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Single bath process for imparting antimicrobial activity and ultraviolet protective property to bamboo viscose fabric

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Abstract Bamboo viscose, a new cellulose-based textile material was investigated for biomedical applications such as ultraviolet protective ability and antimicrobial activity. Untreated bamboo viscose fabric was found to afford poor protection against UV radiation and also possessed minimal antimicrobial properties. To enhance UV protection characteristics, fabrics were subjected to different treatments viz., dyeing; finishing with commercial UV absorbers; and one-bath dyeing and finishing with UV absorber. Treatment conditions were optimized with regard to the concentration of UV absorber and dye. Results obtained showed that the UPF values increase with increase in UV absorber and dye concentration. Subsequently, a single bath process to apply both antimicrobial and UV protective treatments to bamboo fabric was studied. Results showed that both treatments are compatible for application from a single bath. The effectiveness of the antimicrobial agent was not adversely affected by the presence of an UV absorber and the treated fabric also retained excellent UV protective properties.

Keywords Bamboo viscose · UV protection · Antimicrobial activity · Single bath

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Introduction

Bamboo viscose is a new regenerated cellulosic fiber that has recently evinced keen interest primarily because the bamboo plant is a fast-growing renewable resource and therefore, the fiber can arguably be considered a “sustainable” fiber (Scurlock et al. 2000; Devi et al. 2007). Structurally, bamboo viscose is cellulose II with a low degree of crystallinity and high water retention and release ability (Xu et al. 2007). As a result, the fiber possesses desirable comfort properties such as good moisture absorption and permeability; aesthetic properties such as soft handle and pleasing tactile sensation (Shen et al. 2004) and can be processed easily because of its excellent dyeing and finishing abilities.

Another feature of bamboo viscose fiber that has garnered considerable attention is claims about its protective abilities, namely that the fiber possesses UV properties and antimicrobial function that are inherited from the bamboo plant itself (Xu et al. 2007; Li et al. 2004). The reasons behind the assertions are that bamboo plants flourish without the need for pesticides and are not attacked by pathogens and therefore, by extension, bamboo viscose fiber most likely possesses similar properties. However, there is a paucity of literature in this area and therefore the need for additional inquiry. In this study, we initially investigated the UV and antimicrobial properties of untreated bamboo viscose fabric. Subsequently, methods to impart and enhance UV property and antimicrobial activity via a single bath process using conventional additives such as dyes, UV absorbers and antimicrobial agents were examined.

Experimental

Materials

A 100% bamboo viscose knit single jersey with no previous finishing treatment (thickness 0.66 mm, weight 153 g/m^2) was sourced from China for the study. A fiber-reactive dye (CI Reactive Violet 1) was used for dyeing. Rayosan® (Clariant Corporation, Charlotte, NC) and UV-Sun® Cel (Huntsman Textile Effects, Charlotte, NC) were the two UV absorbers chosen because of their widespread use in the industry. The antimicrobial agent used was Tinosan® (Ciba Specialty Chemicals Corporation, NC). The chemical composition of the commercial UV absorbers and the antimicrobial agent is proprietary. However, it is reported in literature that Rayosan® is a triazine derivative and the active ingredient in Tinosan® is 5-chloro-2-(2,4-dichlorophenoxy phenol). *Staphylococcus aureus* (ATCC® 6538, PML Microbiologicals, Wilsonville, OR, USA) and *Escherichia coli* (ATCC® 25922, PML Microbiologicals, Wilsonville, OR, USA) were the two microorganisms used in the study. *S. aureus* is a gram-positive bacterium and *E. coli* is a gram-negative bacterium. Standard microbiological procedures were employed to maintain cultures of the bacteria in the laboratory.

Methods

Fabric dyeing

Fabric samples were dyed as received without prior preparatory treatments. Dyeing was done by employing the traditional reactive dyeing procedure. The concentration of dye was varied between 1 and 4% (on weight of fabric). Conditions of dyeing were as follows: Glauber's salt 60 g/L, caustic soda 4 ml/L, temperature 70 °C, time 60 min.

