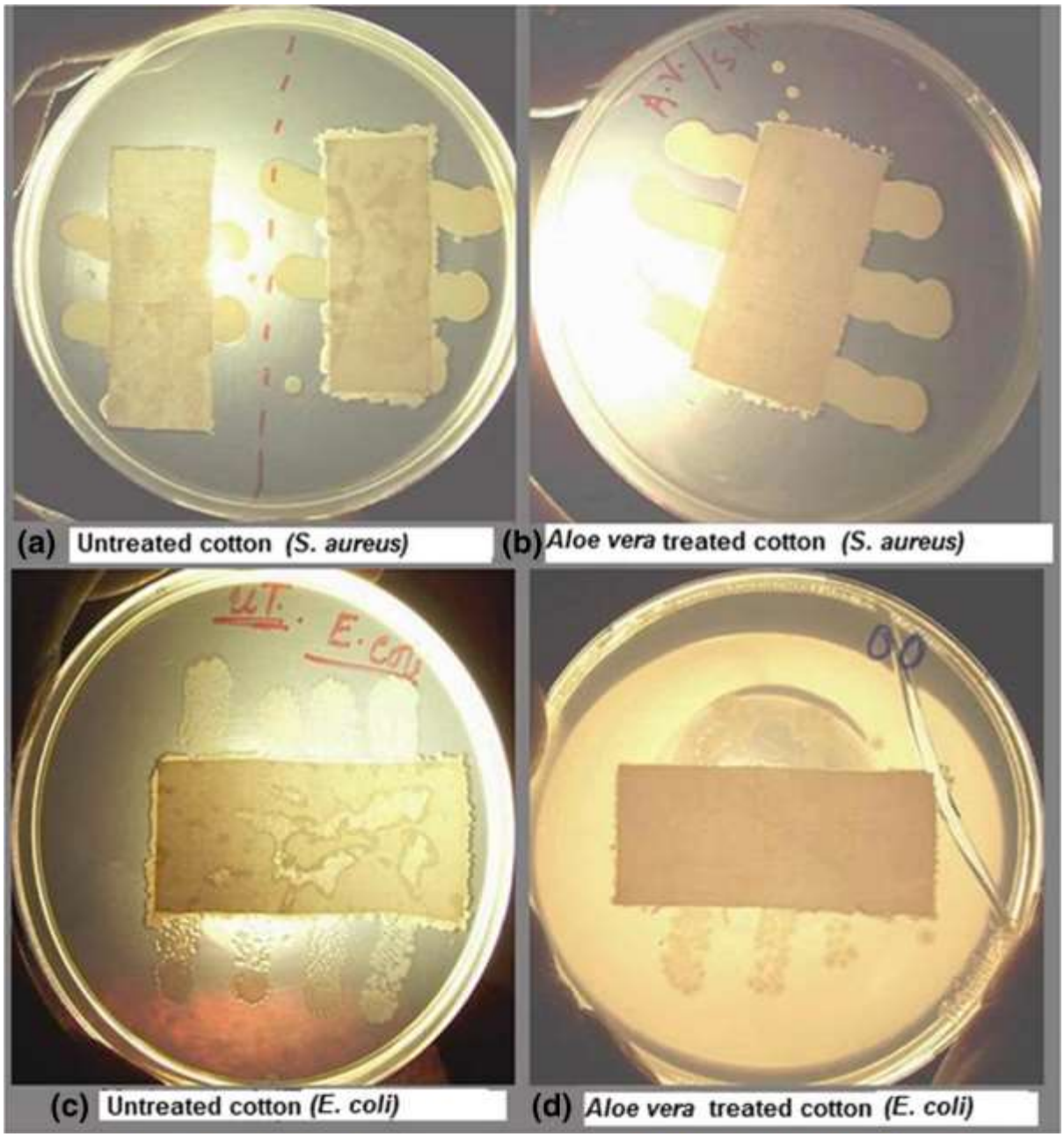


Barbaloin: 1, 8-Dihydroxy-10-(beta-D-glucopyranosyl)-3-(hydroxymethyl)-
9 (10H) -Anthracenone

