Optimisation of process conditions of cotton fabric treatment with *Terminalia chebula* extract for antibacterial application

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The methanol extracts of *Terminalia chebula* fruits as antibacterial agent and citric acid as a crosslinking agent have been applied on cotton plain woven fabric and the treated fabrics are then tested for antibacterial activity against bacterial strains like *Staphylococcus aureus* and *Escherichia coli*, under agar diffusion test and quantitative assessment. The results indicate that the treated cotton fabric shows a clear antibacterial activity with 27-38 mm zone of inhibition in the agar diffusion test against the above-mentioned strains. The treated samples show 93.33\% reduction against *Staphylococcus aureus* and 82.14\% reduction against *Escherichia coli* as per quantitative assessment. The antibacterial finished textile samples have also been evaluated for the physical properties like tensile strength, tearing strength, water absorbency and air permeability. Process parameters are optimized for better performance of antibacterial treated material by the response surface methodology adopted using Box – Behnken design and the regression equations have been obtained for fabric properties. The optimized process parameters for higher antibacterial ability of the treated textile material with optimum physical properties are extract concentration of 25\%, crosslinking agent of 7.5\% and the curing temperature of 94.16°C.

**Keywords:** Antibacterial efficacy, Box – Behnken method, Cotton, Physical properties, Response surface methodology, *Terminalia chebula*

1 Introduction

The textile materials are good media for generation and propagation of micro organism. Among various functional abilities, the antibacterial property is considered to be important with fabrics, which are in direct contact with human body\(^1\). Carbohydrate presents in the cellulosic fibre can act as a nutrient for the growth of microorganism. The growth of microorganism in clothing causes unpleasant odor, staining and loss of mechanical strength as well as health related problem to the user\(^2\). Hence, it is important to provide necessary protection from the microorganism; the fabric must have the antibacterial properties. There are several antibacterial agents used to improve the functional ability of the clothing material\(^3\). But recently there are lot of attraction towards natural based herbs as an antibacterial agent because of their ecofriendly and health hazardless nature\(^4\)\(^-\)\(^11\).

Antibacterial activity of *Terminalia chebula* extracts against several bacterial strains has already been reported\(^12\). The advancement in wound dressing sector shows significantly improved application areas of cotton fabric as wound contact layer, where the cotton material is coated with various finishes to protect the wound bed from the bacterial strains and infections\(^13\)\(^-\)\(^16\). Extracts from different parts of diverse species of plants like root, flower, leaves and seeds, exhibit antibacterial properties and are hence applied on cotton material for wound, healthcare care application\(^17\).

The antibacterial activity of the *Terminalia chebula* fruit extract treated textile material has already been reported using both methanol and water extract\(^18\). This investigation was aimed at studying the effect of antibacterial treatment on the physical properties of textile material. Methanol extract of the *Terminalia chebula* fruit was applied on cotton textile with a crosslinking agent (citric acid) to improve the durability of the treatment. The influences of different process parameters on the textile properties were also analysed.

The objective of the present study is to evaluate the antibacterial properties of textile material treated with *Terminalia chebula* extract without altering much of physical properties. The physical properties like tensile strength, tearing strength, water absorbency and air permeability of the textile material has great importance during the application of textile as health...
care material for improved performance. Hence, physical properties of the antibacterial finished cotton fabric have been evaluated and process parameters like extract concentration, curing temperature and crosslinking agent percentage are optimized for better performance of the finished fabric using response surface methodology (Box – behnken design), a fractional factorial design for three independent variables. A total of 15 experiments were necessary to estimate 10 coefficients of the model using multiple linear regression analysis.

2 Materials and Methods

2.1 Herbal Extraction

*Terminalia chebula* fruits, chosen for this study, were purchased from the commercial outlets of the Coimbatore District, Tamilnadu, India. The collected quantities of *Terminalia chebula* fruits were shade dried and powdered. The methanol extract of the powder was obtained. 10000 mg of powder was soaked in 100 mL of methanol separately for 24 h to obtain 10% concentrated solution; the active substances were dissolved in methanol. The extract was filtered and used for antibacterial finishing.

2.2 Microorganism

Bacterial cultures used in the present studies, *Staphylococcus aureus* (MTCC 737), *Escherichia coli* (MTCC 1687), were obtained from Microbial Type Culture Collection (MTCC) from IMTECH, Chandigarh.

