

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

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ABSTRACT

In this study cotton fabrics were finished with *Aloe vera* gel along with 1,2,3,4-butanetetracarboxylic 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

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

32 In the last few decades, research has been carried out in developing novel technologies to
33 produce enhanced antimicrobial activity on textiles by using different synthetic antimicrobial
34 agents such as triclosan, metal and their salts, organometallics, phenols and quaternary
35 ammonium compounds (Windler *et al.* 2013). Although the synthetic antimicrobial agents are
36 very effective against a range of microbes and provide a durable effect on textiles, they are a
37 cause of concern due to the associated side effects and ecological problems such as water
38 pollution. Hence, there is a need and demand for antimicrobial textiles based on eco-friendly
39 agents which not only help to reduce the ill effects associated due to microbial growth on
40 textile materials but also comply with the statutory requirements imposed by the regulating
41 agencies. There is a vast resource of natural products with active antimicrobial ingredients
42 amongst which the plant based products cover a major range (Joshi *et al.* 2009). Healing
43 power of some of the plant materials has been well-known and used since ancient times
44 worldwide. Although there are many natural products rich in antimicrobial agents, only
45 chitosan (Zhang *et al.* 2003; Hsieh *et al.* 2004; Aly *et al.* 2004; Shanmugasundaram *et al.*
46 2006; Tavarria *et al.* 2012; Teli *et al.* 2013) and natural dyes (Gupta *et al.* 2004; Gupta *et al.*
47 2005; Han and Yang 2005; Gupta and Laha 2007; Prabhu *et al.* 2011; Rajendran *et al.* 2013)
48 have been widely used as potential antimicrobial agents for textile application. A systematic
49 study on integrating neem seed and bark extracts to cotton (Purwar *et al.* 2008) and
50 cotton/polyester blend (Joshi *et al.* 2007) has been reported. The major challenges in the
51 application of natural products for textile application are most of these plant materials are
52 complex mixtures of several compounds and also the composition varies in different species
53 of the same plant. The durability, shelf life and antimicrobial efficiency of natural products

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

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

74 The antifungal and antibacterial properties of *Aloe vera* can be exploited for medical
75 textile applications, such as wound dressing, suture and other bioactive textiles. The
76 combined activities of *Aloe vera*, chitosan and curcumin on cotton, wool and rabbit hair with
77 their different concentrations by exhaust method have been studied (Ammayappan and Moses
78 2009).

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

86 **EXPERIMENTAL**

87 **Materials**

88 A plain weave cotton fabric (100 ends × 80 picks) weighing 80 g/m² was used throughout the
89 study. Commercial *Aloe vera* gel from Fruit of the Earth, Inc, USA without any modification
90 was used as an antibacterial agent. 1, 2, 3, 4-butanetetracarboxylic acid (BTCA) (Qualigens)
91 was used as cross-linking agents. Sodium hypophosphite (NaH₂PO₂, H₂O, Lobal Chemie)
92 was used as a catalyst for carboxylic acids. All the chemicals used were of reagent grade.

93 **Methods**

94 **Finishing treatment**

95 *Pad-dry-cure method*

96 Cotton fabric was treated with different concentration of *Aleo vera* gel ranging from 1, 3, 5
97 and 7 w/v along with BTCA (6% w/v) as cross-linking agent & sodium hypophosphite (4.1%
98 w/v) as catalyst through a two bowl horizontal laboratory padder (pressure 2 kg/cm²,
99 LabIndia, New Delhi) with two dip and two nip process to give a wet pick up of 100%. After
100 padding the treated fabric samples were dried at 85°C for 5 min and cured at 150°C for 2 min
101 in a laboratory stenter.

102 **Wash fastness**

103 The *Aloe vera* gel treated fabrics were washed in a Launder-o-meter using 5g/l non-ionic
104 detergent, Lissapol N (Purwar *et. al.* 2008) at 50⁰ C for 45 min keeping M:L ratio 1:40.