401

402 Fig. 2 Antimicrobial ingredients in Aloe vera

403



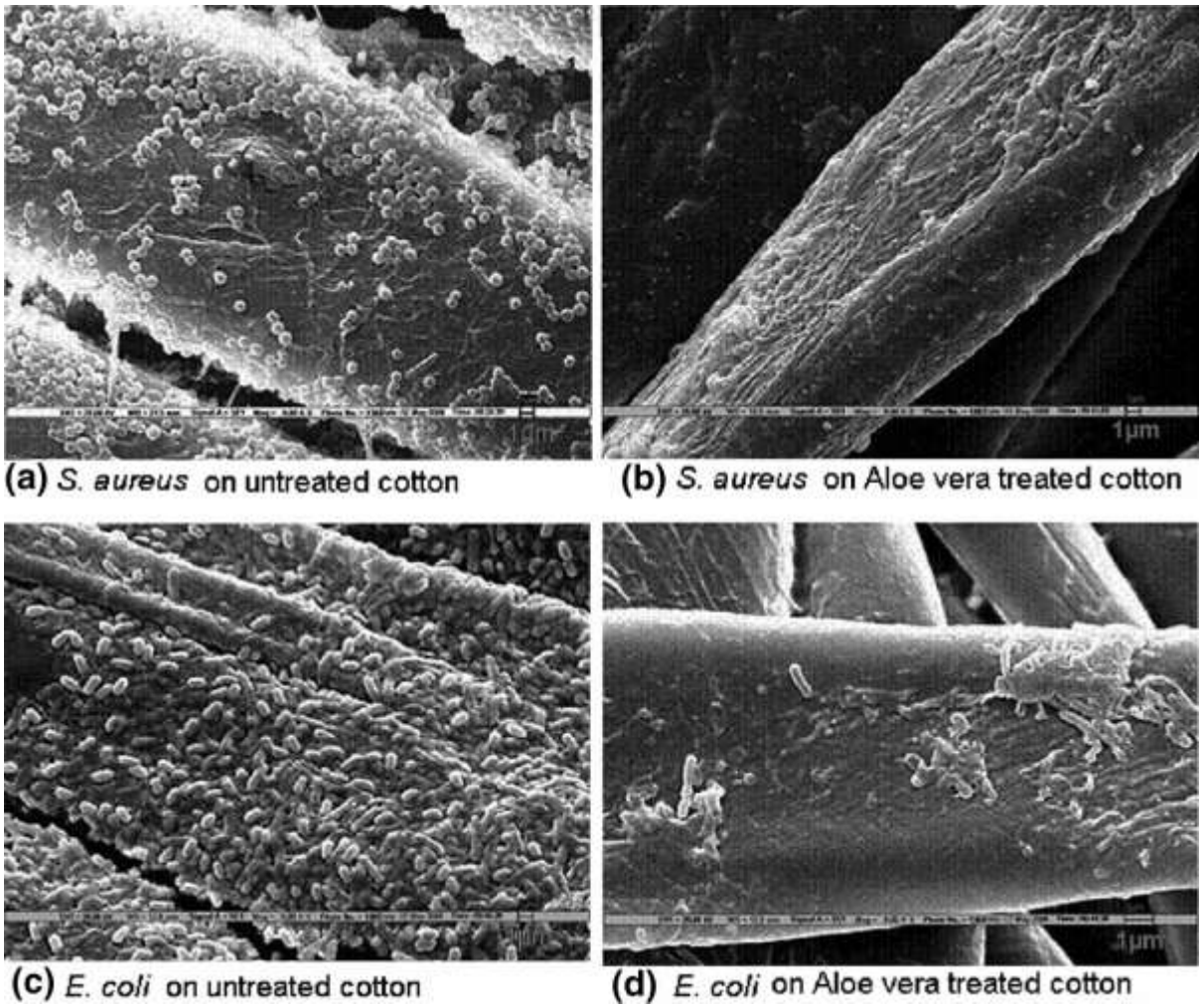
404

405 Fig. 3 Agar plate pictures of the parallel streak method: a untreated cotton against S. aureus;

406 b3 %Aloe vera-treated cotton against S.aureus; c untreated cotton against E. coli; d 3 % Aloe