2.3 Finishing

Plain woven cotton fabric with warp density 140 ends/inch and weft density 78 picks/inch was desized, scoured and bleached prior to the application of the antibacterial finish. The methanol extracts of *Terminalia chebula* were applied to the cotton fabric by dipping in the bath with material-to-liquor ratio of 1:10 and then pad-dry-cured at 100°C. Further increment in curing temperature (120°C) causes yellowness and degradation in fabric, hence the temperature for curing is restricted with 110°C. Finally, the fabric samples were tested for antibacterial activity as per the AATCC test standards.

2.4 Antibacterial Property Assessment

2.4.1 Agar Diffusion Method (SN 195920: 1992)

The treated and untreated fabric samples were placed in the AATCC bacteriostasis agar (AATCC, 2005), which was previously inoculated (mat culture) with a test organisms (*Staphylococcus aureus, Escherichia coli*). After incubation, a clear area of uninterrupted growth underneath and along side of the test material indicates the antibacterial effectiveness of the fabric. The area of the inhibition is a qualitative measure of antibacterial activity.

2.4.2 Quantitative Assessment (aatcc-100:2004)

The treated samples were cut into circular swatches of 4.8 cm in diameter. The fabrics were stacked into the glass plate until 1.0 mL of inoculum get fully absorbed. After that the specimens of the test material were shaken with a known concentration of bacterial suspension and the reduction in bacterial activity at standard time was measured for *Staphylococcus aureus* and *Escherichia coli*, using serial dilution method with distilled water as dilution medium. The efficiency of the antibacterial treatment was determined by comparing the reduction in bacterial concentration of the treated sample with that of control sample expressed as a percentage reduction of standard time. To calculate reduction percentage of bacteria, following formula was used:

\[ R = \left( \frac{B - A}{B} \right) \times 100 \qquad \ldots \quad (1) \]

\[ R = \left( \frac{C - A}{C} \right) \times 100 \quad \ldots \quad (2) \]

where \( R \) is the % reduction; \( A \), the number of bacteria recovered from the inoculated treated test specimen swatches in the jar incubated over the desired contact period (24 contact time); \( B \), the number of bacteria recovered from the inoculated treated test specimen swatches in the jar immediately after inoculation (at 0 contact time); and \( C \), the number of bacteria recovered from the inoculated untreated control specimen swatches in the jar immediately after inoculation (at ‘0’ contact time). If \( B \) and \( C \) are not similar, the larger number should be used.

2.5 Physical Property Assessment

The antibacterial treated cotton fabric samples were tested to assess the following physical properties as per the standard methods. Ten samples were tested for each test and the average value was used for the discussion. The standard methods used are ASTM D-5035 for tensile strength, ASTM D-1424-96 for tearing strength, ASTM D 737-99 for air permeability and AATCC 39-1980 for water absorbency.
2.6 Process Optimization by Response Surface Methodology

Response surface methodology is an empirical modelization technique devoted to the evaluation of the relationship of a set of controlled experimental factors and observed results. In this study, the variable like extract concentration (15, 20 and 25%) crosslinking agent percentage (5, 10 and 15) and curing temperature (90, 100 and 110°C) are the significant variables, designated as X₁, X₂ and X₃ respectively. The low, middle and high levels of the variables are designated as -1, 0 and +1 respectively. The calculation was carried out using multiple regression analysis using the least square method.

The quadratic polynomial equation approximates the mathematical relationship of three independent variables X₁, X₂ and X₃ on the response system. The equation was

\[ Y = C_0 + C_1X_1 + C_2X_2 + C_3X_3 + C_{12}X_1X_2 + C_{13}X_1X_3 + C_{23}X_2X_3 + C_{11}X_1^2 + C_{22}X_2^2 + C_{33}X_3^2 \]

where Y is the predicted yield; C₀, the constant; C₁, C₂ and C₃, the linear coefficients; C₁₂, C₁₃ and C₂₃, the cross product coefficients; and C₁₁, C₂₂ and C₃₃, the quadratic coefficients. The coefficients were obtained using multiple regression analysis to predict the response. The design of experiment was done by Box-Behnken, three variable designs. The bacterial inhibition and the physical properties like tensile strength, tearing strength, water absorbency and air permeability were also evaluated.

