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Effect of biopolishing and UV absorber treatment on the UV protection properties of cotton knitted fabrics

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ABSTRACT

Cotton knitted fabrics were manufactured with gauge number 20 G by circular knitting machine with conventional ring spun yarn and torque-free ring spun yarn. Torque-free ring spinning is a new spinning technology that produces yarns with low twist and balanced torque. This study examined whether the impact of biopolishing and UV absorber treatment on UV protection properties on cotton knitted fabric made of torque-free ring spun yarn is different. Biopolishing agent and UV absorber were used to treat the cotton knitted fabrics after scouring and bleaching. The UV protection properties were measured in terms of UV protection factor (UPF) and UV ray transmittance. Experimental results revealed that knitted fabric made from torque-free ring spun has better UPF than knitted fabric made from conventional ring spun yarn in untreated and biopolished states. However, knitted fabric made from conventional ring spun yarn has better UPF than knitted fabric made from torque-free ring spun after UV absorber treatment and combined UV absorber and biopolishing treatment.

1. Introduction

The application of enzymes in textile processing started in the middle of 19th century when malt extract was used for desizing of some textiles (Aly, Moustafa, & Hebeish, 2004; Guebitz, Buchert, Cavaco-Paulo, & Heine, 2006). In the last few decades, enzymes have increasingly developed and been used for pretreatment to finishing processes (Parvinzadeh, 2007; Parvinzadeh, Assefipour, & Kiumarsi, 2009; Parvinzadeh, Assefipour, Kiumarsi, & Parvinzadeh, 2013). One of the important enzymes called cellulase has been commonly used in knitted fabric processing to enhance smoothness (Kan & Wong, 2011). Cellulase can remove fuzzy fibre and pills from the surface, decreasing the pilling and providing a soft hand and feel (Cavaco-Paulo, Almeid, & Bishop, 1996; Tyndall, 1990). This process is called bio-polishing. Cotton's chemical composition is pure cellulose, consisting of highly ordered crystalline region and loosely structured amorphous region. The amorphous region is responsible to form the fuzz and pilling on fabric surface. The use of cellulase is responsible for degradation of the amorphous region with minimum weight loss. Therefore, use of cellulase for biopolishing helps removal of surface fibrils, small protruding fibres, seed coat fragments and other natural impurities of cotton fibre (Anish, Rahman, & Rao, 2007).

Previous findings have stated that the biopolishing action of cellulase on cotton results in significant structural changes in the treated fabric (Buschle-Diller, Zeronian, Pan, & Yoon, 1994; Haga & Takagishi, 2001) and improves the subsequent chemical processing (Kan, Yuen, & Lam, 2009; Kan, Yuen, Lam, & Chan, 2009). However, little discussion has been reported on the effect of biopolishing and UV treatment on anti-UV properties of cotton knitted fabric. In this study, two types cotton knitted fabrics were made from conventional ring spun yarn and torque-free ring spun yarn. Torque-free ring spinning is a new spinning technology that produces yarns with low twist and balanced torque (Tao, Lo, & Lau, 1997a, 1997b; Wong et al., 2004). The mechanical properties, especially softness of the fabric produced by torque-free ring spinning method are similar to conventional ring spun fabric (Wong et al., 2004). This study examined whether the impact of biopolishing and UV treatment on anti-UV properties would be different on cotton knitted fabric made of torque-free ring spun yarn. Biopolishing agent and UV absorber are used to treat scoured and bleached cotton knitted fabrics in order to understand their effect on UPF values of treated fabrics. The purpose of this study is thus to investigate the influence of biopolishing agent and UV absorber on anti-UV properties, expressed as UV protection factor (UPF) and UV ray transmittance of cotton knitted fabrics made from conventional ring spun yarn and torque-free ring spun yarn with the same knitting.

2. Experimental

2.1. Material and fabric preparation

Plain knitted fabrics were produced with circular knitting machine (DXC Fukuhara) with gauge number 20 and with yarn

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Table 1
Specifications of the knitted fabrics.