105 **Fourier transforms infrared spectroscopy (FTIR)**

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

111 **Antibacterial activity**

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

121 The antibacterial activity of the *Aloe vera* treated fabrics was quantitatively evaluated by
122 shake flask method. This method is specially designed for specimens treated with non
123 releasing antibacterial agents under dynamic contact conditions. In this test, the fabric sample
124 (2.5 cm × 2.5 cm) was dipped into a flask containing nutrient broth bacterial culture solution
125 with a cell concentration of 1×10^6 CFU/ml. The flask was then shaken at 200 rpm for 24 hrs.
126 at 37 °C. After 24 hrs. incubation, serial dilution of the liquid was made in sterilized distilled
127 water. Dilution of 10^{-4} and 10^{-5} were used for colony counting. 10 µl were spread on to the

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

130
$$\text{Antibacterial activity (\%)} = (A - B) / A \times 100$$

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

133 **Scanning electron microscopy (SEM)**

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

142 **Transmission electron microscopy (TEM)**

143 Transmission Electron Microscopy (TEM) of *Aloe vera* treated bacteria (both Gram-positive
144 and Gram-negative) was carried out to find out the destruction mechanism of the bacterial
145 cell. Morgagni 268 D TEM was used for taking the images. 1 ml of Gram-positive bacteria
146 (*Staphylococcus aureus*) from 10⁶ CFU/ml bacteria culture was inoculated in 100 ml liquid
147 culture containing 3/4th of the MIC value (i.e. 0.0075 mg/ml for *Staphylococcus aureus* and
148 0.00075 mg/ml for *Escherichia coli* bacteria) of *Aloe vera* gel. The samples were kept in an
149 incubator shaker at 37 °C for 6 hrs. After that the samples were centrifuged at 5000 rpm for
150 20 min at 4 °C to discard the supernatant. The bacterial cells were washed with phosphate
151 buffer. The washed samples were fixed with 2% glutaraldehyde. After making the block the
152 samples were fixed on a grid and examined through transmission electron microscopy. One

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

155 **Performance Properties of Finished Fabrics**

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

165 **RESULTS AND DISCUSSION**

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

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

178 BTCA treated fabric (Fig. 1b). This indicates a decrease in the average number of ester
179 groups formed in presence of *Aloe vera*. The lower intensity peak of *Aloe vera* with cross-
180 linking agent treated cotton is due to the interaction of *Aloe vera* active compounds with
181 some of the hydroxyl (-OH) groups of the cotton and also interaction with the free -COOH
182 groups of carboxylic acid molecules which are supposed to form ester linkage with cotton in
183 absence of *Aloe vera* compounds. Hence, the extent of degree of direct chemical cross-
184 linking between cotton and carboxylic acids via ester linkage is effectively less in *Aloe vera*
185 treated samples as some of the -OH groups of cotton are actively occupied by some of the -
186 OH groups (as shown in Fig. 2) of *Aloe vera* ingredients. Thus active ingredients of *Aloe vera*
187 containing -OH groups in their chemical structure can easily form H-bonding with the either
188 -OH groups of cellulose backbone or chemically react with the carboxylic acid during curing
189 process. In some cases the carboxylic acid may act as a bridge between the active ingredients
190 of *Aloe vera* and cotton molecules. Similar results obtained when cotton fabric was finished
191 with neem active ingredients along with glyoxa/glycol cross-linking agent (Purwar *et al.*
192 2008).

193 **Antibacterial activity of the *Aloe vera* treated fabric**

194 *Qualitative analysis*

195 Antibacterial activity of *Aloe vera* finished cotton fabric after (1st washed sample) was
196 evaluated qualitatively by Parallel Streak Method (AATCC 147-1998) against both Gram-
197 positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli*) bacteria. The results
198 of qualitative test are shown in Fig. 3. It was observed that there is no visible growth of
199 bacteria (*both Staphylococcus aureus* and *Escherichia coli*) on the cotton fabric treated with
200 3% (w/v) *Aloe vera* concentration. However, there is no clear zone of inhibition found around
201 the treated fabric. The non-leaching phenomenon of *Aloe vera* from the cotton substrate
202 substantiate that the active ingredients of *Aloe vera* gel is physically as well as chemically

