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RESEARCH

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Ultraviolet resistance on weft knitted fabric coated by benzotriazoles

Tuan Anh Nguyen[1*] and Nhu Tram Nguyen Nu[2]

*Correspondence:
nta@hcmute.edu.vn

[1] Faculty of Fashion and Tourism, Ho Chi Minh City University of Technology and Education, 01, Vo Van Ngan St, Linh Chieu Ward, Thu Duc City, Ho Chi Minh City, Vietnam
[2] Faculty of Mechanical Engineering, Ho Chi Minh City University of Technology, 268, Ly Thuong Kiet St, Ward 14, District 10, Ho Chi Minh City, Vietnam

Abstract

Ultraviolet resistance upon four different types of weft knitted fabrics including Lacoste, Single Jersey, Rib and Interlock were experimentally measured and evaluated by ultraviolet–visible spectroscopy under effects of gauge, specific weight, fiber composition and finishing agent as benzotriazole derivatives. The results showed that ultraviolet protection factor (UPF) of Interlock sample reached the highest value at 42.7. Simultaneously, the higher gauge of Single Jersey knitted fabrics was, the better its ultraviolet protection exhibited. Also, insertion of polyester fibers or spandex fibers into cotton knitted fabrics with a certain ratio strongly increased UPF values. Notably, all UPFs of coated fabrics with a given content of benzotriazole were significantly improved and almost coated samples could undergo several washing cycles and still retain their inherent breathability. This work demonstrated that cotton knitted fabrics coated with benzotriazoles were excellently enhanced ultraviolet protection. Especially, the UPF values on Interlock or Rib specimens as well as Single Jersey samples blended with polyester/spandex fibers were found to be higher than 15.

Keywords: Ultraviolet protection, Weft knitted fabric, Benzotriazoles (BTZ), Cotton fabric, Ultraviolet protection factor (UPF)

Introduction

Ultraviolet or UV rays are invisible radiations that are often classified into UVA (315 to 400 nm), UVB (280 to 315 nm) and UVC (100 to 280 nm), which their wavelength is shorter than visible light but longer than X-ray. Impact degree of ultraviolet radiation depends on geographical location and elevation, daytime and surrounding environment. Notably, health effects caused by ultraviolet radiations usually are related to cell destruction with several risks such as skin cancer, premature aging and skin damage, cataracts and eye damage and immune suppression (Gallagher & Lee, 2006). As exposed to long-term ultraviolet rays, textiles could be seriously damaged (e.g., loss in tensile strength and discoloration, depending on radiation type and contacting period) (Bashari, Shakeri, & Shirvan, 2019). Accordingly, it can be affirmed that protective clothes and accessories such as outdoor jacket, hat, shoe, umbrella, cover cloth, etc. ought to be able to resist ultraviolet radiations. In laboratory tests, ultraviolet protection factor (UPF) was used to measure radiation after passing through fabric sample according to the AATCC 183 standard method as the following equation (Hilfiker et al., 1996)

$$\mathrm{UPF} = \frac{\sum \mathrm{S}(\lambda).\mathrm{E}(\lambda)\Delta(\lambda)}{\sum \mathrm{S}(\lambda).\mathrm{E}(\lambda).\mathrm{T}(\lambda)\Delta(\lambda)} \tag{1}$$

where λ is the wavelength in nm, $\mathrm{S}(\lambda)$ is the solar irradiance of light source, $\mathrm{E}(\lambda)$ is the relative erythemal response and $\mathrm{T}(\lambda)$ is the fraction of incident radiation transmitted by sample.

Based on standard guide of labelling ultraviolet protective textiles (ASTM D6603), UPF value should be higher than 15. Besides, sun protection factor (SPF) is used for evaluating ultraviolet protection of sunscreen that UVB rays were tested only.