Fabric	1	2
Fabric weight (g/m^2)	178.0	157.5
Fabric thickness (mm)	0.82	0.90
Fabric density		
Courses per cm	14	12
Wales per cm	13	11
Number of twist per cm	6.92	4.68

count of 30 tex. (The yarns were provided by Central Textiles (H.K.) Ltd.) Fabric specifications are listed in Table 1. The major difference between Fabric 1 and Fabric 2 is the amount of twist in the yarn. In this paper, yarn twist level is defined as the number of twists per 1 cm of yarn. The yarn in Fabric 1 was made by conventional ring spun yarn while Fabric 2 was manufactured by torque-free ring spun yarn. As indicated in Table 1, yarn of Fabric 2 had lower twist.

Fabrics were scoured and bleached by hydrogen peroxide (50%) (12 ml/L), detergent (Sandopan DTC) (0.5 g/L), sodium silicate (0.5 g/L), stabilizer AWN (0.5 g/L) and with caustic soda added to the liquor until the pH reached 10. The fabrics were scoured and bleached in the same bath for 60 min. The liquor-to-goods ratio was 50:1. After scouring and bleaching, the fabrics were rinsed thoroughly first with hot water and then cold water. Finally, the fabrics were neutralized with cold dilute acid solution (0.5% H_2SO_4). The fabrics were rinsed again with tap water, until they were free from acid and were air dried. The fabrics were conditioned under standard atmospheric conditions, $20 \pm 2\,^\circ$C temperature and 65 ± 2% relative humidity for at least 24 h before use.

2.2. Biopolishing process

The biopolishing process was carried out with the use of Bactosol CNX (an acid cellulase). A bath was prepared in an oscillating machine with a liquor-to-goods ratio of 50:1. Fabric with weight of 2 g was used. The bath was initially set at 40 °C and the fabrics were added into the bath. Then the bath temperature was increased steadily to 60 °C within 10 min. When the bath temperature reached 60 °C, 1% (owf) Bactosol CNX was added and the pH was adjusted to 4.5–5.5 with buffer solution. After adding the Bactosol CNX, the biopolishing treatment was carried out for further 60 min. After biopolishing treatment, the fabrics were rinsed with deionized water to lower the temperature quickly and to wash away abraded fibres attached on fabrics. The fabrics were then treated with deionized water at 80 °C to deactivate the enzyme action. After that the fabrics were squeezed to remove excessive water and were dried in an oven at a temperature of 70 °C. After drying for 2 h in the oven, the fabrics were placed for conditioning under standard atmospheric pressure at a temperature of $20 \pm 2\,^\circ$C and 65 ± 2% relative humidity for at least 24 h before further use.

2.3. UV absorber treatment

In order to apply UV absorbing agent to the fabric, a bath of liquor-to-goods ratio of 50:1 was prepared. Initially, the bath temperature was set at 40 °C for the whole treatment and 60 g/L Glauber's salt was added, together with the fabric. After running for 5 min, 1% (owf) Rayosan C (UV absorber) was added. After 10 min, 6 g/L soda ash was added and the bath was then run for another 40 min. Finally, the fabrics were rinsed with hot and cold water and dried by air. After drying, fabrics were subjected to conditioning under standard atmospheric pressure at $20 \pm 2\,^\circ$C temperature and 65 ± 2% relative humidity for at least 24 h before further use.

Table 2
AS/NZS 4399 UPF classification system.

UPF range	UVR protection category	Effective UVR transmission (%)
15–24	Good protection	6.7–4.2
25–39	Very good protection	4.1–2.6
40–50, 50+	Excellent protection	<2.5

2.4. UPF measurement

UV properties of fabrics were evaluated by the Australian/New Zealand standard (AS/NZS 4399) with a Varian Cary 300 Conc UV–visible spectrometer. The UV protection properties in terms of UV protection factor (UPF) and UV ray transmittance were measured by the spectrophotometer. Fabrics (size: 22 mm × 34 mm) were cut out from the middle of each piece of fabric. These fabrics were then mounted, without tension, on the slide frames for measurement. The UV spectrophotometer recorded the transmittance between 290 nm and 400 nm at every 5 nm. For each fabric sample, four measurements were taken and the mean UPF was calculated according to Eq. (1) (Hoffmann, Kaspar, Gambicher, & Altmeyer, 2000). Table 2 shows the classification system of good sun protection according to AS/NZS 4399.

