CHAPTER 6

IMPARTING FUNCTIONAL PROPERTIES IN COTTON
USING COMBINATIONS OF CHITOSAN AND PCAs

6.1 INTRODUCTION

In the previous studies of this research, PCAs such as maleic acid, itaconic acid, citric acid and tartaric acid have been used in single as well as in combinations successfully for imparting multiple easy-care functional properties in cotton as discussed in chapter 3 and chapter 4. Chitosan has been found to be useful in imparting hygiene and protective properties like very good antimicrobial property, adequate flame retardancy, improved soil release characteristics and marginally improved crease recovery properties with very low strength loss as explained in chapter 5.

Addition of PCAs with chitosan in the finish bath formulation helps to crosslink chitosan with cellulose (Tahlawy 2005). In the studies carried out so far using the combination of PCAs and chitosan, PCAs have been used only for making stronger bonds between chitosan and cellulose by the formation of crosslinks (Kim et al 2003 and Montazer & Afjeh 2007). The main objective of these studies was to improve the durability of antimicrobial activity. But crosslinking of chitosan with cellulose by PCAs is expected to impart easy-care properties along with hygiene and protective properties in the finished fabric. Therefore, in this part of the study, suitable combination of PCAs and chitosan were applied on cotton to achieve an optimum blend of the functional properties listed above.
6.2 METHODOLOGY

Procedure for crosslinking of chitosan with cellulose using PCAs and the functional properties tested for the samples are explained here.

6.2.1 Finishing of Cotton with Combinations of Chitosan and PCAs

Quality particulars of the fabric, PCAs, chitosan and other chemicals were discussed in section 3.2 of chapter 3 and 5.2 of chapter 5. Three PCAs which were found successful in the previous studies viz., maleic acid, itaconic acid and citric acid were chosen. Omission of tartaric acid for this part of the study has been justified by the results of preliminary laboratory trials carried out with all four PCAs combined with chitosan. Table 6.1 shows the categories of combination, concentration of chitosan and PCAs in different combinations and the curing condition. The concentration of the finishing chemicals and their combinations were selected based on the preliminary trials (appendix 6).

Table 6.1 Concentration and curing condition for chitosan and PCAs combination study

<table>
<thead>
<tr>
<th>Category</th>
<th>Concentration</th>
<th>Curing condition</th>
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<tbody>
<tr>
<td>Chitosan and single PCAs</td>
<td>Chitosan 1% + MA 4%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chitosan 1% + MA 5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chitosan 1% + IA 4%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chitosan 1% + IA 5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chitosan 1% + CA 4%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chitosan 1% + CA 5%</td>
<td></td>
</tr>
<tr>
<td>Chitosan and mixed PCAs</td>
<td>Chitosan 1% + MA 2% &amp; IA 2%</td>
<td>170°C for 3minutes</td>
</tr>
<tr>
<td></td>
<td>Chitosan 1% + MA 2.5% &amp; IA 2.5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chitosan 1% + MA 2% &amp; CA 2%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chitosan 1% + MA 2.5% &amp; CA 2.5%</td>
<td></td>
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<tr>
<td></td>
<td>Chitosan 1% + IA 2% &amp; CA 2%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chitosan 1% + IA 2.5% &amp; CA 2.5%</td>
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</tbody>
</table>
The present study was carried out in two parts. In the first part, samples were treated with combination of chitosan & single PCAs to find out which of the PCAs in combination with chitosan is optimally effective in imparting multiple functional properties. In the second part of the study, binary combination of PCAs were mixed with chitosan and applied on cotton fabric samples to study the effect of combination of PCAs in contributing these functional properties efficiently. This also helps to assess the synergism exhibited by the PCAs in combination.

Pad-Dry-Cure process sequence was followed. Sample size was 50cm × 50cm. Samples were padded in solutions of combinations of chitosan and PCAs with necessary additives like acetic acid and sodium hypophosphite and squeezed in a laboratory padder supplied by M/s Labtex, UK, with a pressure of 3kg/cm². Then the samples were dried at 80°C for 10 min in hot air oven and curing was carried out at 170°C for 3 min using a high temperature curing oven supplied by M/s R.B Electronic & Engineering Pvt. Ltd. Mumbai. These samples were finally washed and dried.