Hazardous effect of ultraviolet rays could be improved by interchanging construction as well as functionalizing textile materials owing to light absorber with suitable finishing techniques (Emam & Ahmed, 2023). Polyester, silk and wool fibers are better ultraviolet blockers than cotton/rayon and polyester fibers due to their aromatic nature. Ultraviolet protection abilities of natural and regenerated cellulose fibers were examined in which hemp fibers were supposed to exhibit the best protection against solar radiation (Kocić et al., 2019). It is known that many natural fibers consist of ultraviolet absorbers such as pectin, waxes and natural dyes. Surface characteristics of fabric (e.g., glossy or opaque face) that might be made by finishing processes also impacted considerably on reflectivity of solar radiation as well as ultraviolet resistance. A previous work showed that dyestuffs (especially reactive dyes) and finishing agents such as titanium dioxide could improve significantly protection property against ultraviolet rays for cotton/jute fabrics (Feng et al., 2007; Ghosh, Bajaj, & Kothari, 2003; Kocić et al., 2019; Wong et al., 2015). Clearly, dyeing parameters such as dyestuff types, concentration, color of dyes, etc. also might cause difference in ultraviolet prevention of textiles. Accordingly, relationship between color properties and ultraviolet resistance on cotton fabric was investigated through the CIE Lab model (Kan & Au, 2015a). In fact, UPF on cotton knitted fabrics was slightly influenced by colors of reactive, direct and sulfur dyes (Kan & Au, 2015b). Also, desizing and bleaching processes caused a deleterious effect on ultraviolet transmission through fabrics (Wang et al., 2001). The influence of structural characteristics (e.g., thickness, weight, stitch density and porosity) on sun protection factor has been revealed for greige and bleached fabrics (Wong et al., 2012). In fact, density and porosity of knitted fabrics were focused to explain variation in blocking ultraviolet rays related to UPF. In general, knitted fabric often is much looser than woven fabric because of its flexibility of yarns and larger spaces, generating better wearing comfort. Nevertheless, an investigation of optimizing comfort (permeability, thermal conductivity) and ultraviolet protection has been performed on Single Jersey and Rib 1×1 knitted fabrics (Chong et al., 2013; Ghosh et al., 2016). Not only works on knitted fabrics, researches on woven cotton fabrics with/without ultraviolet protection treatment have demonstrated to prevent solar radiation (Dubrovski, Fakin, & Ojstršek, 2023; Ghane & Ghorbani, 2016; Majumdar et al., 2012). Recent advances in science and technology have been implemented on anti-ultraviolet treatment of textiles which nanoparticles of ZnO and TiO_2 or SiO_2 increased significantly UPF (Hossain & Rahman, 2015; Nautiyal, Shukla, & Prasad, 2022; Wang et al., 2011). The excellent ULTRAVIOLET absorption of cotton fabric was developed through surface-initiated atom transfer radical polymerization of 2-hydroxy-4-(3-methacryloxy-2-hydroxylpropoxy) benzophenone (Hua et al., 2022). Actually, UPFs of textiles in vitro and in vivo were remarkably affected by wetness and moisture, particularly being higher value for linen, viscose and polyester but lower value for cotton and coated polyester with TiO_2 (Gambichler et al., 2002). Interestingly, laundering cotton knitted garments (especially print cloth) in detergent and water increased UPF due to shrinkage (Wang et al., 2001).

In general, treatment mechanism against ultraviolet rays is based on enhancement of light absorption in order to convert solar energy into unharmful thermal energy spreading surroundings. A lot of ultraviolet blocking agents including inorganic ultraviolet absorbers (titanium dioxide and zinc oxide) and organic ultraviolet absorbers (benzophenone and phenyl triazine/hydrazine) have been successfully treated on various textile materials (Ray et al., 2020). Basically, these agents are required as (1) great affinity for textile fibers to ensure durability in use; (2) no negative effects on colors of fabrics or good compatibility with dyes and finishes; and (3) no toxicity to human body and environment. Benzotriazole derivatives were known as ultraviolet screening chemicals thanks to ultraviolet stability. In recent, some authors have showed that UPF of cotton fabric treated with benzotriazole derivatives was strongly increased due to the formation of covalent bonds with hydroxyl groups of cellulose in the presence of titanium dioxide as well as reversible hydrogen bonds between phenolic hydroxyl group and triazine cycle (Akrman & Přikryl, 2008; Shao, Zhu, & Chen, 2022). Not only cotton fabrics, ultraviolet protective property on polyester fabrics coated with TiO_2/benzotriazole was investigated by scanning electronic microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR) and X-ray crystallography (XRD), indicating that treated fabrics excellently exhibited ultraviolet protection with high fastness to washing cycles (Li, Li, & Ren, 2019). Moreover, effect of benzotriazoles on clothing textile articles through a route of emission into environment were examined (Avagyan et al., 2013; Luongo et al., 2016). In this study, benzotriazole derivatives were coated on cotton knitted fabrics with various knitting types, gauges and blended compositions to evaluate structural effect on UPF values, thereby proposing a suitable solution for sun protection textiles.