407 vera-treated cotton against E. coli

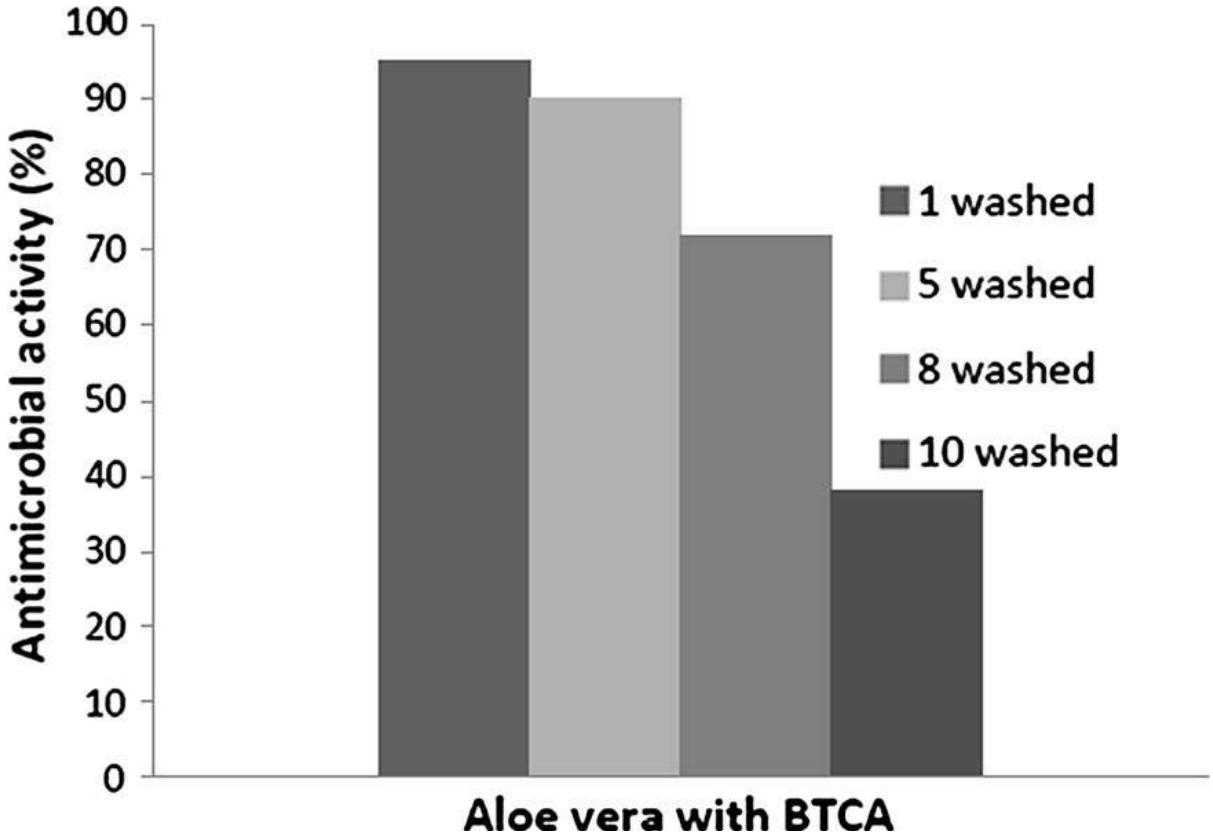
408



409

410 Fig. 4 SEM images of a, c untreated and b, d Aloe vera (3 %)-treated cotton

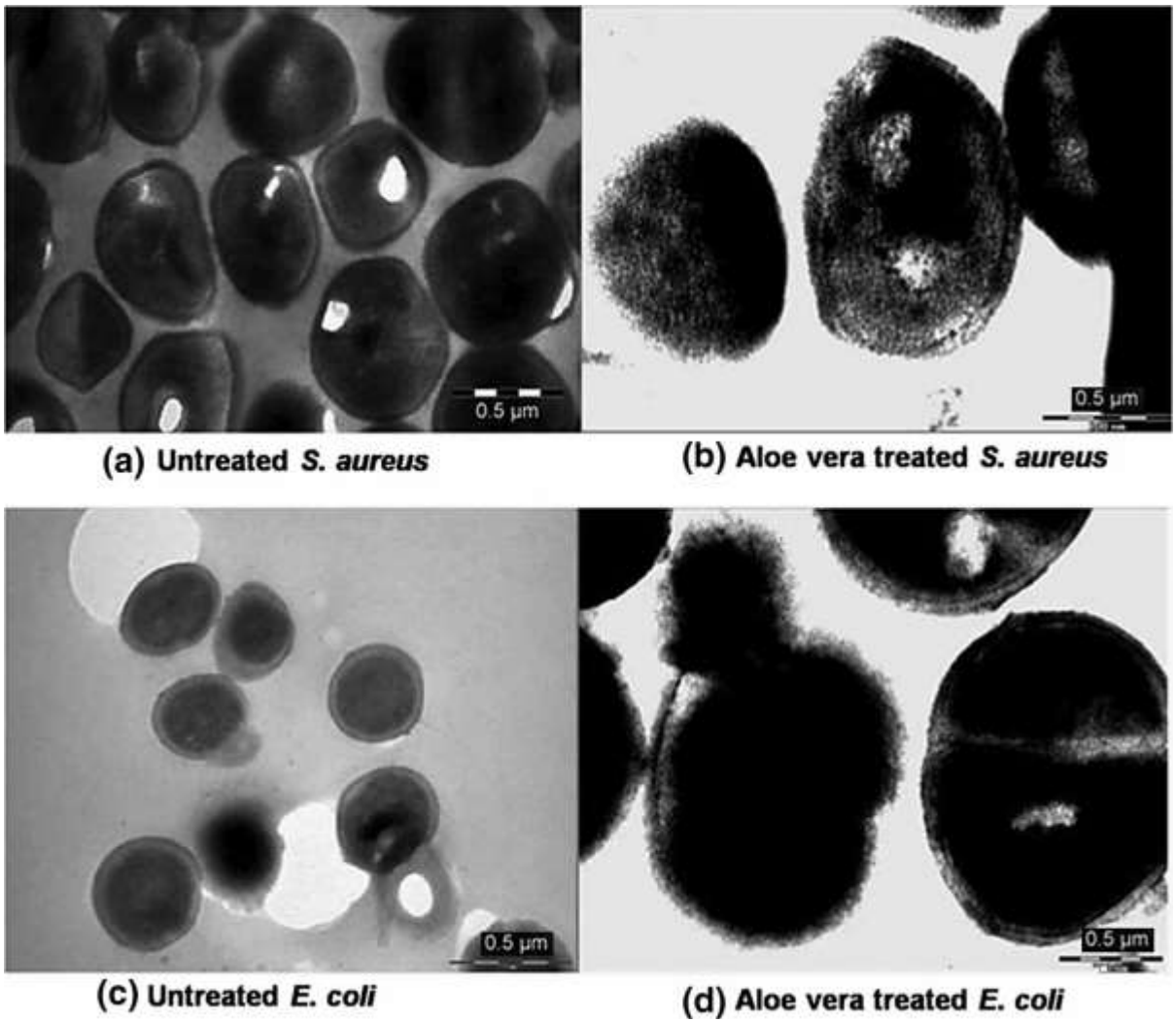
411



412

413 Fig. 5 Washing durability of Aloe vera with cross-linking agent-treated cotton fabric

414



415

416 Fig. 6 TEM images of a untreated S. aureus, b Aloe vera-treated S. aureus, c untreated E. coli,

417 d Aloe vera-treated E. coli

418

419