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

211 The antibacterial activity of the treated samples with different concentration of *Aloe vera*
212 (1%, 3%, 5% and 7% w/v) was evaluated quantitatively using dynamic shake flask method
213 (AATCC 100-1999) against both Gram-positive (*Staphylococcus aureus*) and Gram-negative
214 (*Escherichia coli*) bacteria. The percent antibacterial activity was calculated and the result
215 obtained are summarized in Table 1. Two control samples were tested along with the *Aloe*
216 *vera* treated samples. Untreated fabric was taken as control-I and only BTCA treated fabric
217 sample was taken as control-II. It was found that with increase in concentration of *Aloe vera*
218 gel in finishing bath and subsequently on treated fabric, the antibacterial activity of the
219 treated fabric increases. 3% *Aloe vera* gel treated fabric showed more than 90% antibacterial
220 activity against both types of bacteria. With increase in concentration of *Aloe vera* (up to 7%)
221 the bacterial reduction increased up to 99%. This may be due to the enhanced weight add-
222 on% of the aloe active ingredients on the fabric with increasing *Aloe vera* concentration. It
223 was also observed that only BTCA treated fabric showed bacteria retention of around 70%.

224 The durability of the antibacterial activity of the *Aloe vera* treated cross-linked fabric was
225 evaluated after repeated washing and results obtained are presented in Fig. 5. It was found
226 that the antibacterial activity retains more than 70% up to 5 machine washes and more than
227 50% even after 8 machine washes although there is a sharp reduction in antibacterial activity

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

232 This observation was further reaffirmed by evaluating the crease recovery angle (CRA) of
233 only BTCA treated fabric with repeated laundering. The results are shown in Table 2. The
234 crease recovery angle has also decreased with repeated laundering. With repeated machine
235 washing, crease recovery angle of the BTCA finished cotton fabric decreases. This is due to
236 opening of the bonds between BTCA and cotton. As active ingredients of *Aloe vera* gel also
237 contain –OH groups like cellulosic molecules, and also forms same types of bonds among
238 BTCA and cotton structure, they are going to lose during washing. Thus antibacterial activity
239 is going down due to removal of active ingredients along with the removal of BTCA. This
240 also confirms that the active ingredients of *Aloe vera* gel are chemically / physically linked
241 with the BTCA. Similar results were obtained when cotton fabric was finished with neem
242 extract along with Glyoxal/glycol cross-linking agent. The crease recovery angle as well as
243 antimicrobial activity of the finished fabric decreases with repeated laundering (Purwar *et.al.*
244 2008).

245 **Mode of action of *Aloe vera* on tested bacteria**

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

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

255 **Performance properties of *Aloe vera* treated fabric**

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

270 **CONCLUSIONS**

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

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

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

378

| Samples | Bacteria tested | | | |
|---|--|----------------------------|---|----------------------------|
| | <i>Staphylococcus aureus</i> Colony forming unit (CFU/ml) | Antibacterial activity (%) | <i>Escherichia coli</i> 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 |
| <i>Aloe vera</i> (1%) treated with BTCA | 86 x10 ⁶ | 59 | 61 x10 ⁶ | 68 |
| <i>Aloe vera</i> (3%) treated with BTCA | 17 x10 ⁶ | 92 | 17 x10 ⁶ | 91 |
| <i>Aloe vera</i> (5%) treated with BTCA | 3 x10 ⁶ | 98.5 | 4 x10 ⁶ | 98 |
| <i>Aloe vera</i> (7%) treated with BTCA | 1 x10 ⁶ | 99.5 | 1 x10 ⁶ | 99 |

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385 Table 2 Washing durability of carboxylic acid-treated cotton

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| Sample | Washing cycle | Avg. dry CRA (W + F) (°) | 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 |

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391 Table 3 Physical properties of the finished cotton fabrics