Methods

Fabrics were made from three various knitting machines with model TS-SS, PL-SD 2.5 B/CE and PL-SD 3.9 B/CE at Thanh Cong Textile Garment Investment Trading JSC into Lacoste/Single Jersey, Rib 1×1 and Interlock. Knitting machine was adjusted into gauges of 24G and 28G with cloth speed of 30 rounds per minute. Greige fabrics were singed and desized in stenter setting machine. Fabric parameters such loop length, wales per inch (WPI), courses per inch (CPI), thickness, specific weight were determined in certain condition (20 ± 1 °C, 65% RH). Three different types of yarn were used for making above knitted fabrics including cotton yarn (CM 30/1), CVC 60/40 yarn (30/1) and spandex yarn (40D).

Benzotriazole (BZT) derivatives (commercial name as Panafast KUV 2) in microparticles (approximately 1 μm) were provided by Raon Chemical Ltd (South Korea). BZT derivatives possess some advantages such as (1) not yellowish and scummed phenomenon; (2) stability in hard water, acid, alkali and electrolyte solution; and (3) not sublimation at high temperature above 180 °C. BZT agents were anionic compounds easy to dissolve and store at 25 °C. Its chemical content of 1 to 3% was coated on cotton knitted fabrics through pad-dry-cure method.

Various kinds of weft knitted fabric were selected to evaluate ultraviolet protection before and after finishing process since these textiles are very common and used as outerwear which can be damaged by ultraviolet rays. To carry out effectively, effects of structural properties (knitting type, gauge and fiber content) on ultraviolet resistance were examined before coating BZT then evaluated the fastness of finished samples to 20 washing cycles. Equipment in this study included magnetic stirrer (Microstirrer Velp), padding mangle machine (Lab Padder TD122), laboratory tenter (Lab Stenter TD620), AATCC standard washer (Labtex LBT-M6). A fabric elastic tester (RF35062) according to ASTM D2594-21 were used to determine stretch (%) and growth (%) of knitted fabrics (125mmx500mm) under a specific load of 5 pounds. Vapor permeability of coated fabrics was also designed with an experimental model including steel cups of distilled water (6 cm in diameter) which were wrapped by the round specimens in a glass bowl containing the dried silica gel granules. A scanning electronic microscope (TM4000Plus, Hitachi) was used to observe surface structure of treated fibers.

The finishing solutions were prepared as follows:

- Liquor ratio: 1:10
- BTZ agent: 1–3% (ratio of chemical weight to fabric weight)
- Acetic acid: 0.1% (proportional to weight of fabric)
- Penetrating agent: 0.1 (proportional to weight of fabric)

All solutions according to the above recipe were well stirred before pouring into the bath of laboratory padder with the given parameters (padding pressure of 1 bar, fabric speed of 1.5 m per min and padding time of 4 min) corresponding to the wet pick-up of approximately 80%. After padding, samples were dried at 100 °C for 5 min and cured at 150 °C for 2 min. All washing tests were carried out according to the AATCC LP1:2018 test method. The UPF values were measured by a UV–vis spectrophotometer (Shimadzu) in wavelength range from 190 to 1,100 nm.

Results and Discussion

Effect of knitting type on UPF of weft knitted fabric

Four various types of knitted fabric including Lacoste (LC), Single Jersey (SJ), Rib 1 × 1 (RB) and Interlock (IL) with the same yarn type (CM 30/1) and gauge (24G) were tested ultraviolet protection according to the AATCC 183–2020 standard method. Table 1 showed that various structures generated difference in thickness and specific weight of weft knitted fabric. Basically, UPF increased with thickness and specific weight, which absorption of radiation wavelength transformed into thermal energy better due to higher density (i.e., lower porosity). However, UPF of LC sample was lower than that of SJ sample in spite of higher thickness and specific weight as well as tucked loops in LC structure enlarged size of holes and increased specific weight, as shown in Fig. 1, resulting more penetrating radiation light or less ultraviolet protection.