3 Results and Discussion

3.1 Antibacterial Efficacy

**Agar Diffusion Test**

Figure 1 shows the antibacterial efficacy of treated fabrics. The results indicate the presence of clear zone of inhibition of 34mm and 32mm diameter for methanol extract treated fabric against microorganisms namely *Staphylococcus aureus* (Gram positive) and *Escherichia coli* (Gram negative). The untreated fabric (control) shows bacterial growth under the test specimen.

In Fig. 1 the brown colour indicates the diffusion of herbal extract from the fabric. During the incubation period, the extract material migrates through the agar. The zone of inhibition should not be expected if the antibacterial agent is firmly attached to the textile (e.g. covalently) which prevents its diffusion into the agar. In this case the antibacterial activity can be seen only under the fabric sample. If the antibacterial agent can diffuse into the agar, a zone of inhibition becomes apparent and its size provides some indication of the potency of the antibacterial activity or the release rate of the active agent. However, the usage of crosslinking agent is essential as a fixing agent between fabric and herbal extract to avoid the rapid drug release from the fabric. The HPLC studies of the *Terminalia chebula* fruit extract elucidates, Saponin, ascorbic acid and gallic acid are the active substances, responsible for the antibacterial activity. In this case, the citric acid is (crosslinking agent) one of the well known antibacterial agent. The preliminary studies reveal that the antibacterial ability of the citric acid is meager at low concentration (5%) and at 15% concentration it confirms the zone of inhibition of 24 - 26 mm against *S.aureus* and *E.coli* respectively. Hence, the overall antimicrobial activity of the herbal treated cotton textile material (32-34 mm) is a combination of herbal extract and crosslinking agent (citric acid).

**Quantitative Assessment**

In the quantitative assessment process, the sample with the diameter of 4.8 cm is used per jar to absorb the quantity of 1.0 mL of inoculum (the number of sample used in this experiment is one). Hence, the treated (B) and control (C) samples are not similar and also the value of ‘control sample’ (C) is high than ‘treated sample’ (B) at “0” contact h, the values of “C” is used for the bacterial reduction percentage calculation. The results are summerised in Table 1. It indicates that the herbal treated textile materials show high percentage of bacterial reduction against both the human pathogenic bacterial strains. The methanol extract of *Terminalia chebula* treated cotton fabric shows average reduction of 93.33 % against *Staphylococcus aureus* and 82.14 % of reduction.
against *Escherichia coli*. The colony forming units (CFU) results are average of the two replicas and the standard deviation between the experiments is provided in Table 1 along with the average. Figure 2 shows the various amounts of colony units formed during the dilution ranging from $10^0$ to $10^5$.

### 3.2 Optimisation of Process Parameters

#### Experimental Design

The process variables, antibacterial activity value against *S. aureus* and *E. coli* and physical properties of the treated fabric at each experiment stage are summarized in Table 2.

<table>
<thead>
<tr>
<th>Dilution</th>
<th>S. aureus</th>
<th></th>
<th>E. coli</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>‘0’ h contact time</td>
<td>‘24’ h contact time</td>
<td>% reduction</td>
<td>‘0’ h contact time</td>
</tr>
<tr>
<td>Control CFU (S.D)</td>
<td>Treated CFU (S.D)</td>
<td>Treated CFU (S.D)</td>
<td></td>
<td>Control CFU (S.D)</td>
</tr>
<tr>
<td>$10^0$</td>
<td>TNTC</td>
<td>TNTC</td>
<td>TNTC</td>
<td>TNTC</td>
</tr>
<tr>
<td>$10^1$</td>
<td>TNTC</td>
<td>TNTC</td>
<td>TNTC</td>
<td>TNTC</td>
</tr>
<tr>
<td>$10^2$</td>
<td>TNTC</td>
<td>TNTC</td>
<td>168(0.9)</td>
<td>TNTC</td>
</tr>
<tr>
<td>$10^3$</td>
<td>252(3.5)</td>
<td>242(4.1)</td>
<td>92(2.3)</td>
<td>TNTC</td>
</tr>
<tr>
<td>$10^4$</td>
<td>192(2.4)</td>
<td>204(0.5)</td>
<td>54(3.0)</td>
<td>278(1.2)</td>
</tr>
<tr>
<td>$10^5$</td>
<td>84(1.0)</td>
<td>80(1.8)</td>
<td>TFTC</td>
<td>174(2.1)</td>
</tr>
</tbody>
</table>

TN TC — Too numerous to count.