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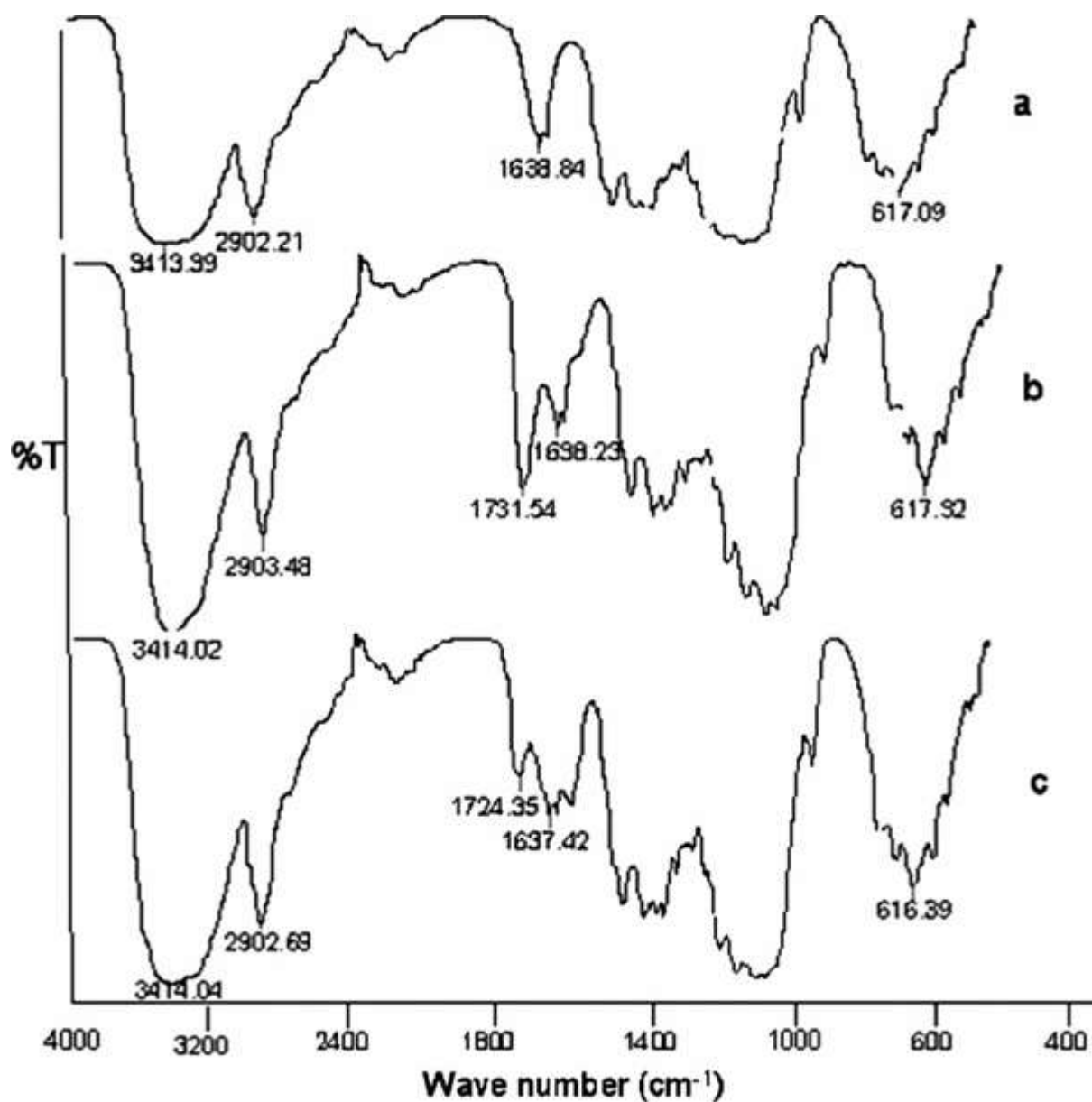
| Samples | Avg. dry CRA (W + F) (°) | CV % of dry CRA | Avg. bending length (cm) | CV% of bending length | Avg. whiteness index - CIE | Tensile strength retention (%) |
|--|-----------------------------------|--------------------------|-----------------------------------|--------------------------------|----------------------------------|---|
| Untreated cotton | 156 | 0.69 | 1.8 | 0.65 | 69.08 | - |
| <i>Aloe vera</i> + 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)

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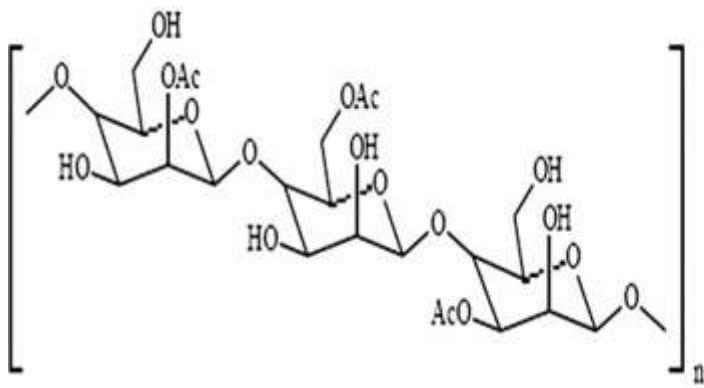