Table 1 UPFs of Lacoste (LC), Single Jersey (SJ), Rib 1 × 1 (RB) and Interlock (IL) fabrics with the same yarn count (CM 30/1) and the same gauge (24G)

Sample	Knitting type	Thickness (mm)	Specific weight (GSM)	Ultraviolet protection factor (UPF)
LC	Lacoste	0.635	173.4	4.6
SJ	Single Jersey	0.412	149.8	6.4
RB	Rib 1 × 1	0.714	198.0	19.4
IL	Interlock	0.684	214.6	42.7

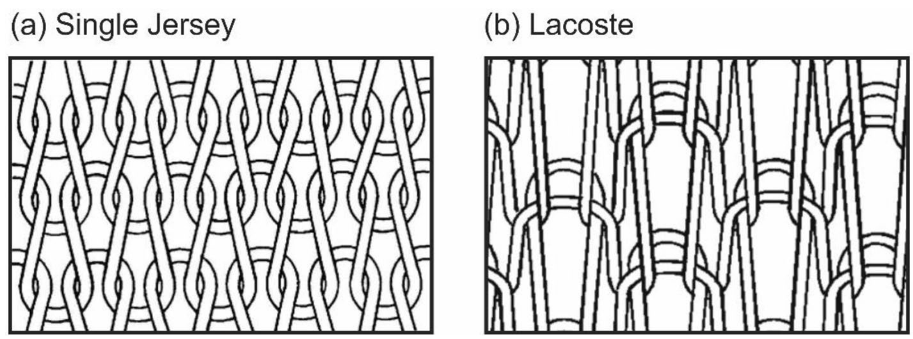

Fig. 1 Knitting structure of **a** Single Jersey and **b** Lacoste

Table 2 UPFs of Single Jersey knitted fabrics with gauges of 24G (JS24G) and 28G (JS28G)

Sample	Knitting type	Gauge (G)	Yarn type	Loop length (mm)	Courses per inch (CPI)	Wales per inch (WPI)	Weight (GSM)	Ultraviolet protection factor (UPF)
JS24G	Single Jersey	24	CM 30/1	2.55	6.4	0.412	149.8	6.4
JS28G	Single Jersey	28	CM 30/1	2.55	19.4	0.424	161.2	7.3

Effect of gauge on UPF of weft knitted fabric

To evaluate effect of needle distance or number of stitches on ultraviolet resistance, UPFs of Single Jersey fabric with gauges of 24G (JS24G) and Single Jersey fabric with gauge of 28G (JS28G) were determined and listed in Table 2. Accordingly, loop length and wale density were nearly the same, however, course density and specific weight of JS24G were remarkably lower than those of JS28G. Particularly, courses per inch and grams per square meter were 6.4 and 149.8 for JS24G, and 19.4 and 161.2 for JS28G, respectively. Consequently, UPF of JS24G was lower than that of JS28G (i.e., UPFs of JS24G and JS28G were 6.4 and 7.3, respectively). It can be concluded that weft knitted fabrics should present better ultraviolet protection with higher gauge due to its denser knitting structure.

Effect of fiber composition on UPF of weft knitted fabric

Many publications have reported that fiber composition played a very important role in preventing transmission as well destruction of textile materials from ultraviolet radiation. In fact, cotton was known to be poor ultraviolet resistant textile material which was necessary to functionally finish for blocking ultraviolet rays. In this work, three different kinds of Single Jersey knits with various fiber compositions including pure cotton fabric (JSCO100) and blended cotton fabric with 40% of polyester (JSCO/PE) and blended cotton fabric with 3% of inserted spandex yarn (JSCO/SP) were experimented to determine UPF. All obtained results in Table 3 affirmed that UPFs of blended cotton fabric were improved significantly, especially JSCO/PE. For JSCO/SP sample, UPF was relatively high (9.4) because of higher courses per inch (76 course/inch) and higher specific weight (194.0 g/m^2) although percent of inserted spandex into knitted structure was only 3%. It can be explained that spandex not only itself possessed ultraviolet resistance better than cotton but also contributed to increase course density and specific weight as well as thickness owing to its high elasticity, thereby rising UPFs.

Effect of benzotriazole content on UPF of weft knitted fabric

To enhance ultraviolet protection, benzotriazoles were coated on weft knitted fabrics by using the pad-dry-cure method at pressure of 1 bar and speed of 15 m per min. Also, based on supplier's recommendations, the content of benzotriazoles (in percent) which was calculated by a ratio of chemical weight to fabric weight was investigated on Single Jersey (28G) to evaluate its impacts on ultraviolet protection as shown in Fig. 2.