Application of UV absorbers

The UV absorbers were applied by the exhaust method. Concentration of UV absorber varied from 1 to 4% (on weight of fabric). The fabric samples were introduced in the bath containing the UV absorber and circulated for 10 min. Glauber's salt (60 g/L) was gradually added and the temperature of the bath was raised to 70 °C. Four milliliters per liter caustic soda was then added and application continued further. Total treatment time was 60 min. Finally, the bath was cooled and the fabric samples were rinsed and air dried.

Single bath dyeing and application of UV absorber

For simultaneous dyeing and application of UV absorber, baths were prepared containing the dye and UV absorber prior to introduction of fabric samples in the bath. All other conditions remained the same.

Antimicrobial treatment

Fabric samples were treated with 1–4% of the antimicrobial agent (on weight of fabric) in a bath containing the optimum concentration of dye and UV absorber determined previously. After treatment, fabric samples were rinsed and air dried.

Determination of ultraviolet protection factor

Ultraviolet Protection Factor (UPF) is the scientific term used to indicate the amount of UV protection provided to skin by fabric. UPF is defined as the ratio of the average effective UV irradiance calculated for unprotected skin to the average UV irradiance calculated for skin protected by the test fabric (Crews et al. 1999; Hatch 2001). The higher the value, the longer a person can stay in the sun until the area of skin under the fabric becomes red (Crews et al. 1999; Hatch 2001). An effective UVR dose (ED) for unprotected skin is calculated by convolving the incident solar spectral power distribution with the relative spectral effectiveness function and summing over the wavelength range 290–400 nm. The calculation is repeated with the spectral transmission of the fabric as an additional weighting to get the effective dose (ED_m) for the skin when it is protected. The UPF is defined as the ratio of ED to ED_m and calculated as follows (Gies et al. 1994):

$$\mathrm{UPF} = \frac{\mathrm{ED}}{\mathrm{ED}_m} = \frac{\sum_{290\mathrm{nm}}^{400\mathrm{nm}} E_\lambda S_\lambda \Delta_\lambda}{\sum_{290\mathrm{nm}}^{400\mathrm{nm}} E_\lambda S_\lambda \Delta_\lambda} \quad (1)$$

where E_λ is the erythemal spectral effectiveness, S_λ is the solar spectral irradiance in W m^{-2} nm^{-1}, T_λ is the spectral transmittance of fabric, Δ_λ is the bandwidth in nm, λ is the wavelength in nm.

UPF's were measured in vitro using a labsphere® UV-100F Ultraviolet Transmission Analyzer. Fabrics with a UPF value in the range 15–24 are classified as having "Good UV Protection"; when the UPF values are between 25 and 39 fabrics are classified as having "Very Good UV Protection" and "Excellent UV Protection" classification is used when the UPF is 40 or greater (Hatch 2003). Color strength was evaluated using *K*/*S* values generated by a HunterLab ColorQuest XE diffuse/8° spectrophotometer. *K*/*S* is a function of color depth and is represented by the equation of Kubelka and Munk (Eq. 2). Higher the value of *K*/*S* greater is the color strength.

$$\frac{K}{S} = \frac{(1-R)^2}{2R} \quad (2)$$

where R is the reflectance of the dyed fabric, K is the sorption coefficient, and S is the scattering coefficient. The spectrophotometer was standardized for a 1 in. diameter specimen viewing aperture in reflectance—specular included mode. Illuminant D65 and CIE 10° observer were used.

Determination of antimicrobial activity

Five streaks of the microorganisms were inoculated on nutrient agar plates (peptone 5 g/L, beef extract 3 g/L, nutrient agar 15 g/L, NaCl 8 g/L, pH 6.8 ± 0.1). Fabric samples of were then placed in intimate contact with the bacteria inoculated agar. The plates were incubated for 24 h at 37 °C. At the end of this period the plates were examined for presence of clear area of interrupted growth underneath and adjacent to the test fabric which gave an indication of the antibacterial activity of the fabric. Evaluation of treated fabrics was done by calculating the zone of inhibition of the samples using Eq. 3. An inhibition zone >2 mm was taken as an indication of antimicrobial effect.

$$W = \frac{(T-D)}{2} \quad (3)$$

where W is the width of clear zone of inhibition in mm, T is the total diameter of test specimen and clear zone in mm, D is the diameter of the test specimen in mm.