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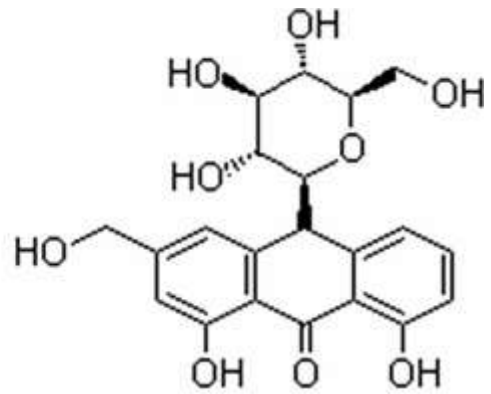
398 Fig. 1 FTIR spectra of a untreated cotton b BTCAtreated cotton. c Aloe vera and BTCAtreated cotton

399 treated cotton

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Polysaccharide acemannan

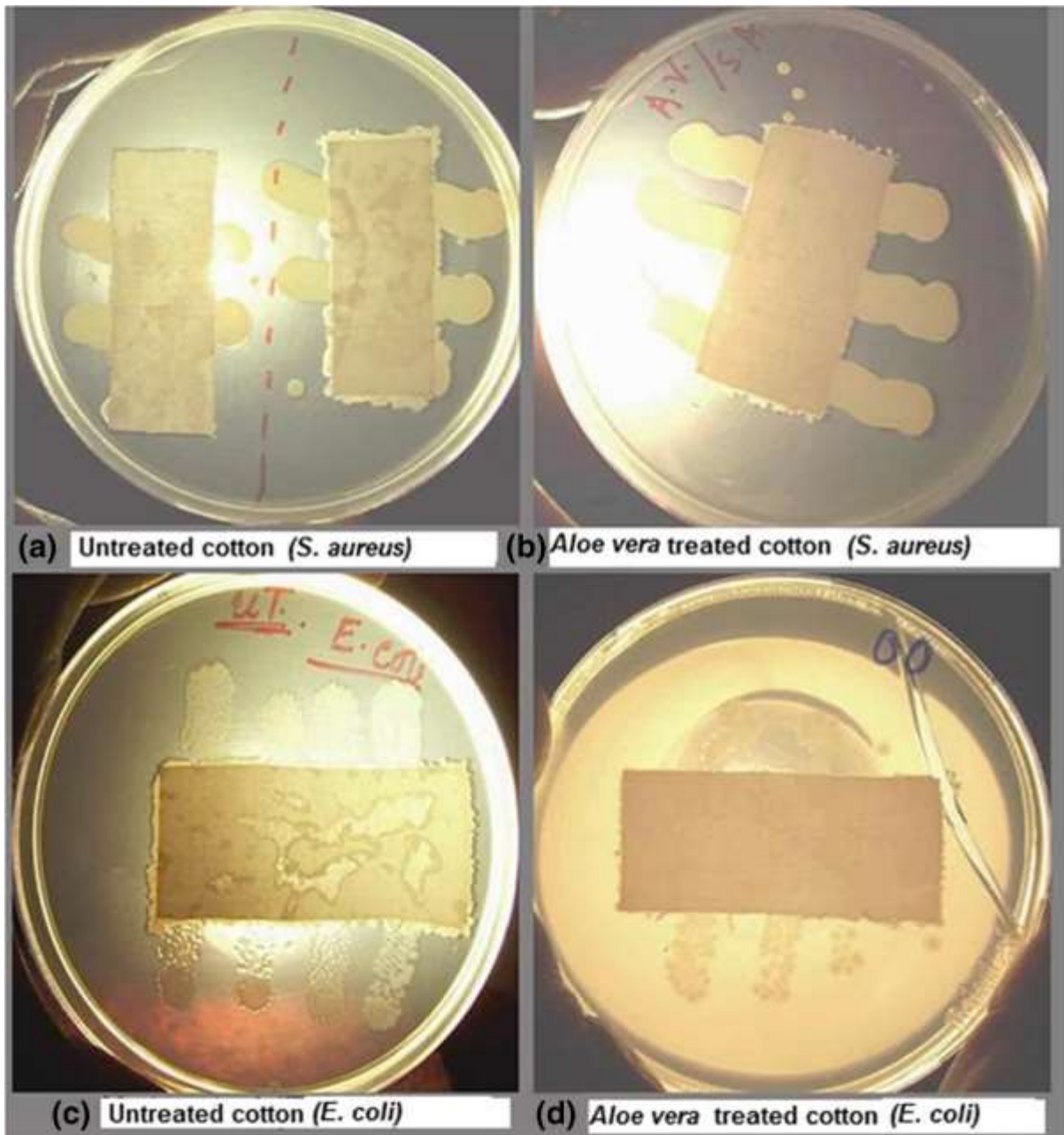


Barbaloin: 1, 8-Dihydroxy-10-(beta-D-glucopyranosyl)-3-(hydroxymethyl)-9 (10H) -Anthracenone