TFTC — Too few to count.

* Values for treated CFU (SD).

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Fig 2 — Bacterial reduction in different dilution at ‘0’ h contact time (a) *E. coli* and (b) *S. aureus*, and at ‘24’ h contact time (c) *E. coli* and (d) *S. aureus*. [Each plate represents the bacterial count after successive serial dilution]
Development of Empirical Models

Table 3 shows the empirical relationships between the main process parameters, namely extract concentration (ECON) $X_1$, crosslinking agent percentage (CA) $X_2$ and curing temperature (TEM) $X_3$. The regression equation obtained after analysis of variance gives the level of antibacterial efficacy (zone of inhibition) of herbal finished fabric against Gram positive (SA—Staphylococcus aureus) and Gram negative (EC—Escherichia coli) bacterial strains and the physical properties of the textile material like tearing strength, tensile strength, air permeability, water absorbency, as a function of different concentration, crosslinking agent percentage and the curing temperature.

<table>
<thead>
<tr>
<th>Concentration %</th>
<th>Crosslinking agent, %</th>
<th>Curing temp., °C</th>
<th>Zone of inhibition, mm</th>
<th>Physical properties</th>
<th>Tensile strength lbs</th>
<th>Tear strength kg</th>
<th>Air permeability cc/cm²/s</th>
<th>Water absorbency, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>5</td>
<td>100</td>
<td>32</td>
<td>Gram positive (SA)</td>
<td>140</td>
<td>25</td>
<td>9.13</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24</td>
<td>Gram negative (EC)</td>
<td>160</td>
<td>25</td>
<td>10.8</td>
<td>23</td>
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<tr>
<td>25</td>
<td>5</td>
<td>100</td>
<td>29</td>
<td></td>
<td>140</td>
<td>27</td>
<td>10.8</td>
<td>27</td>
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<tr>
<td>15</td>
<td>5</td>
<td>100</td>
<td>26</td>
<td></td>
<td>155</td>
<td>32</td>
<td>11.4</td>
<td>18</td>
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<tr>
<td>25</td>
<td>10</td>
<td>90</td>
<td>29</td>
<td></td>
<td>125</td>
<td>39</td>
<td>11.3</td>
<td>30</td>
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<tr>
<td>25</td>
<td>10</td>
<td>110</td>
<td>27</td>
<td></td>
<td>155</td>
<td>27</td>
<td>9.72</td>
<td>40</td>
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<tr>
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<td>20</td>
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<td>90</td>
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<td>90</td>
<td>20</td>
<td></td>
<td>140</td>
<td>30</td>
<td>9.6</td>
<td>39</td>
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<tr>
<td>20</td>
<td>5</td>
<td>110</td>
<td>29</td>
<td></td>
<td>150</td>
<td>23</td>
<td>8.66</td>
<td>57</td>
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<tr>
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<td>15</td>
<td>110</td>
<td>27</td>
<td></td>
<td>130</td>
<td>32</td>
<td>9.4</td>
<td>28</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>100</td>
<td>27</td>
<td></td>
<td>145</td>
<td>25</td>
<td>12.3</td>
<td>20</td>
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<tr>
<td>20</td>
<td>10</td>
<td>100</td>
<td>25</td>
<td></td>
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<td>25</td>
<td>12.3</td>
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<td>20</td>
<td>10</td>
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<td></td>
<td>145</td>
<td>25</td>
<td>12.3</td>
<td>20</td>
</tr>
</tbody>
</table>

Here $Y_1, Y_2, \ldots, Y_6$ are the predicted responses for S.aureus and E.coli, tensile strength, tearing strength, air permeability, water absorbency respectively. For all the responses the significant level of quadratic regression equation and square regression are given in Table 3 with the F ratio and P -values. The P-values are used as a tool to check the significance of each coefficient, which also indicates the interaction strength between each independent variable. The smaller the P value the higher is the significance of the corresponding coefficient. $R^2$ represents the proportion that the model can explain for the variation in the responses. Models with $R^2$ value of $\geq 0.6$ (60%) can be considered as a valid model.
3.3 Effect of Process Parameter on Antimicrobial Activity