$$\mathrm{UPF} = \frac{\sum_{290}^{400} E_\lambda \cdot S_\lambda \cdot \Delta_\lambda}{\sum_{290}^{400} E_\lambda \cdot S_\lambda \cdot T_\lambda \cdot \Delta_\lambda} \qquad (1)$$

where S_λ is the solar spectral irradiance (in W m^{-2} N m^{-1}), E_λ is the erythemal spectral effectiveness from CIE (1987), T_λ is the spectral transmission through the textile, Δ_λ is the bandwidth (in nm), λ is the wavelength (in nm).

2.5. Surface structure

Surface structure of the cotton knitted fabric was evaluated by a Leica M125 stereomicroscope and the yarn diameter was measured with 12.5× magnification.

3. Results and discussion

In this study, results of the four treatment conditions are discussed as follows:

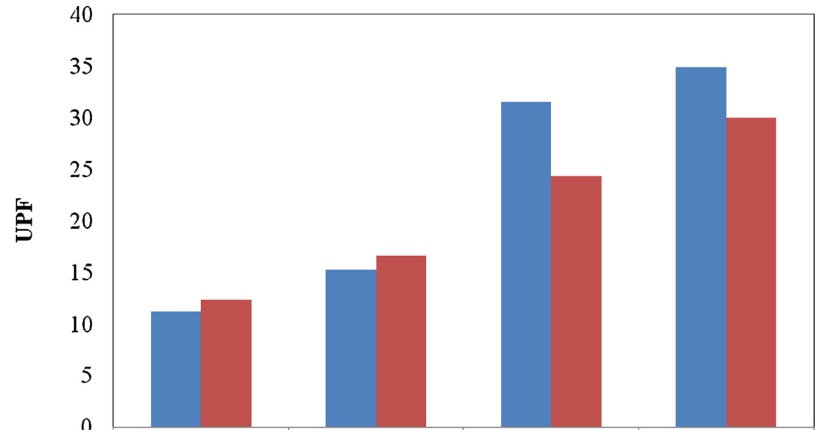
(i) Control (untreated) – fabric without treatment;
(ii) Biopolishing – fabric treated with cellulase only;
(iii) UV absorber – fabric treated with UV absorber only; and
(iv) UV absorber + biopolishing – fabric treated with biopolishing first followed by UV absorber.

3.1. Influence of biopolishing and UV absorber treatment on UPF

The results obtained from measurement of the UPF of cotton knitted fabrics treated under different conditions are shown in Fig. 1.

Results of UPF measurements of control fabrics are not good which indicates that the control fabrics without any treatment do not have UV protective ability as their UPF values are around 11–12 (<15) which cannot be classified as good protection. Meanwhile, control fabric without treatment made from torque-free ring spun yarn has a slightly better protection effect against UV radiation when compared with conventional ring spun yarn.

When the knitted fabrics were treated with biopolishing agent, UPF values increased from 11–12 to 15–17. There is an increase of about 35% in UPF values of both types of knitted fabrics. The increase in UPF may be due to the decrease in porosity of the knitted fabric as the microfibrils protruding from the surface of the



	Control	Biopolishing	UV absorber	UV absorber + biopolishing
Fabric 1	11.2	15.2	31.5	34.9
Fabric 2	12.3	16.6	24.3	30.0

Fig. 1. UPF values of fabrics.

fabric were degraded and thus the knitted fabric became more compact due to the lower porosity. The treated fabric becomes more opaque to UV rays (Sarkar, 2007). On the other hand, the hydration or moisture content could be another factor responsible for increasing UPF values after biopolishing. The cellulase used in biopolishing may result in swelling of fibres due to increased moisture absorption, thus reducing the interstices and accordingly the UV rays transmittance (Saravanan, 2007). Moreover, biopolishing is a textile wet processing technique for modification of fabric surface appearance, hand properties and mechanical characteristics of fabrics. Coefficient of friction of the fabric generally declines after enzyme treatment, which results in smoother knitted fabric on both face and back sides (Kan, Yuen, & Lam, 2009; Kan, Yuen, Lam, & Chan, 2009). Consequently, smoother fibre surface reflects more UV rays (Dong, Bai, Zhang, Liu, & Zhu, 2006) and, therefore, there is a slight increase in UPF values after biopolishing.