Clearly, UPFs increased with content of benzotriazoles, being 12.7, 13.5 and 15.0 at 1, 2 and 3% owf of benzotriazoles, respectively. Thus, the ratio of 3% would be used for all following investigations to optimize the efficiency of ultraviolet resistant treatment on cotton fabrics since benzotriazoles content of more than 3% could be ineffective in washing conditions owing to drifting away from materials that will be clarified further in the following section.

In Fig. 3, SEM images clarified the presence of benzotriazole agent on treated fabrics as comparing to untreated samples through some adhered scales to the surface of cotton fibers. Obviously, finishing agents were deeply penetrated into structure of cellulose fibers to form stable linkages. Moreover, the experimental results of stretch and growth as well as vapor permeability on the treated JSCO100 samples were slightly decreased as

Table 3 Effect of fiber composition as 100% cotton (JSCO100), 60% cotton and 40% polyester (JSCO/PE), 97% cotton and 3% spandex (JSCO/SP) on ultraviolet protection of knitted fabric

Sample	Knitting type	Composition (%)	Courses per inch (CPI)	Wales per inch (WPI)	Thickness (mm)	Specific weight (g)	Ultraviolet protection factor (UPF)
JSCO100	Single Jersey	100% cotton	52	41	0.424	161.2	7.3
JSCO/PE	Single Jersey	60% cotton 40% polyester	54	41	0.456	166.5	31.4
JSCO/SP	Single Jersey	97% cotton 3% spandex	76	41	0.506	194.0	9.4

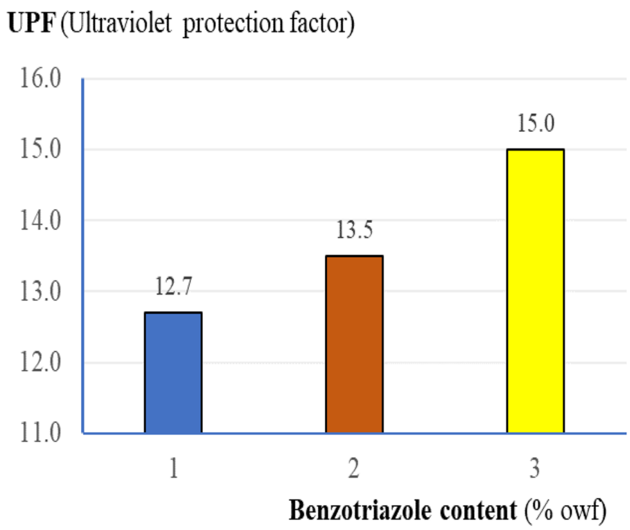

Fig. 2 UPF of Single Jersey (SJ) fabric coated by 1, 2 and 3% owf of benzotriazoles