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402 Fig. 2 Antimicrobial ingredients in Aloe vera

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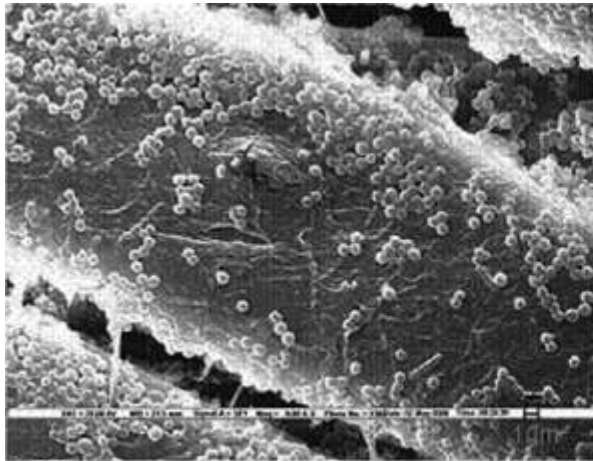
404

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

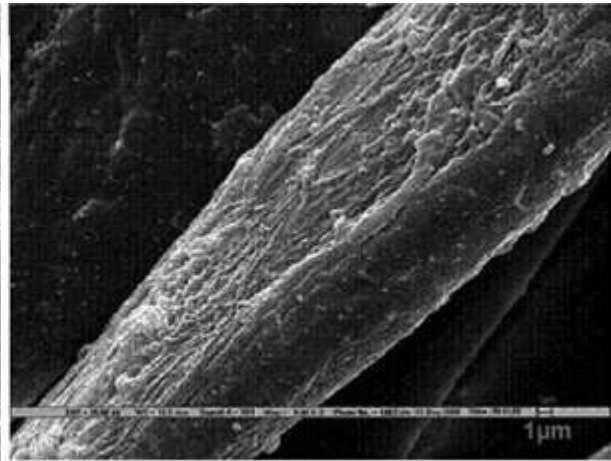
406 b3 %Aloe vera-treated cotton against *S.aureus*; c untreated cotton against *E. coli*;