In addition, Fig. 1 also shows that the presence of UV absorber on the fabrics exhibits the outstanding improvement in UPF values compared with the control and biopolished fabrics. The control fabrics have UPF value of only 11–12 which cannot be classified as good protection (UPF $\geq$ 15). Nevertheless, fabrics treated with UV absorber promote a very good level of protection (UP $\geq$ 25). Remarkable change in UPF rating as well as in protection category can be discussed in terms of the extent of higher UV absorption and cutting effect induced by UV absorber. The results show that incorporation of the UV absorber in the fabrics improves significantly both UPF values and protection grades. The UPF value further increases when both UV absorber and biopolishing finishing are applied to the fabrics. This confirms that biopolishing results in a certain degree of increase in UPF values since it reduces the coefficient of friction after enzyme treatment, which results in smoother knitted fabric on both face and back-sides (Mori, Haga, & Takagishi, 1992).

If the yarn type is taken into consideration, UPF values of control fabrics do not have significant difference and in the case of biopolished fabrics, a similar effect was noted. However, in the case of UV absorber treatment, although UPF values are increased for both types of fabrics, UPF value of knitted fabric made from torque-free ring spun yarn is lower than the one made from conventional ring spun yarn. A similar trend is also noted in the process with both biopolishing and UV absorber treatments. Since the conventional ring-spun yarn has more twist than the torque-free ring spun yarn, during wet treatment with the UV absorber, the residual torque in the yarn is released from the conventional ring spun yarn and the fabric becomes distorted and shrinks. Thus, the structure of knitted fabrics made from conventional ring spun yarn becomes more compact which helps resist penetration of UV rays.

3.2. Influence of UV absorber and biopolishing and UV ray transmittance

The sun emits ultraviolet radiation across a broad spectrum from the high energy UVC (200–290 nm) and UVB (290–320 nm) to UVA (320–400 nm) (Snezana, Dusan, Goran, & Mateja, 2009). UV protection textile should have as high UV rays reflecting and/or absorbing properties as possible so that it prevents UV rays from reaching the wearers' skin. The key property for determining the quality of fabric is transmittance. The UV ray transmittance of UVA and UVB region through fabrics was evaluated in this experiment. The less is the UV transmittance of a fabric, better is its UV protection ability. The average transmittance of untreated fabrics is usually very high in UVB region for both fabric types (Wang, Kopf, et al., 2001). To investigate the UV protection ability of biopolishing and UV absorber treatment, ultraviolet transmittance spectra of knitted fabrics with or without chemical processing were compared. Figs. 2 and 3 show the calculated average transmittance in the UV radiation region which separates into UVA and UVB regions of Fabrics 1 and 2, respectively. As shown in Figs. 2 and 3, there is a significant difference between control and treated knitted fabrics in the ultraviolet transmittance spectra. The control fabric has a high ultraviolet transmittance. The ultraviolet transmittance of the control fabric was about 12–18%. This indicates that the resistance of control fabrics to ultraviolet radiation was not very good. However, after biopolishing and UV absorber treatments, ultraviolet transmittance decreased accordingly. The presence of UV absorber considerably decreases transmittance values along the wavelengths within the ultraviolet region because the UV absorber used is a heterocyclic compound, which forms a covalent bond with the macromolecule of cellulose (Todorova & Vassileva, 2003). Particularly in UVB region (280–320 nm), decrease of UV transmission is very remarkable due to increased absorption of UV light by the UV absorber. Moreover, fabric treated with UV absorber resulted in a filtration effect of the harmful UV light.