Results and discussion

Ultraviolet protection

Initial investigations regarding the UV protective property of untreated bamboo viscose fabric samples showed that the fabric afforded poor protection against ultraviolet radiation. The UPF value of untreated fabric was 8.9. An UPF value <15 indicates no protection against transmission of UV radiation through fabric and onto skin. However, it has been well documented that UV protective properties of cellulosic fibers and fabrics can be enhanced by application of dyes and/or UV absorbers. Consequently, this approach was followed to improve the UPF of the bamboo viscose fabric.

Mean ultraviolet protection factor values at different dye concentrations and corresponding *K*/*S* values are given in Table 1. As reflected in the data, dyeing significantly improves the UV protective property of bamboo viscose fabric samples. The UPF value increases to 15.6 (Good UV protection) at a 2% dye (on weight of fabric) concentration and further to 25.8 (Very Good UV protection) at 6% concentration of dye (on weight of fabric). Dyes act as effective UV absorbers because the absorption band for all dyes

Table 1 Effect of dyeing on UV protective property of bamboo viscose fabric

Dye concentration (%, on weight of fabric)	Ultraviolet protection factor (UPF)	*K*/*S*
Untreated fabric	8.9	0.20
2	15.6	1.89
4	23.9	2.67
6	25.8	3.32

Table 2 Effect of UV absorber application on UV protective property of bamboo viscose fabric

UV absorber concentration (%, on weight of fabric)	Ultraviolet protection factor (UPF)	
	Rayosan®	UV-Sun® Cel
2	19.4	29.7
4	26.5	42.3
6	32.9	–

extends into the UV radiation band (290–400 nm). The hue of the dye also has an effect on the UPF value. For fabrics of identical weight and construction, darker colored fabrics give higher UPF values than lighter shades (Pailthorpe 1998; Capjack et al. 1994; Gies et al. 1994).

Treatment with the two UV absorbers also enhances the UPF values as seen in Table 2. As with dyeing, the improvement in UV property is a function of concentration of UV absorber. In the case of Rayosan®, the UPF value obtained is 32.9 (Very Good UV protection) at 6% concentration. With UV-Sun® Cel, "Excellent UV protection" (>40.0) was obtained at 4% (on weight of fabric) concentration. UV absorbers are effective since their chromophore systems absorb in the 290–400 nm UV band region of the electromagnetic spectrum (Reinert et al. 1997).

Combining several processing steps to reduce time and cost is preferred in the textile industry and so the synergistic effect of dyeing and UV absorber treatment from a single bath was explored. Results are shown in Table 3. It was found that dyeing and application of UV absorber in tandem works excellently for bamboo viscose fabric and indeed enhances the UV protective ability better than either dyeing or application of UV absorbers alone. At 4% (on weight of fabric) concentration of dye and either UV absorber, UPF values obtained were >40 indicating "Excellent UV protection".

Table 3 Effect of single bath dyeing and application of UV absorber on UV protective property of bamboo viscose fabric

Dye concentration (%, on weight of fabric)	UV absorber concentration (%, on weight of fabric)		Ultraviolet protection factor (UPF)
	Rayosan®	UV-Sun® Cel	
2	2	–	27.9
4	2	–	33.8
2	4	–	40.1
4	4	–	44.1
4	–	4	>50.0

Antimicrobial protection

Initial examination of antimicrobial activity of bamboo with no antimicrobial treatment revealed little action against *S. aureus* and *E. coli*. A zone of inhibition was observed adjacent to the fabric but there was growth underneath the fabric (Fig. 1). Treatment of fabric with 2% (on weight of fabric) Tinosan® yielded a clear area of interrupted growth underneath and adjacent to the test fabric (Fig. 2). The zone of inhibition was 23.1 mm for *S. aureus* and 16.5 mm in the case of *E. coli*, both concrete indicators of excellent antimicrobial action.