407 vera-treated cotton against *E. coli*

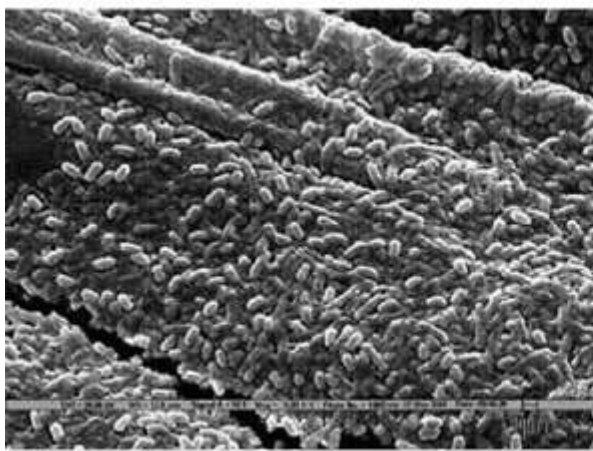
408



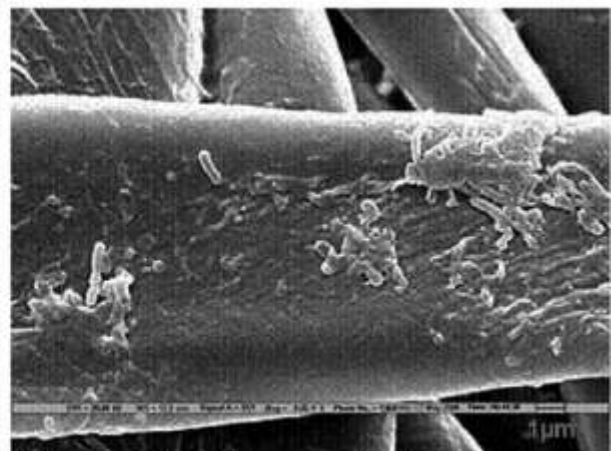
(a) *S. aureus* on untreated cotton



(b) *S. aureus* on Aloe vera treated cotton



(c) *E. coli* on untreated cotton



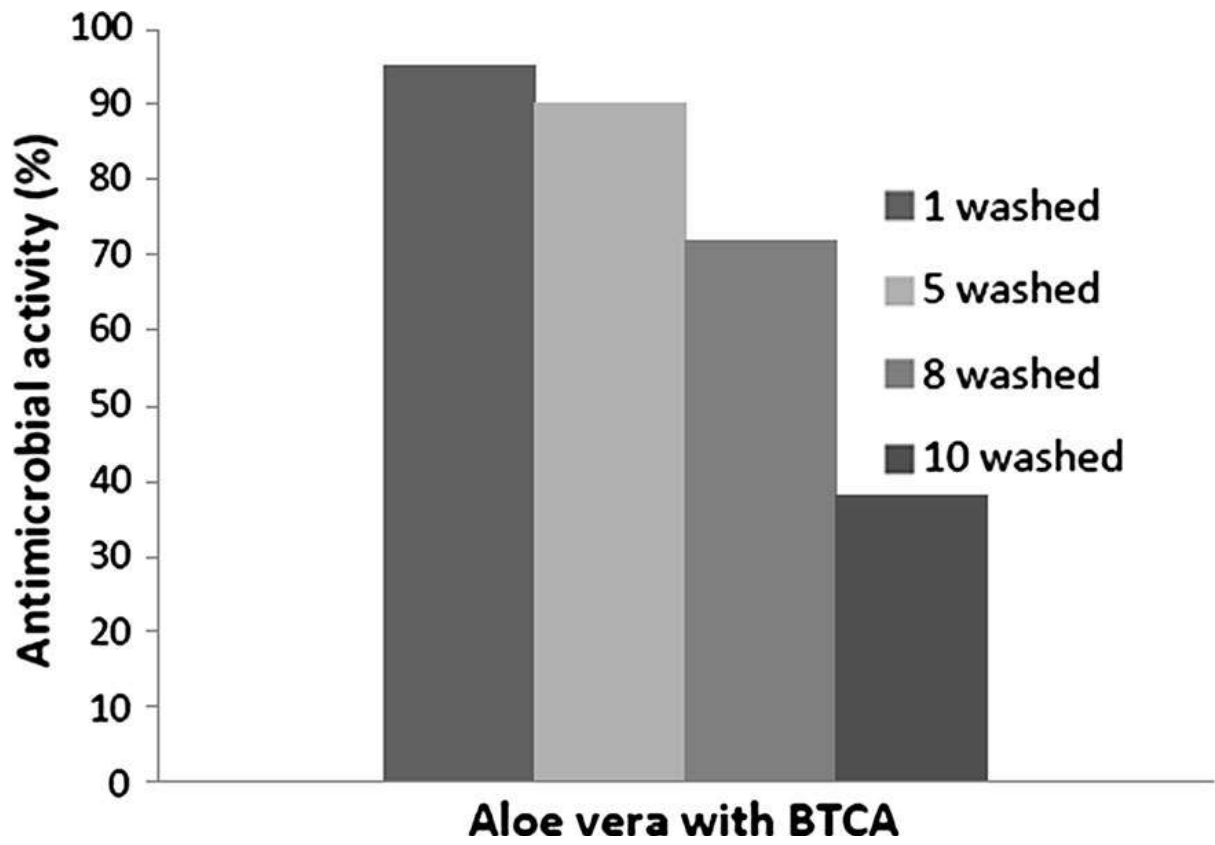
(d) *E. coli* on Aloe vera treated cotton