6.2.2 Preparation of Control Samples

Two control samples were prepared using commercially successful chemicals for comparison purpose. First sample for comparing crease recovery properties have been prepared using DMDHEU resins as discussed in section 3.2.3 of chapter 3. Another sample for comparing flame retardancy was prepared with commercial flame retardant chemical tetrakis hydroxy methyl phosphonium chloride (THPC) using the procedure explained in section 5.2.3 of chapter 5.
6.2.3 Testing of the Samples

All the samples were conditioned for 8 hours at the standard testing atmosphere of $65\% \pm 2\%$ RH and $20^\circ\pm 2^\circ$C in a conditioning chamber. These samples were tested for the functional properties viz., antimicrobial activity, flammability, soil release properties, crease recovery angle, tensile strength, tearing strength and stiffness using international testing standards as mentioned in the previous chapters.

6.3 RESULTS AND DISCUSSION

6.3.1 Effect of Combination of Chitosan and PCAs on Antimicrobial Property

Antimicrobial activity in terms of zone of inhibition (mm) for all samples treated with combinations of chitosan and single PCAs was evaluated using AATCC 147 - 1998, Parallel Streak Method. E. coli ATCC 11229 and S. aureus ATCC 6538 were the bacterial strains used.

Finishing with combinations of chitosan and PCAs imparted good antimicrobial property on cotton fabric. Zone of inhibition for samples treated with chitosan and PCAs was found in the range of 21mm to 25mm for E. coli and 24mm to 27mm for S. aureus as depicted in Figures 6.1 to 6.4. Antimicrobial activity imparted in these samples might have been contributed mainly by the chitosan and not by the PCAs mixed with it. This is evident from the observation that there is no significant difference between the inhibition values of samples treated with 1% chitosan alone (Table 5.3) and the values of samples treated with combination of chitosan and PCAs. The mechanism of antimicrobial activity exhibited by chitosan can be explained in the same manner as explained in chapter 5. The presence of PCAs contributes
to the durability of the antimicrobial activity as the PCAs crosslink the chitosan with cellulose. The zone of inhibition was higher for gram positive bacterium *S. aureus* than the zone of inhibition for gram negative bacterium *E. coli*, which is well in agreement with the findings of Rajendran et al (2012). This trend is common in all combinations of PCAs and chitosan.

Durability of antimicrobial activity of chitosan and PCAs has been studied and depicted in Figures 6.1 – 6.4. Zone of inhibition values decrease to an extent of 10-20 percent after 20 laundry washes for samples of MA & IA combined with chitosan. For CA and chitosan samples, the values decrease up to 30%. As there is better crosslinking of chitosan with cellulose using PCAs, the durability behavior is better than the durability of the samples treated with chitosan solely (comparing Figures 5.2 & 5.3 with Figures 6.1–6.4). This finding conforms to the results of earlier investigations on the durability of the antimicrobial activity of the chitosan and derivatives of chitosan treated samples (Kim et al 2003).

![Graph](image)

**Figure 6.1** Durability of antimicrobial activity of 1% chitosan and 4% PCAs for *E. coli*
Figure 6.2  Durability of antimicrobial activity of 1% chitosan and 5% PCAs for *E.coli*

Figure 6.3  Durability of antimicrobial activity of 1% chitosan and 4% PCAs for *S. aureus*
6.3.2 Effect of Combination of Chitosan and PCAs on Flammability

Samples were tested for flammability using ASTM D1230-1994 standards. Chitosan and PCAs treatment reduced the degree of flammability from class III to class I which is due to nitrogen groups present in chitosan (Schindler & Hauser 2004). Maleic acid and chitosan treated samples produced a maximum protection with a flame propagation time of 16.84 s which is nearer to 17.89 s for the control sample. Maleic acid/sodium hypophosphite system (Wu & Yang 2007) has been found to possess good flame resistant characteristics by retaining more phosphorous in cellulose. Therefore in combination with chitosan, nitrogen present in the chitosan when combined with phosphorous (Schindler & Hauser 2004), improves the thermal resistance of the maleic acid and chitosan treated samples. It is interesting to observe the same trend in combinations containing mixed PCAs and chitosan in which maleic acid is present.
However, citric acid and itaconic acid have no significant contribution in improving the flammability characteristics of the samples treated with combination of chitosan and these PCAs. This is evident from the observation that there is no marked difference in the flame propagation time of the samples treated with itaconic acid & chitosan and citric acid & chitosan and the flame propagation time of the samples treated with 1% chitosan alone (as observed in Figures 6.5 & 6.6 and Figure 5.4, 5.5 & 5.6).