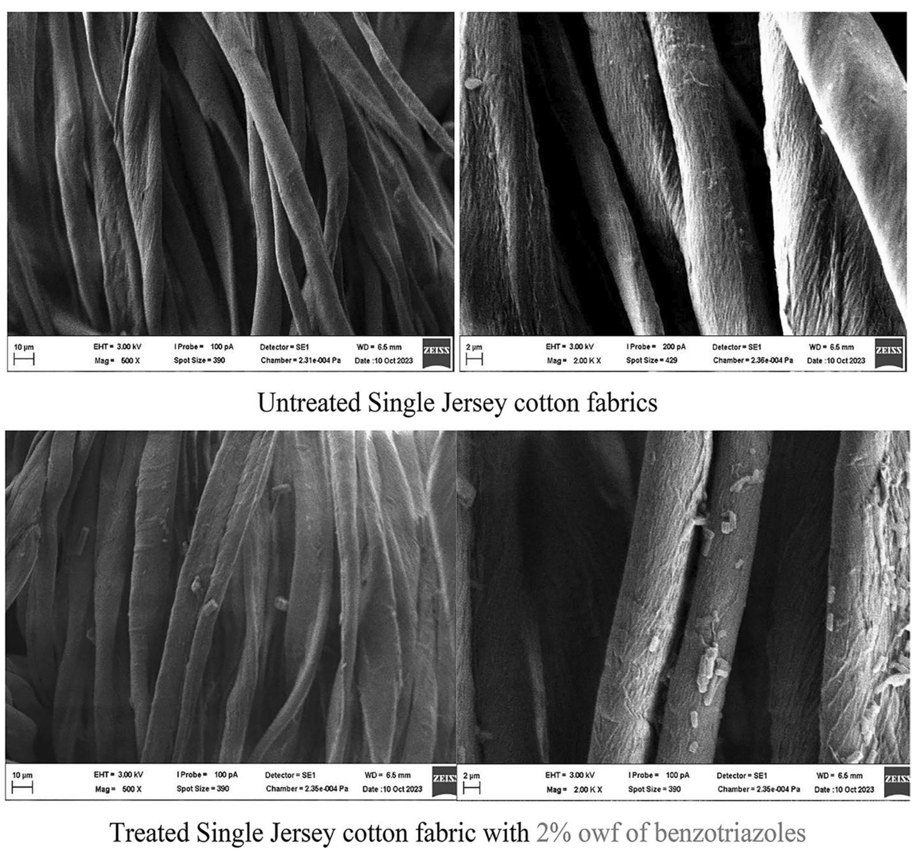

Fig. 3 SEM photos of untreated and treated Single Jersey fabrics (28G) with benzotriazoles

comparing with untreated JSCO100 samples as illustrated in Fig. 4. It could be affirmed that the presence of benzotriazole compounds in cotton fabrics generated more intermolecular interactions among cellulose molecules, leading to a more structural stability.

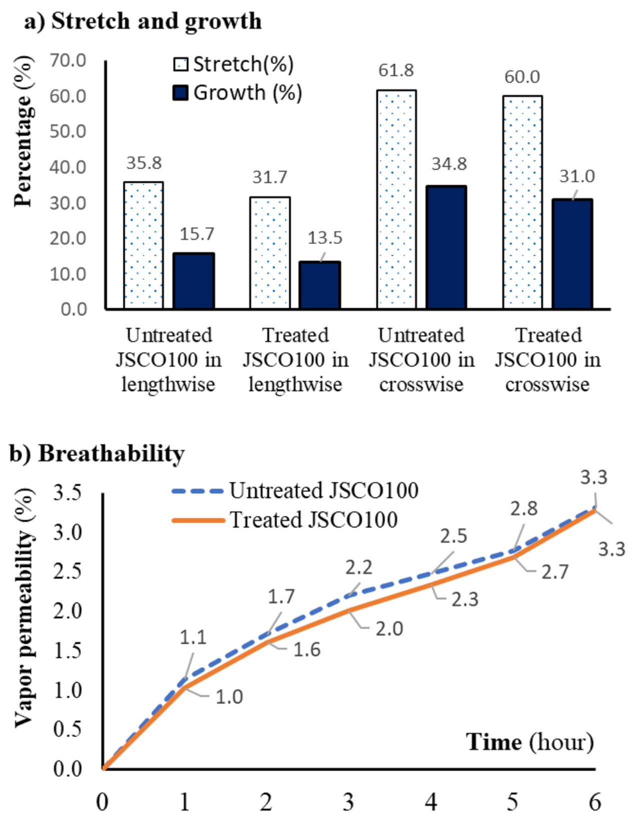

Fig. 4 Stretch, growth (in lengthwise grain and crosswise grain) and vapor permeability of untreated and treated SJCO100 samples with benzotriazoles

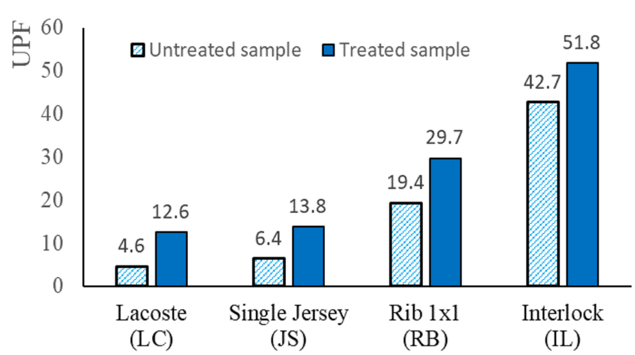

Fig. 5 UPF of untreated and treated samples with benzotriazoles on Lacoste (LC), Single Jersey (SJ), Rib 1 × 1 (RB) and Interlock (IL) knits

Effect of knitting type on UPF of coated fabric with benzotriazoles

Lacoste, Single Jersey, Rib 1 × 1 and Interlock fabrics with the same gauge (24G) and composition (100% cotton) were coated with benzotriazoles. Ultraviolet resistance of these samples was measured and compared with untreated samples as shown Fig. 5 and Table 4. UPF values of Lacoste, Single Jersey, Rib 1 × 1 and Interlock samples were significantly increased from 4.6, 6.4, 19.4 and 42.7 to 12.6, 13.8, 29.7 and 51.8, respectively. Although, increases (%) in UPF for Lacoste and Single Jersey samples were extremely high (i.e., 173.9 and 115.6%) but still did not meet requirements of sunscreen textiles