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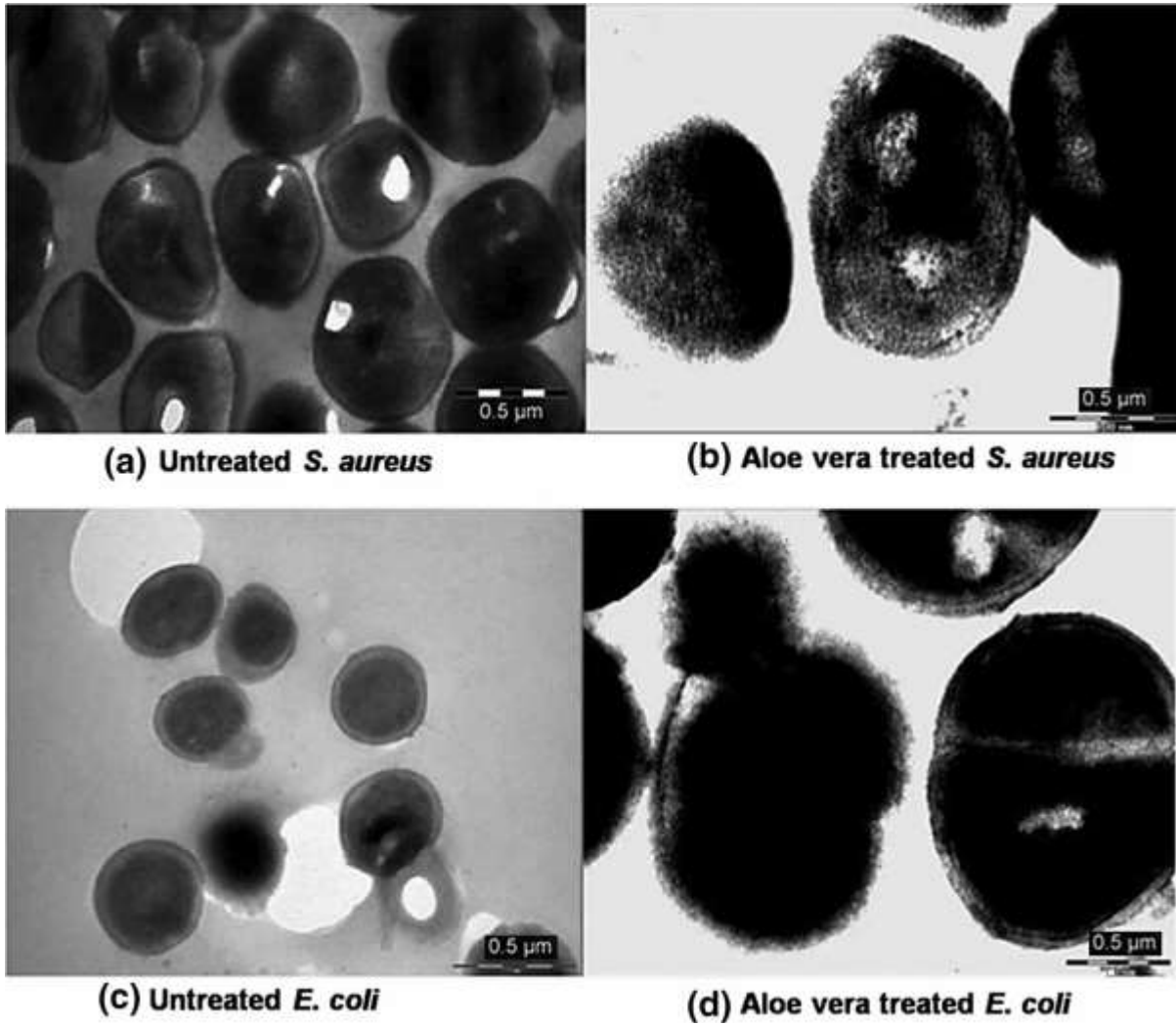
Fig. 4 SEM images of a, c untreated and b, d Aloe vera (3 %)-treated cotton



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

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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*

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