Figure 6.5 shows that both 4% and 5% MA in combination with chitosan have produced samples with flame propagation time of more than 15 seconds which is higher than the other two combinations. It can be understood from Figure 6.6 that in case of combinations containing mixed PCAs and chitosan too, two combinations in which MA is present show greater flame propagation time than the third combination in which mixture of IA and CA is combined with chitosan. Improved flame resistance for maleic acid treated samples was very well supported by the findings of Cheng & Wang (2009) and Wu & Yang (2009).

![Figure 6.5](image)

**Figure 6.5**  Effect of concentration of chitosan and single PCAs on flammability
6.3.3 Effect of Combination of Chitosan and PCAs on Soil Release Characteristics

Soil release property is influenced by the hydrophilic nature of the fibre and both are interdependent properties. Improved hydrophilic nature of the fabric helps easy removal of soil particles. In general, chemical finishing treatments which impart hydrophobic nature decreases the fabric’s soil release property. Chemicals used for stiff finishing, soft finishing and resin finishing are a few examples by which a hydrophobic layer is created on the surface of the fabric and thereby decreasing the soil release capacity.

Finishing treatment with PCAs has increased the soil release property to a grade of 5 in the scale of grades 1 to 5, due to the presence of unreacted hydrophilic carboxyl groups. Chitosan finishing also has increased the soil release grade of the samples to 4, which may be due to the presence of hydrophilic amino groups. When the samples treated with combinations of PCAs and chitosan both carboxyl groups of PCAs (Sauperl & Ribitsch 2009)
and the amine groups of chitosan (Schindler & Hauser 2004) together contribute to improved hydrophilicity and in turn to improved soil release properties. When these samples were tested by AATCC 130: 2000 using Soil Release – Oil Stain Release method, a soil release grade of 5 was obtained for all samples. All chitosan and PCAs treated samples have shown the same level of soil release grade 5, irrespective of the type of PCAs added. Soil release grade has increased from grade 3 for untreated sample to grade 5 which demonstrates that the nature of the fabric shifts more towards easy-care domain.

6.3.4 Effect of Combination of Chitosan and PCAs on Crease Recovery Behavior

Though chitosan treatment improves the crease recovery behavior marginally as discussed in section 5.3.4, combination of chitosan and PCAs has improved this property significantly. Total crease recovery angle CRA, was measured for all the combination samples. Effect of concentration of PCAs combination of chitosan on CRA is depicted in Figures 6.7 and 6.8. CRA values lie in the range of 248° to 261° which is comparable to the CRA value of 265° for resin treated control sample. Further, these values are much better than that of the parent sample and the samples treated with chitosan alone.
Figure 6.7  Effect of concentration of chitosan and single PCAs on CRA

Figure 6.8  Effect of concentration of chitosan and mixed PCAs on CRA
Increase in CRA is mainly due to the crosslinking of cellulosic chains. PCAs form ester cross links with cellulose through esterification reaction and therefore able to mask –OH groups of cellulose polymer and impart crease recovery behavior (Qiu & Yang 2005). Samples treated by chitosan alone show only a marginal increase in CRA values in the range of 220° - 230°. On comparing the CRA values of the samples treated with the combination of chitosan and PCAs with these values, it is inferred that chitosan cannot improve the crease recovery property of cotton fabric in a significant manner, but addition of PCAs help to improve this behavior through molecular crosslinking and makes the fabric more functional.

The crease recovery angle of the treated samples increased with increase in concentration of PCAs. Statistically, there is significant difference between the CRA values among the different single PCA and chitosan treated samples at 5% level of significance (p-value<0.05). 5% Concentration of PCA along with chitosan show greater values of CRA than the values of 4% samples as understood from the Figure 6.7 & 6.8. In single PCA combination with chitosan, MA performed better than the other two acids with a maximum CRA of 258°. 4% CA with chitosan has produced least value of 248° only. The trend is different in samples treated with combinations of mixed PCAs and chitosan. There is no significant difference between CRA values among different mixed PCAs and chitosan treated samples (p-value>0.05). Figure 6.8 shows that almost all samples show good CRA of around 260° uniformly, irrespective of the constituent PCAs present in the combination. This may be due to synergism exhibited by PCAs in combination (Qiu & Yang 2005).