Having established that treatment with an antimicrobial agent was necessary to impart antimicrobial property to bamboo viscose fabric, the next set of experiments were directed towards incorporating the antimicrobial agent in the bath containing 4% dye and 4% UV absorber (on weight of fabric). The antimicrobial agent concentration was varied from 1 to 4% (on weight of fabric). Results of evaluation of antimicrobial activity and UV protective property of the fabric samples treated in this single bath are shown in Table 4. The data show that combining the

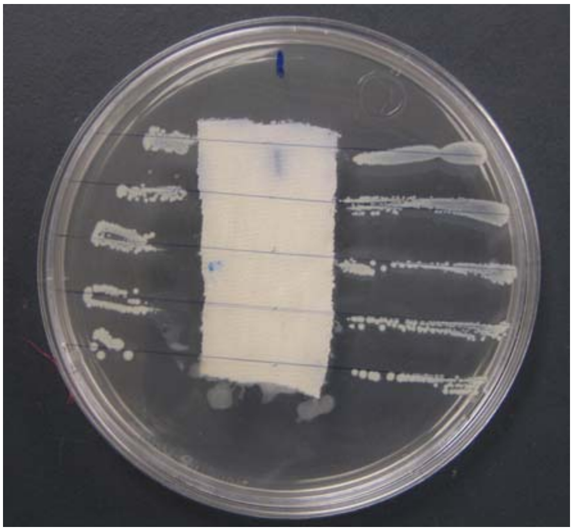

Fig. 1 Antimicrobial property of untreated bamboo viscose fabric

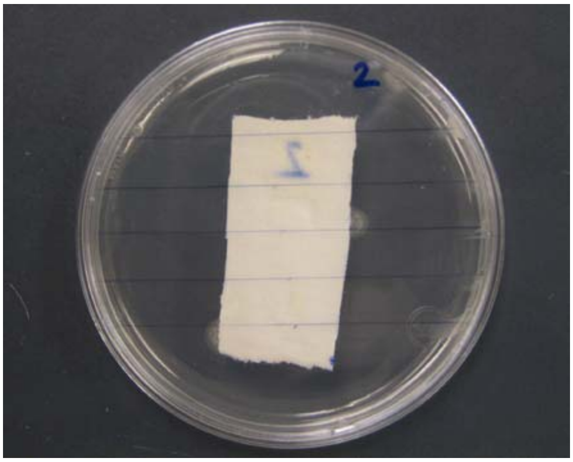

Fig. 2 Antimicrobial property of bamboo viscose fabric treated with 2% Tinosan®

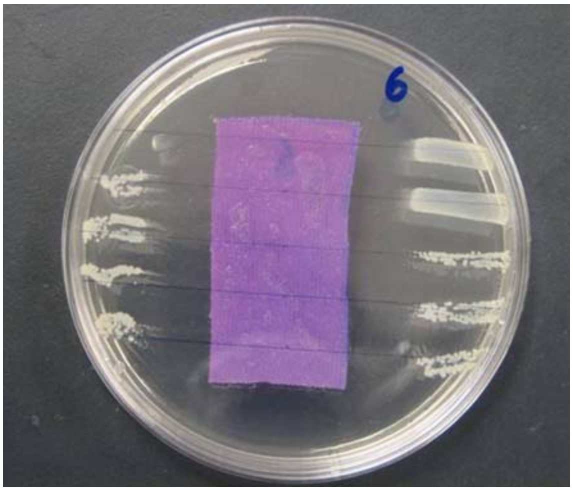

Fig. 3 Antimicrobial property of bamboo viscose fabric treated with 4% reactive dye + 4% Rayosan® + 4% Tinosan®