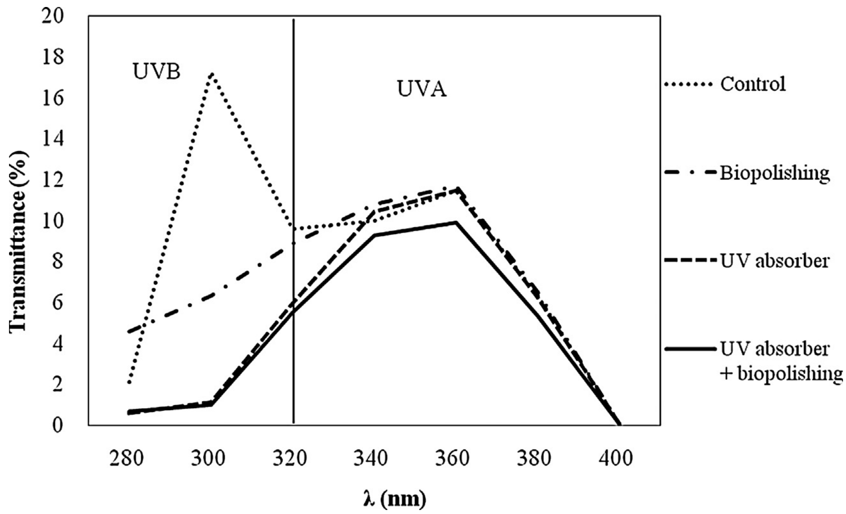


Fig. 2. Ultraviolet transmittance of Fabric 1.

UV absorber absorbs a great amount of UV radiation in the UVB zone which is considered as the most dangerous wavelengths in the UV region. Moreover, UVB radiation is more effective in causing sunburn than UVA radiation, approximately 1000 times (Wang, Setlow, et al., 2001). The average transmittance further decreased when the biopolishing finishing was applied. The most probable explanation is that hydration or moisture content after biopolishing treatment could be a factor in increasing UPF values (Sarkar, 2007) because the fibre swells due to increased moisture absorption and therefore interstices and UV transmittance are reduced (Saravanan, 2007). A synergetic effect of two chemicals (UV absorber and biopolishing agent) is observed and thus the blocking of UV radiation is accelerated when the UV absorber and biopolishing finish are added simultaneously.

When the yarn spinning method is taken into consideration, the control fabric made from torque-free ring spun yarn has a lower ultraviolet transmittance in the UVB region than the one made from conventional ring spun yarn. If a yarn with lower twist is used, the cohesion of fibre in the yarn is not strong when compared with high twist yarn. Hence, bulkiness of the yarn is increased and more surface fibre is found in the yarn surface. When light rays impinge upon the yarn, the light is reflected and therefore influencing the UV ray absorbing property (Kim et al., 2004). Therefore, the control fabric made from torque-free ring spun yarn achieves a better UVB shielding than the fabric made from conventional ring spun yarn.

3.3. Surface morphology after UV absorber and biopolishing treatments

Surface morphology and inter-fibre pores of knitted fabrics before and after various finishing treatments were assessed visually by a microscope with magnification of 25 (micrographs are shown in Fig. 4). The micrograph shows the nature of treatment and its effect on fabric surface. After biopolishing, physical characteristics of the knitted fabric were modified as they released tension and redistributed the stress applied (Mori et al., 1992). Generally speaking, the hairy surface of the yarns contributes to the hairy surface of the knitted fabrics (Fig. 4(a) and (e)). It is assumed that the losse fibre can be removed by enzyme during biopolishing and thus the fibre ends from the fabric surface shift to the inter-yarn pores contributing additionally to the closing of structure after biopolishing. This assumption is confirmed by visual examination of the fabrics. Micrographs of cotton knitted fabrics before and after biopolishing treatment (Fig. 4) show that there is less hairiness in biopolishing treated fabrics (Fig. 4(b) and (f)) than in untreated