Among the samples of single PCAs combination with chitosan, the samples treated with chitosan and CA has produced the least CRA values. However, the CRA values of the samples of CA mixed with other two PCAs have been found to be uniformly good among the samples of mixed PCAs and
chitosan. Combinations of CA with other PCAs increase the functionality of PCAs in terms of increased number of carboxylic acid groups and effects more crosslinking (Yang et al 1998). This argument holds good when these combinations are applied along with chitosan also.

6.3.5 Effect of combination of chitosan and PCAs on strength

Since there is no crosslinking between chitosan and cellulose, strength of the chitosan treated fabric is not much affected. Significant strength loss in the range of 11% to 18% was observed in samples treated with different combinations of chitosan and PCAs. The reason may be due to the formation of inter-molecular and intra-molecular crosslinks by PCAs which reduce the possibility of equalizing the stress distribution among all molecules, causing reduction in the capacity to withstand load (Xu & Li 2000). In comparison with the resin crosslinked fabric, the PCAs finished samples have shown better strength retention properties. This is due to the fact that PCAs crosslinking is softer than resin treated one and allows more stress to be borne (Yang et al 1998).

Table 6.2 shows the tensile strength and tearing strength values of the samples treated with combination of chitosan and single PCA. Among the samples, chitosan and 5% maleic acid samples show minimum tensile strength value of 28.58 kg and 22.23 kg in warp-way and weft-way against 34.02 kg and 27.22 kg for parent sample respectively. The same sample shows minimum tearing strength values of 944 g and 848 g in warp-way and weft-way against 1120 g and 992 g for parent sample respectively. Strength values of CA and IA combination samples are found to be better than the MA combinations.
Table 6.2  Strength and stiffness properties of combination of chitosan and single PCAs treated samples

<table>
<thead>
<tr>
<th>Combinations &amp; Concentration</th>
<th>Tensile Strength*, kg</th>
<th>Tearing Strength*, g</th>
<th>Bending Length, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warp-way</td>
<td>Weft-way</td>
<td>Warp-way</td>
</tr>
<tr>
<td>CHT &amp; IA 4%</td>
<td>29.94</td>
<td>23.13</td>
<td>960</td>
</tr>
<tr>
<td>CHT &amp; IA 5%</td>
<td>29.03</td>
<td>22.68</td>
<td>944</td>
</tr>
<tr>
<td>CHT &amp; MA 4%</td>
<td>29.03</td>
<td>22.68</td>
<td>944</td>
</tr>
<tr>
<td>CHT &amp; MA 5%</td>
<td>28.58</td>
<td>22.23</td>
<td>944</td>
</tr>
<tr>
<td>CHT &amp; CA 4%</td>
<td>29.49</td>
<td>24.04</td>
<td>960</td>
</tr>
<tr>
<td>CHT &amp; CA 5%</td>
<td>29.49</td>
<td>24.04</td>
<td>960</td>
</tr>
</tbody>
</table>

*-Strength values are normalized by calculating the strength loss against the value of parent sample and plotted in figures 6.9.-6.12.

In case of mixed PCAs combination with chitosan also, if MA is a constituent of the combination, the strength is recorded lower as observed in Table 6.3. MA shows reduced strength for the reasons explained already in section 3.3.2 (Xu & Li 2000). But the performance of MA combinations in other functional properties is found to be better than the other PCAs combinations.

Table 6.3  Strength and stiffness properties of combination of chitosan and mixed PCAs treated samples