three treatments in a single bath resulted in lower ultraviolet properties than that obtained via separate treatments for the 4% dye/4% Rayosan®/4% Tinosan® combination. Of practical implication, however, is that even the lower UPF value of 37.5 is still in the range of "Very Good UV Protection" category. For the 4% dye/4% UV-Sun® Cel/4% Tinosan® combination, UPF values were not affected. Additionally, the antimicrobial activities for all combinations of dye/UV absorber/antimicrobial agent were excellent as evidenced by the large zones of inhibition. Representative pictures of the zone of inhibition for fabric samples treated with 4% dye/4% UV absorbers/4% antimicrobial agent combinations are shown in Figs. 3 and 4. A single bath process for imparting antimicrobial activity and UV protective property to bamboo viscose fabric is therefore, feasible and in fact may be warranted to reduce costs and processing times. The additives are compatible since no chemical interaction in the solution was observed. Additionally, protective properties were not sacrificed as the effectiveness of the antimicrobial agent was not adversely affected by the presence of an UV absorber and the treated fabric also retained excellent UV protective properties.

Conclusions

Untreated bamboo viscose fabric in this study did not posses inherent UV protective property and also showed minimal antimicrobial activity towards *S. aureus* and *E. coli*. These desirable properties

Table 4 Antimicrobial activity and UV property of bamboo viscose fabric on treatment in a single bath containing reactive dye + UV absorber + antimicrobial agent

Treatment combinations (on weight of fabric)	Mean zone of inhibition (mm)		Ultraviolet protection factor (UPF)
	S. aureus	*E. coli*	
Untreated fabric	2.0	5.7	8.9
4% dye/4% Rayosan®/1% Tinosan®	9.3	6.3	30.6
4% dye/4% Rayosan®/2% Tinosan®	12.5	8.3	35.2
4% dye/4% Rayosan®/3% Tinosan®	14.0	9.2	36.4
4% dye/4% Rayosan®/4% Tinosan®	17.0	11.2	37.5
4% dye/4% UV-Sun® Cel/1% Tinosan®	13.0	6.2	42.4
4% dye/4% UV-Sun® Cel/2% Tinosan®	14.3	7.0	>50.0
4% dye/4% UV-Sun® Cel/3% Tinosan®	17.0	10.3	>50.0
4% dye/4% UV-Sun® Cel/4% Tinosan®	17.5	10.5	>50.0

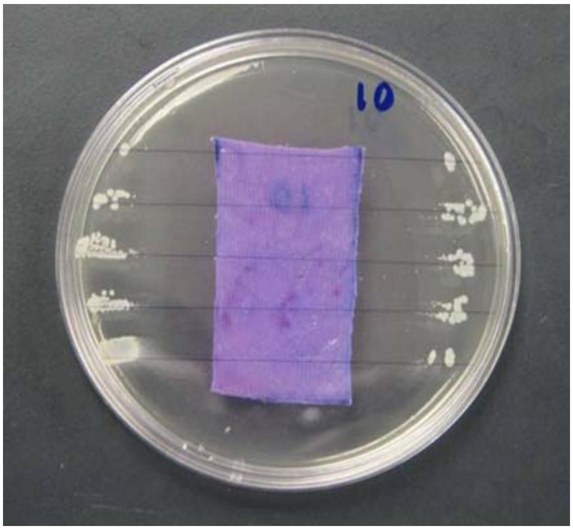

Fig. 4 Antimicrobial property of bamboo viscose fabric treated with 4% reactive dye + 4% UV-Sun® Cel + 4% Tinosan®

were, however, easily imparted via treatment from a single bath containing a reactive dye, UV absorber and an antimicrobial agent. From the results of this study, a bath containing 4% dye/4% UV absorber/4% antimicrobial agent on weight of fabric seems to be the optimum combination to introduce multi-functional protective properties viz., UV and antimicrobial protection to bamboo viscose fabric. Future studies should be conducted towards determining the durability of these treatments to washing and exposure to light.

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