Facile Fabrication of Cellulosic Textiles with Durable Antibacterial Properties Using Soy Protein Isolate and Silver Nanoparticles

Sudarat Srisod, Kanjana Motina, Thitirat Inprasit, and Penwisa Pisitsak*
Faculty of Science and Technology, Thammasat University, Pathum Thani 12121

Abstract

This work highlights a facile, effective method for the fabrication of antibacterial cellulosic fabrics (rayon). Soy protein isolate (SPI, 50–100 ppm) was used as a reducing agent, as well as a stabilizer, for the synthesis of silver nanoparticles (AgNPs). Glutaraldehyde (GA) cross-linking of SPI at room temperature resulted in durable coatings of AgNPs on the rayon fabric. The synthesized AgNPs were roughly spherical with a mean diameter of 11 nm. Antibacterial testing (AATCC 100-2004) against Escherichia coli and Staphylococcus aureus indicated that while untreated rayon showed no bactericidal activity, all treated fabrics exhibited excellent antibacterial properties (99.99% bacterial reduction), even after 50 washing cycles. Chemical finishing of rayon fabrics can thus successfully impart excellent antibacterial properties, be energy efficient and convenient requiring only one aqueous finishing stage with low chemical loadings, and be achieved using simple equipment under mild conditions.

Keywords: Antibacterial textile, biomaterial, cellulose, rayon, silver nanoparticle, soy protein

1. Introduction

Cellulosic textiles such as cotton or rayon are ubiquitous in our daily lives. Unfortunately, they provide suitable environments for microbial growth, leading to hygiene issues, and the deterioration of fabric properties [1]. To address the former, metallic nanoparticles have emerged as promising antimicrobial agents due to their large surface to volume ratio, which enhances their bactericidal effects. The growing prevalence of antibiotic resistant microbes in Nature is a further factor prompting urgent research into new categories of antimicrobials for medical use, and for fabrication in everyday consumer products [2].

Silver nanoparticles (AgNPs) have attracted considerable public attention due to their well-known antimicrobial profile, and low toxicity to humans [3]. These particles can be prepared using several methods, and although chemical reduction using traditional toxic reducing agents (e.g. NaBH₄) is the most common [4], greener, more benign chemicals are now being considered [5, 6]. Soy protein is one such example, having found numerous applications as food additives, and in paints, paper coatings, cosmetics, textile fibers, and adhesives [7, 8]. Pisitsak et al [9] employed soy protein isolate (SPI) to improve the natural dyeing properties, and UV protection, of cotton fibers. Zhao et al. [5] fabricated highly active antibacterial films based on blends of SPI and AgNPs; it was postulated that the SPI reducing power towards AgNO₃ relates to the protein tyrosine content.

To date, literature studies relating to the fabrication of antimicrobial rayon fabrics are limited, although introduction of copper nanoparticles [10], chitosan [11, 12], TiO₂-SiO₂ [13], and AgNPs [4, 14, 15] either by a spinning dope prior to fiber formation, or in the finishing bath during fabric treatment, have been reported. However, improving textile affinity towards AgNPs can require multiple steps, and use of numerous chemical reagents. As these increase costs and potential waste generation, one-step padding of textiles in a finishing
bath would be far more attractive. Accordingly, this report highlights a simple, cost effective method for the fabrication of durable antibacterial rayon textiles.

2. Experimental Methods

2.1 Sample Preparation

An SPI dispersion (100 ppm) was prepared by adding 0.025 g SPI (90% purity) to 250 ml DI water (pH 10, adjusted with NaOH) under vigorous stirring. AgNO₃ (0.025 g, 100 ppm) was then added, resulting in the dispersion changing from colorless to yellow. Finally, 1.75 ml of 25% w/w GA solution was introduced, and the resultant dispersion continuously stirred at room temperature for 30 min. After diluting to half the original silver concentration with DI water, the dispersion was padded onto plain-weave rayon fabrics (83.4 g/m², 5 g) at 2 bar pressure, 100% wet-pick-up, using a padder.

2.2 Sample Characterization

Fabric color parameters were measured based on the CIE Lab color space (L*, a*, b* and ΔE*) using a spectrophotometer (GretagMacbeth color i5); L* corresponds to brightness, a* to the red-green coordinate, and b* to the yellow-blue coordinate. K/S represents the color strength, whereas ΔE* represents the color difference between the sample and the control. Synthesized AgNPs were characterized using UV-visible spectrophotometry (Perkin-Elmer Lambda 25) and transmission electron microscopy (TEM) (JEOL, JEM-2100Plus). Fabric morphologies were examined using a scanning electron microscope (JEOL, JSM-5410 LV), with antibacterial properties being evaluated against Gram positive Staphylococcus aureus, and Gram negative Escherichia coli as outlined in AATCC 100-2004. To study the durability of antibacterial fabrics, samples were washed (Gyrowash washing machine, James H. Heal Co., Ltd.), following protocol AATCC 61/2A. For sample depiction, two set of numbers were used, indicating the concentration of AgNPs and number of washing cycles employed such that fabric treated with 100 ppm AgNO₃ and subject to 10 washing cycles is denoted as “100-10”. Untreated fabric is therefore designated as “Blank”.