<table>
<thead>
<tr>
<th>Combinations &amp; Concentration</th>
<th>Tensile Strength*, kg</th>
<th>Tearing Strength*, g</th>
<th>Bending Length, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warp-way</td>
<td>Weft-way</td>
<td>Warp-way</td>
</tr>
<tr>
<td>CHT &amp; IA 2% MA 2%</td>
<td>28.58</td>
<td>23.59</td>
<td>976</td>
</tr>
<tr>
<td>CHT &amp; IA 2.5% MA 2.5%</td>
<td>29.03</td>
<td>23.13</td>
<td>944</td>
</tr>
<tr>
<td>CHT &amp; IA 2% CA 2%</td>
<td>29.94</td>
<td>24.04</td>
<td>960</td>
</tr>
<tr>
<td>CHT &amp; IA 2.5% CA 2.5%</td>
<td>29.49</td>
<td>23.59</td>
<td>976</td>
</tr>
<tr>
<td>CHT &amp; MA 2% CA 2%</td>
<td>29.49</td>
<td>23.59</td>
<td>976</td>
</tr>
<tr>
<td>CHT &amp; MA 2.5% CA 2.5%</td>
<td>28.58</td>
<td>23.59</td>
<td>944</td>
</tr>
</tbody>
</table>

*-Strength values are normalized by calculating the strength loss against the value of parent sample and plotted in figures 6.9.-6.12.
The values of tensile strength loss percentage are plotted against the concentration of PCAs in combination with 1% chitosan and shown graphically in Figures 6.9 & 6.10. These figures show the effect of type and concentration of the PCAs on the tensile strength loss in warp-way and weft-way for the samples treated with combination of chitosan and single PCAs and mixed PCAs. A maximum of 16% strength loss in warp-way and 18.4% strength loss in weft-way for MA combination with chitosan. CA combination with chitosan shows a minimum strength loss of 11.7% even at 5% concentration. In case of itaconic acid and chitosan treated samples, the strength loss is slightly lower than that of MA and chitosan treated samples. Invariably, the strength loss values are more at 5% concentration of PCAs in all combination samples. The standard deviation measured for tensile strength values of the samples in warp-way is 0.54 and the coefficient of variation (CV) is 1.88%; the corresponding values in weft way are 0.28 and 1.22%. There is significant difference among the weft-way tensile strength values of the samples at 5% level of significance (p-value<0.05).

![Figure 6.9](image)

**Figure 6.9**   Effect of concentration of chitosan and single PCAs on tensile strength loss %
Figure 6.10  Effect of concentration of chitosan and mixed PCAs on tensile strength loss %

Figure 6.11  Effect of concentration of chitosan and single PCAs on tearing strength loss %
Figures 6.11 & 6.12 depict the effect of type and concentrations of PCAs on the tearing strength loss percentage. In case of tearing strength testing, all samples show uniform loss values of around 13 - 15% in warp-way and 11 - 14% in weft-way irrespective of the type of PCAs used. This trend is common for combination of chitosan and single PCA and as well as for combination of chitosan and mixed PCAs. The standard deviation measured for tearing strength values of all the samples in warp-way is 15.7 and the coefficient of variation (CV) is 1.63%; the corresponding values in weft way are 12.04 and 1.39%. Weft-way tearing strength values differ significantly among the samples at 5% level of significance (p-value<0.05).
6.3.6 Effect of Combination of Chitosan and PCAs on Stiffness

Finishing with PCAs in single as well as in combinations has reduced the stiffness of the fabric significantly. But no significant reduction in stiffness has been observed in chitosan finishing. Rather, stiffness has been marginally more than that of parent sample. Combination of chitosan and PCAs has reduced the stiffness considerably but not to the extent of treatment with PCAs alone.

Table 6.2 shows the bending length values of 1.25 cm – 1.50 cm obtained for samples treated with combinations of chitosan and single PCAs. Compared to the warp-way values, weft-way values are lower. This trend is already observed in samples finished with combination of PCAs and explained in section 5.3.3. Bending length values among the single PCAs and chitosan combination samples are found to be uniform. 5% MA and chitosan treated samples show the highest value of 1.50 cm among them.

Combination of chitosan and mixed PCAs show higher bending length values compared to the values of combination of chitosan and single PCAs as shown in Table 6.3. Maximum value of 1.60 cm is obtained for 5% concentration of mixed PCAs of IA and CA. As the chitosan treatment has increased or sustained the stiffness of the fabric as explained in section 5.3.4, it can be inferred that reduction in stiffness is due to the addition of PCAs. As PCAs are involved in softer crosslinking (Yang et al 1998), softness of the fabric doesn’t get affected. Hence, there is a reduction of stiffness observed in the combination of chitosan and PCAs treated fabrics.