*Staphylococcus aureus*

Figure 3 (a) shows the contour plots, plotted against amount of antibacterial activity versus extract concentration and crosslinking agent percentage. Here the activity of the treated sample increases with the increase in extract concentration and decreases with the increase in crosslinking agent percentage. The maximum zone of inhibition of 36 mm is observed at 24-26% extract concentration and 4-6% crosslinking agent concentration. The contour plot in Fig. 3 (b) represents the zone of inhibition versus extract concentration with curing temperature. Here, the antibacterial activity increases with the increase in extract concentration and curing temperature. The activity reaches a maximum of 36 mm for the extract concentration 24-25% and curing temperature 90°C. The plot in Fig. 3 (c) represents the activity with crosslinking agent percentage and curing temperature. The increase in curing temperature increases the zone of inhibition. The optimum condition for the better activity is found to be 4% of crosslinking agent and 110°C of curing temperature.

*Escherichia coli*

Figure 4 (a) shows that the zone of inhibition of the treated sample increases with the increase in extract concentration and crosslinking agent percentage. The maximum inhibition identified is 28mm at 12% of...
crosslinking agent with 25% extract concentration. This will be the optimum process condition to protect the fabric against E.coli. Figure 4 (b) shows that the inhibition zone increases with the increase in extract concentration and curing temperature. The maximum inhibition is noted at an extract concentration of 24 – 25% and the temperature of 110°C. Figure 4 (c) shows that the increase in crosslinking agent percentage increases the activity initially but after 10% it reduces step by step. While considering the curing temperature the maximum zone of inhibition is noticed at 10% of crosslinking agent with the curing temperature of 110°C.

For both the bacterial stains the increase in extract concentration directly increases the activity of the treated cotton fabric. The citric acid as a crosslinking agent plays a vital role, which reacts with hydroxyl group of cellulose and forms the ester bond between the cyclic anhydride ring and the hydroxyl group on the cellulose and also with the carboxylic group of active substances in herbal extract. Hence, the citric acid crosslinks the two macromolecules effectively, resulting in an improvement of the crosslinking between the herbal extract and the cotton material. The increase in curing temperature with crosslinking agent improves the fixation rate of antibacterial agent on the fabric surface, which ultimately increases the zone of inhibition of herbal extract treated cotton material against both the strains.

3.4 Effect of Process Parameter on Tensile Strength

Figure 5 (a) shows the influence of extract concentration and crosslinking agent on the tensile strength. It indicates that the tensile strength is maximum at high extract concentration. But the increase in crosslinking agent percentage reduces the tensile strength of the material. This may be due to the acidic nature of the crosslinking agent, which degrades the cellulosic material. The maximum strength of 150 lbs attained at extract concentration of 25% and low crosslinking agent presence.

Figure 5 (b) represents the effect of extract concentration with curing temperature on tensile strength of the material. It is observed that the percentage of extract concentration has less influence on the tensile strength of the material, where the crosslinking agent percentage remains constant. The higher values of tensile strength is obtained at higher temperature. However, further increase in temperature after 110°C leads to reduction in tensile strength. This is because of structure degradation at higher temperature.

Figure 5 (c) shows the tensile strength changes with crosslinking agent concentration and curing temperature. The maximum strength of 150 lbs is obtained at 110°C of curing temperature and 4% of crosslinking agent. The acidity of polycarboxylic acid has a significant effect on the reduction of tensile strength of the treated cotton when compared to extract concentration and curing temperature. The loss in tensile strength of cotton fabric treated with polycarboxylic acid is a result of the acid-catalyzed depolymerisation of cellulose molecules. Crosslinking of cellulose molecules increases the brittleness of cotton fibres and, in turn, reduces the
strength of the crosslinked fabrics. The magnitude of the tensile strength loss is enhanced with the increase in degree of crosslinking\textsuperscript{36}. The crosslinking reactions can only be produced at high temperatures. So at lower temperature, the strength loss mostly occurs due to degradation of the polymer and reduction of the interfacial binding strength between the crystals and the amorphous regions. At high temperature, strength loss mostly occurs due to the crosslinking and depolymerization of the macromolecules\textsuperscript{37}.