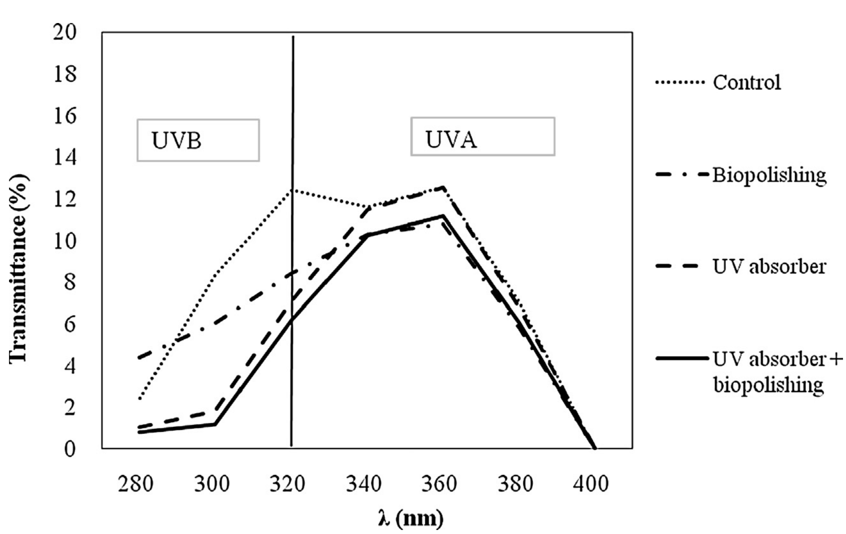


Fig. 3. Ultraviolet transmittance of Fabric 2.