Figure 6.13 depicts the effect of type of PCA and its concentration in combination with chitosan on the flexural rigidity values of the finished samples. Though there is no significant variation in the bending length values among the samples of combination of single PCAs and chitosan, their flexural
rigidity values differ markedly as the flexural rigidity is proportional to the cube of the bending length. Maximum value of 34.08mg.cm has been obtained for chitosan and 5% MA sample. CA combinations have produced sample with lower values of 19.72mg.cm.

Figure 6.13 Effect of concentration of chitosan and single PCAs on flexural rigidity

Figure 6.14 Effect of concentration of chitosan and mixed PCAs on flexural rigidity
The behavior of PCAs in combination among themselves and with chitosan in influencing the stiffness of the fabric can be understood from Figure 6.14. Warp-way flexural rigidity values of samples of combination of chitosan and mixed PCAs are greater than the corresponding values of single PCAs and chitosan samples. Combination of two PCAs has resulted in a copolymer with greater functionality and this might have caused a less flexible crosslinking compared to single PCAs. Reduced stiffness in case of combination of PCAs and chitosan finishing claims the advantage that there is no need of an exclusive chemical treatment with a softener or inclusion of softener in the finishing bath formulation as required in case of resin finishing.

6.4 CONCLUSION

Following conclusions are made after critically analyzing the results obtained in the study of combination of chitosan and PCAs.

i) Chitosan can be crosslinked with cellulose using PCAs and therefore better bonding has resulted between chitosan and cotton fabric.

ii) Because of the better bonding of chitosan and the crosslinking of cellulose by PCAs, an optimum blend of functional properties viz., durable antimicrobial protection, low flammability characteristics, improved crease recovery with greater strength retention, excellent soil release properties and reduced stiffness can be achieved in cotton.

iii) Antimicrobial property exhibited by the fabric treated with all combination samples is good with zone of inhibition ranging from 21mm to 25mm for *E.coli* and 24mm to 27mm for *S. aureus*. 
iv) Though the zone of inhibition does not differ widely among the samples, chitosan in combination with MA or IA samples have slightly higher inhibition values than the CA combination.

v) Antimicrobial activity is mainly contributed by chitosan and not influenced by the presence of PCAs in combination. The durability of antimicrobial activity is improved by the type of PCAs present.

vi) All the chitosan and PCAs combination samples show class I flammability which means that these samples are suitable for applications that require lower flammability. Flammability is mainly contributed by chitosan in case of samples IA or CA combination with chitosan.

vii) MA has increased the flame propagation time. 5% MA and chitosan sample show a flame propagation time of 16.84s, which is the highest among all the samples and is comparable to that of THPC treated control fabric.

viii) Combination of PCAs with chitosan has imparted excellent soil release characteristics in the finished fabric with a maximum soil release grade of 5. This enhances the easy-care nature of the fabric.

ix) Another vital characteristic imparted by combination of PCAs and chitosan finishing is the crease recovery behavior. CRA of the finished sample has increased up to 261° which is very much closer to the value of 265° for the resin treated control sample. PCAs crosslinking contributes to the improved crease recovery behavior mainly and the presence of chitosan does not interfere in it.
x) Among the combinations of single PCA and chitosan samples, almost all the samples have shown their CRA values above 250°. In case of combinations of mixed PCAs and chitosan, CRA values are uniformly around 260°. Increase in CRA values here may be due to the synergic effect in crosslinking.

xi) Strength loss values are very low compared to the control samples. 18.7% of tensile strength loss has been obtained for 5% MA and chitosan combination. In case of tearing strength, almost all samples exhibited strength loss values in the range of 13% - 15%. On comparison with resin treated sample, all the samples treated with combination of PCAs and chitosan have better strength retention both in tensile and tearing strength.

xii) Combination of PCAs and chitosan treatment has reduced the stiffness of the samples in comparison with the stiffness of the control sample. Therefore, there is no need of a softener treatment as required in case of resin finishing.

Though all combinations of PCAs and chitosan have been found to be successful in imparting the functional properties, considering the over-all performance in various functionalities imparted, MA combinations with chitosan have an edge over combinations of chitosan with other two PCAs. Among the finishing combinations, 1% chitosan + 5% maleic acid in single PCAs combination and 5% of maleic acid & itaconic acid (total concentration is 5%) + 1% chitosan in mixed PCAs combinations are found the optimum combinations for achieving the multifunctional properties in an efficient manner on cotton textiles.