3.5 Effect of Process Parameter on Tear Strength

Figure 6 (a) shows the combined effect of extract concentration and crosslinking agent concentration on tearing strength of treated material. It is observed that the extract concentration and crosslinking agent concentration has low influence on tearing strength. Figure 6 (b) represents the effect of extract concentration with curing temperature on tear strength of the material. From the results it can be noted that the percentage of extract concentration has less influence on the tear strength of the material. Figures 6 (b) and (c) show that the tearing strength reduces with the increase in crosslinking agent concentration and the curing temperature\textsuperscript{38}. This may be due to the loss of fabric strength as the crosslinking agent percentage and curing temperature increase as already mentioned in the discussion of tensile strength. The strength loss of cotton crosslinked by a polycarboxylic acid is caused by irreversible acid-catalyzed depolymerization and reversible crosslinking of cellulose molecules\textsuperscript{39}. The maximum of tearing strength obtained at 85-90°C temperature and 6% of crosslinking agent.

3.6 Effect of process parameter on Air Permeability

Figure 7 represents the influence of extract concentration and crosslinking agent concentration on air permeability of treated fabric. The results show that the increase in crosslinking agent percentage slightly increases the air permeability upto 12% and further increase in crosslinking agent percentage leads to reduction in air permeability of the material. The air permeability values of the extract treated cotton material is inversely proportional to the extract concentration and crosslinking agent concentration. The increase in crosslinking agent percentage after certain point reduces the air permeability of the treated cotton material due to their crosslinking effect on molecular and morphological level\textsuperscript{40}. The extract concentration has less influence on air permeability while the temperature remains constant. The increase in extract concentration reduces the air permeability and the increase in curing temperature improves air permeability upto 100°C and reduces further. The filling of interfibre pores and voids of cotton fabric leads to lower the air permeability at higher concentration of herbal extract\textsuperscript{41}. The maximum of 12cc/cm\textsuperscript{3}/s is noted at the extract concentration of 20% and the crosslinking agent of 6% and 100°C of curing temperature.

3.7 Effect of Process Parameter on Water Absorbency

Figure 8 shows that the water absorbency of the treated material improves with the increase in the extract concentration. Crosslinking agent concentration and curing temperature has less
influence on water absorbency. However, increasing the crosslinking agent concentration and curing temperature can induce reductions in the crystallinity and strength of the treated fabric. The reduction in crystallinity contributes greatly to the reduction in interfacial binding strength between the crystals and the amorphous regions. The reduction in crystallinity and interfacial binding strength might soften and improve the absorbency of the finished material. These results are also supported by findings of Ibrahim et al. The minimum of 20s is observed as maximum absorbency with maximum extract concentration of 25%, crosslinking agent percentage of 6 and curing temperature of 100°C.

### 3.8 Optimisation of Process Parameter for Responses

The optimization of process parameter against the responses is performed by numerical optimization method, with the help of design expert software. The numerical optimization will search the design space, using the models created in the analysis to find factor settings that meets the goal. In this research achieving the better antibacterial activity of the herbal treated fabrics is the major objective. Hence, the added emphasis and higher importance are given for the microbial inhibition results of Gram positive and negative bacterial strains than the physical property.
However, they are provided with the secondary importance. Based on the above stated condition the numerical optimization analysis provides a set of top 11 combinations of the process parameters which yields higher microbial protection along with better physical property (Table 4). It is observed that extract concentration of 25%, crosslinking agent of 7.5% and the curing temperature of 94.16°C will give higher antibacterial ability of the treated textile material with optimum physical properties. The antimicrobial ability of the treated cotton material will be of whole numbers. However, the two decimal data are used as such as obtained from the software, because the top ten optimized conditions do vary in decimal places alone.

4 Conclusion
The study shows that the treated samples have 93.33% of bacterial reduction. The samples of agar diffusion results also show high and clear zone of inhibition (27-38 mm) against wide spectrum of human pathogenic bacterial strains. The *Terminalia chebula* treated materials are bactericidal as well as bacteriostatic.

The zone of inhibition of treated sample increases with the concentration of the herbal extract. The influence of curing temperature and crosslinking agent percentage on the zone of inhibition is significant for both the strains. In the case of physical properties, the selected process parameter has their significant influence in the responses. The tensile strength, tearing strength and air permeability of the extract-treated textile reduces with the increase of crosslinking agent percentage. The change in water absorbency of treated fabric is found to be insignificant with respect to process parameters. These results are also supported by the excellent correlation obtained between the experimental and the modeled results by formulating the linear relationship between crosslinking agents, extract concentration and curing temperature. The optimized process parameters for higher antibacterial ability of the treated textile material with optimum physical properties are extract concentration of 25%, crosslinking agent of 7.5% and the curing temperature of 94.16°C.

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