Table 4 Increase of UPF on knitted fabrics including Lacoste (LC), Single Jersey (SJ), Rib 1 × 1 (RB) and Interlock (IL) after coating with benzotriazole derivatives

Knitting	Specific weight (g)	Thickness (mm)	Ultraviolet protection factor (UPF)		Increase (%)
			Untreated	Treated	
Lacoste (LC)	173.4	0.653	4.6	12.6	173.9
Single Jersey (SJ)	149.8	0.412	6.4	13.8	115.6
Rib 1 × 1 (RB)	198.0	0.714	19.4	29.7	53.1
Interlock (IL)	214.6	0.684	42.7	51.8	21.3

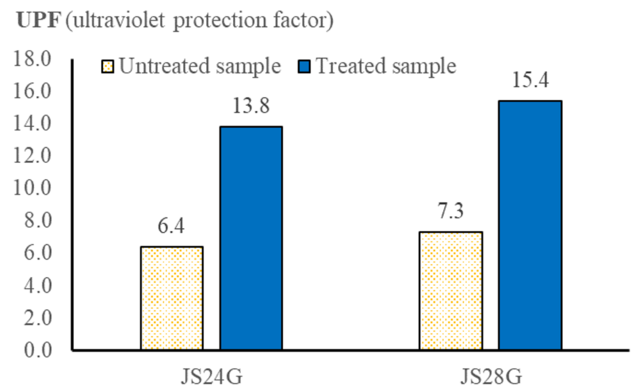

Fig. 6 Change in UPF of Single Jersey 24G (JS24G) and 28G (JS28G) cotton knitted fabrics after coated with 2% owf of benzotriazoles

(i.e., UPF > 15). UPFs of Rib 1 × 1 and Interlock samples were increased 53.1 and 21.3%, respectively, less than Lacoste and Single Jersey samples. However, these materials inherently presented ultraviolet protection as discussed above, such increases were meaningful to develop some sun protection textiles.

Clearly, benzotriazoles exhibited greatly Lacoste, Single Jersey, Rib 1 × 1 and Interlock resistance on almost weft knitted fabrics but their applicability should be considered because of their strongly dependence of knitting structures. In this cause, the best weft knitted fabrics using for producing sunscreen textile products should be Rib 1 × 1 and Interlock fabrics.

Impact of gauge on UPF of coated fabric with benzotriazoles

Similarly, impacts of gauge of fabrics coated with benzotriazoles were evaluated through comparison of UPF between treated and untreated samples on Single Jersey cotton fabrics with gauges of 24 and 28G (namely, JS24G and JS28G). As mentioned above, various gauges caused difference in specific weight and thickness, leading to variation of ultraviolet resistance (i.e., the higher the material density is, the better the ultraviolet resistance is). Particularly, UPFs of JS24G and JS28G were 6.4 and 7.3 for untreated samples and 13.8 and 15.4 for treated samples as shown Fig. 6. Accordingly, weft knitted fabrics with higher gauges could enhance ultraviolet protection for either uncoated samples or coated samples with benzotriazoles.

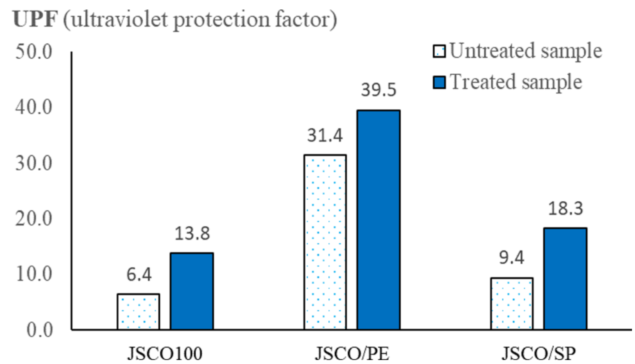

Fig. 7 Comparison of UPFs on cotton 100% (JSCO100), cotton/polyester (JSCO/PE) and cotton/spandex (JSCO/SP) after coated with benzotriazoles

Table 5 Increase in UPFs for pure and blended cotton fabrics after coating with benzotriazoles derivatives