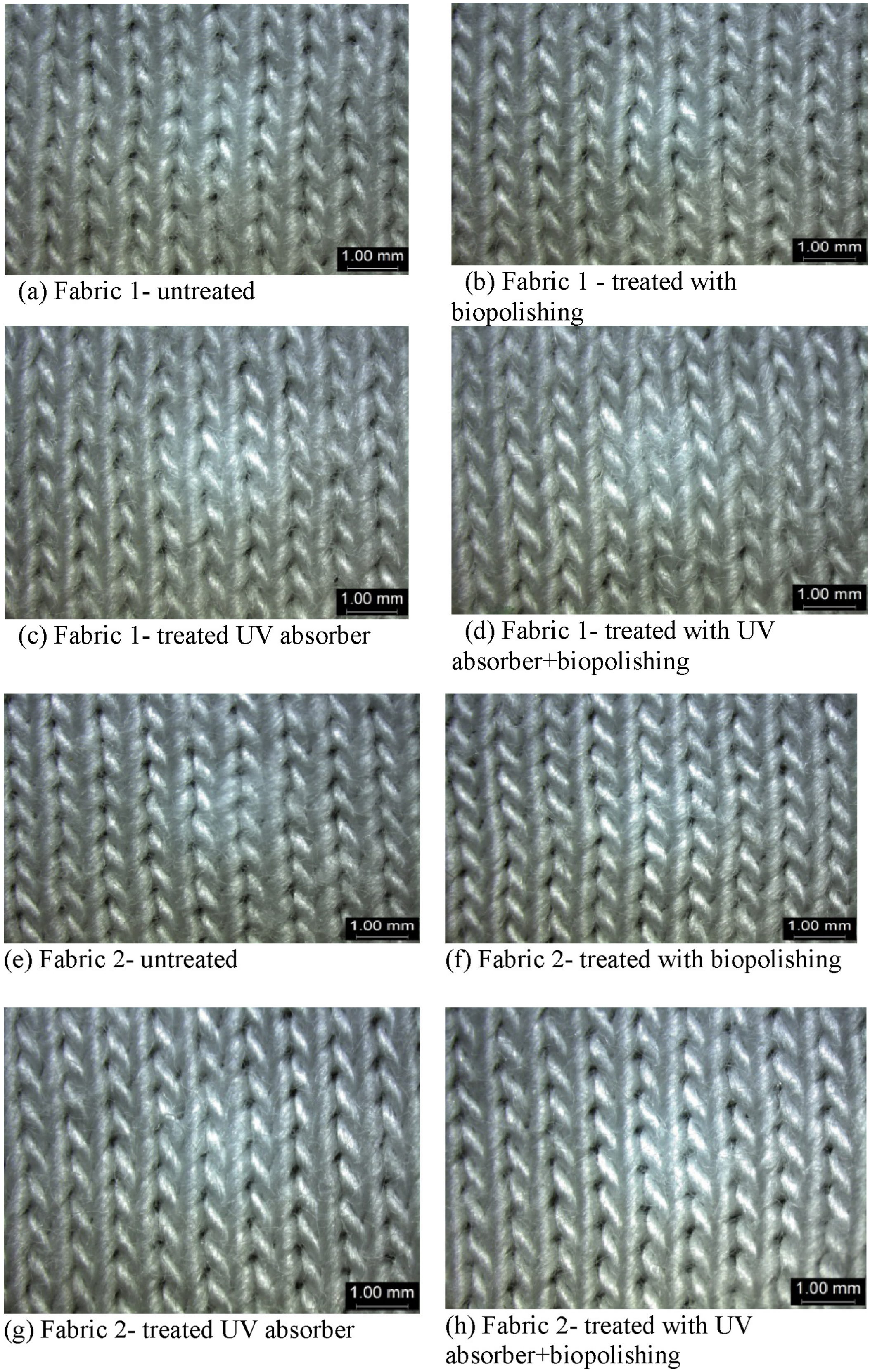


Fig. 4. The fabric surface of knitted fabrics before and after UV absorber and biopolishing treatment.

fabrics (Fig. 4(a) and (e)). The protruding fibres of treated fabrics were removed and thus the inter-yarn pores could interlay together. Moreover, the more compact structure reduces porosity of the fabric and reduces UV ray transmittance, enabling the increase of UPF which is discussed in the previous section. As the protruding fibres were removed, geometrical roughness decreased after the fabrics were biopolished. That means the enzyme treated fabric becomes smoother and has a cleaner surface which enhances

Table 3
Yarn diameter under different treatment conditions.

Sample	Treatment condition			
	Untreated	Biopolishing	UV absorber	UV absorber + biopolishing
Fabric 1	0.50 mm	0.53 mm (↑6%)	0.60 mm (↑20%)	0.75 mm (↑50%)
Fabric 2	0.52 mm	0.54 mm (↑3.8%)	0.58 mm (↑11%)	0.65 mm (↑25%)

UV rays reflection from the fabric surface to increase the UPF (Vankar & Shanker, 2008).

For UV absorber treated (Fig. 4(c) and (g)) and UV absorber + biopolishing treated fabrics (Fig. 4(d) and (h)), the structure of Fabric 1 is more packed than Fabric 2 because the residual torque was released from the conventional ring spun yarn and the fabric has become distorted and shrunk. Thus, the structure of knitted fabrics made from conventional ring spun yarn becomes more compact to resist the penetration of UV rays. In addition, more pores are observed in Fabric 2 than Fabric 1. Both factors may be contributed from the distortion and shrinkage effect of Fabric 1. The distortion and shrinkage effect may block UV rays transmission in the fabric and thus increase the UPF value of the fabric.

Table 3 shows the results of yarn diameter under different treatment conditions as measured from Fig. 4. The experimental results revealed that the yarn diameters are increased under different treatment conditions. The conventional ring spun yarn has more residual torques than the torque-free ring spun yarn. When cotton absorbs moisture or water, it will swell and the residual torques were released which explains why the yarn diameter increased after different treatments. The conventional ring spun yarn has a greater increment in yarn diameter when compared with the torque-free ring spun yarn under different treatment conditions because more residual torques were released to increase the yarn size. Thus, the increase in yarn diameter will reduce inter-yarn space and then the structure of the knitted fabrics made from conventional ring spun yarn becomes more compact to prevent the penetration of UV rays. In addition, lesser pores are observed in Fabric 1 than Fabric 2 due to the compact fabric structure. Both factors may contribute to the blocking of UV rays transmission in the fabric and thus increase the UPF value of the fabric.

4. Conclusion

This study examined the effect of UV absorber and biopolishing on UPF value, UV ray transmittance and surface morphology of cotton knitted fabrics made from torque-free ring spun yarn and conventional ring spun yarn, in order to assess the UV protection ability of knitted fabrics. The results confirmed that biopolishing has positive effects on increasing UPF value of cotton knitted fabric. A synergetic effect of UV absorber and biopolishing on UPF of treated knitted fabric was observed. It was confirmed that blocking of UV radiation is accelerated when the UV absorber and biopolishing treatment are conducted together. In addition, it was noted that the torque-free ring spun yarn itself could produce knitted fabrics with good UVB protection.

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