3. Results and Discussion

The formation of AgNPs was confirmed by the distinct absorption peak at 410 nm in the UV-visible spectra (Figure 1) of the obtained dispersion, which corresponds to the surface plasmon resonance. According to the TEM image and particle size distribution shown in Figure 2(a)-(b), AgNPs have a roughly spherical morphology, with an average particle size of approximately 11 nm.

![Figure 1. The UV-visible spectrum of prepared AgNPs](image1.png)

Color parameters of fabric samples are reported in Table 1, and as expected higher AgNP loadings result in more intense brown coloration. Repeated washing results in color fading, indicating a degree of nanoparticle detachment from the fabric surface as reflected by increases in L*, as well as reductions in K/S and ΔE* with cycle number. However, as indicated below, despite the detachment of some AgNPs the antibacterial properties of the washed fabrics remained excellent over the duration of the study.

![Figure 2(a)-(b). Fabric Morphology](image2.png)
Figure 2. (a) Transmission electron micrograph (TEM) image of AgNPs, and (b) particle size distribution.

Table 1. Color parameters of fabric samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>K/S</th>
<th>ΔE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank</td>
<td>91.97</td>
<td>6.59</td>
<td>-21.85</td>
<td>0.51</td>
<td>-</td>
</tr>
<tr>
<td>50-0</td>
<td>81.46</td>
<td>8.22</td>
<td>-7.90</td>
<td>0.79</td>
<td>17.54</td>
</tr>
<tr>
<td>50-10</td>
<td>86.33</td>
<td>6.91</td>
<td>-11.60</td>
<td>0.60</td>
<td>11.70</td>
</tr>
<tr>
<td>50-20</td>
<td>89.46</td>
<td>6.06</td>
<td>-15.79</td>
<td>0.53</td>
<td>6.58</td>
</tr>
<tr>
<td>100-0</td>
<td>77.23</td>
<td>7.07</td>
<td>-3.56</td>
<td>0.94</td>
<td>23.50</td>
</tr>
<tr>
<td>100-10</td>
<td>80.74</td>
<td>6.62</td>
<td>-8.02</td>
<td>0.74</td>
<td>17.82</td>
</tr>
<tr>
<td>100-20</td>
<td>83.91</td>
<td>6.36</td>
<td>-10.98</td>
<td>0.64</td>
<td>13.53</td>
</tr>
</tbody>
</table>

SEM images in Figure 3 show distinct surface striations on pristine fibers, small ridges running parallel to the fiber axis, in contrast to treated fibers where surface irregularities are evident with some ridges partly obscured. Prior to washing more AgNP agglomerates (seen as white spots) are noticeable in the samples than, those after washing. Mechanical friction during washing possibly led to partial removal of AgNP.

Figure 3. SEM images of samples (a) Blank, (b) 50-0, (c) 100-0, (d) 50-20, and (e) 100-20.

Table 2 highlights the excellent antibacterial efficiency of treated fabrics against both bacterial strains, in contrast to untreated rayon. Although the origin of AgNP antimicrobial activity is not completely understood, binding to thiol and amino groups in proteins may be a factor. Cell wall pitting by AgNPs in Gram-negative bacteria, e.g. *E. coli*, results in increased membrane permeability and respiratory chain inactivation [16]. In this study, the affinity between AgNPs and protein allows adherence of particles to fibers, prolonging the antibacterial effect. This affinity between cellulosic fibers and SPI may be partly due to hydrogen bond formation, although during wet treatment soluble protein cannot be retained on cellulosic fibers without cross-linking; GA addition and cross-linking thus renders the protein insoluble, improving the integrity of the AgNPs-SPI coating towards mechanical abrasion (washing).

In contrast to cotton, very few studies have focused on AgNP-containing rayon textiles [18-21]. This work addresses some of the key limitations in this area, providing cost-effective, easily fabricated fabrics with excellent antibacterial properties and good durability.
Table 2. Antibacterial properties of fabric samples according to AATCC 100-2004

<table>
<thead>
<tr>
<th>Samples</th>
<th>% bacterial reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S. aureus</td>
</tr>
<tr>
<td>Blank</td>
<td>0</td>
</tr>
<tr>
<td>50-0</td>
<td>99.99</td>
</tr>
<tr>
<td>50-10</td>
<td>99.99</td>
</tr>
<tr>
<td>50-20</td>
<td>99.99</td>
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<tr>
<td>50-30</td>
<td>99.99</td>
</tr>
<tr>
<td>50-50</td>
<td>99.27</td>
</tr>
<tr>
<td>100-0</td>
<td>99.99</td>
</tr>
<tr>
<td>100-10</td>
<td>99.99</td>
</tr>
<tr>
<td>100-20</td>
<td>99.99</td>
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<tr>
<td>100-30</td>
<td>99.99</td>
</tr>
<tr>
<td>100-50</td>
<td>99.54</td>
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</table>

4. Conclusion

AgNPs with a mean diameter of 11 nm were synthesized by chemical reduction of AgNO₃ using soy protein isolate as a reducing agent and stabilizer, and glutaraldehyde as a protein cross-linker. Entrapment of AgNPs within the fabric coating derived from cross-linked SPI results in prolonged maintenance of antibacterial activity. All coated fabrics exhibited excellent antibacterial performance profiles against E. coli and S. aureus (99.99% reduction even after 30 washing cycles). These results, and the ease of fabrication may allow for new innovative advances in rayon textiles, and provide the means for cost-effective large scale production.

5. Acknowledgement

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References