Knitting	Specific weight (g)	Thickness (mm)	Ultraviolet protection factor (UPF)		Increase (%)
			Untreated	Treated	
JSCO100	149.3	0.412	6.4	13.8	115.6
JSCO/PE	166.5	0.456	31.4	39.5	25.8
JSCO/SP	194.0	0.506	9.4	18.3	94.7

Effect of fiber composition on UPF of coated fabric with benzotriazoles

Single Jersey cotton fabrics were blended with polyester fibers (40%) and inserted spandex yarn (3%) into (JSCO/PE) and (JSCO/SP) fabrics, respectively to consider efficiency of fiber compositions as coating benzotriazoles derivatives. As displayed in Fig. 7 and Table 5, UPF of JSCO100 increased from 6.4 to 13.8 while UPFs of JSCO/PE and JSCO/SP increased from 31.4 and 9.4 to 39.5 and 18.3, respectively, eligible to the requirement of sunscreen textiles. Thus, cotton fabric is necessary to be blended polyester or spandex fibers with a certain blending ratio before coating benzotriazoles to obtain appropriate UPFs of higher than 15.

Impact of washing cycles on ultraviolet protection of coated fabric with benzotriazoles

Figure 8 indicated that washing process generally caused slight declination of UPF value on knitted fabrics coated with benzotriazoles. Obviously, benzotriazoles exhibited highly affinity with cotton fibers owing to functional groups of benzotriazole such as amine group. In the first washing cycle, UPF sharply decreased because of drifted chemicals away from fabric surface, however it tended to reduce a little in next washing times (evenly UPF was still high after 20 washing cycles). Furthermore, UPFs of treated fabric as tucking spandex fibers decreased less than those of treated fabric as using pure cotton fibers. This is because spandex made coated fabrics more elastic and dimensionally stable after washing conditions, thereby lasting ultraviolet resistance longer. Accordingly, knitted fabric—Single Jersey tucked with spandex and coated by benzotriazoles were

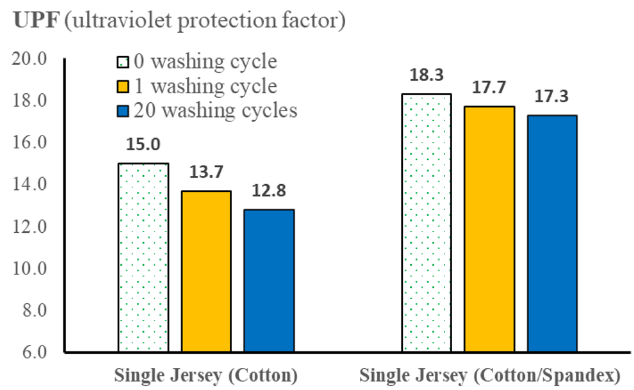

Fig. 8 Reduction in UPF of Single Jersey cotton knitted fabric and Single Jersey cotton/spandex knitted fabrics after 0, 1 and 20 washing cycles

a suitable choice for sun protection textile products because of either high ultraviolet resistance or high washing fastness.

Conclusions

The work found that knitting structure caused highly effect on ultraviolet protection of weft knitted fabrics. Particularly, rib and interlock fabrics exhibited highest UPFs (more than 15), even without ultraviolet resistant finishes. Change in gauge causes difference in CPI, which a higher gauge induced a smaller hole (gap) and a better ultraviolet resistance (higher UPF). Especially, insertion of spandex into knitted cotton fabrics increased not only elastic properties but also UPF value. In this study, weft knitted fabrics coated with benzotriazoles derivatives significantly improved ultraviolet protection (especially, Single Jersey fabric with 100% cotton). However, Single Jersey and Lacoste cotton fabrics coated with benzotriazoles presented UPFs lower than 15 because of relatively low specific weight while Rib 1 × 1 and Interlock displayed high ultraviolet protection on not only untreated samples but also treated samples. Results of evaluating fastness on ultraviolet coated fabrics to washing were quite good and applicable.

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Author contributions
TAN instructed and interpreted the data that NTNN reviewed and carried out all the experiments in the research. All authors read and approved the final manuscript.

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Tuan Anh Nguyen is working as an Assistant Professor and a Dean of Faculty of Fashion and Tourism, HCMUTE.

Nhu Tram Nguyen Nu is a graduate student of Textile and Garment Technology at Faculty of Mechanical Engineering, HCMUT.