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The Effects of Yarn Number and Liquid Ammonia Treatment on the Physical Properties of Hemp Woven Fabrics

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Abstract: The effects of yarn number and liquid ammonia (L/A) treatment on the physical properties of woven fabrics prepared with pure hemp spun yarns were investigated. As a result of L/A treatment, the crystal structure of hemp fiber was changed from cellulose I to the mixtures of cellulose III and cellulose I and its crystallinity was slightly decreased by 13 %. The crease recovery of hemp fabric treated with L/A was improved upto 78 %. The washing shrinkage of hemp fabric treated with L/A decreased significantly to less than 0.4 %, while the washing shrinkage of hemp fabric prepared with the fined yarn was superior to that of hemp fabric prepared with the coarsed yarn. Especially, the wicking speed and drying ratio of hemp fabrics treated with L/A were higher than those of the untreated as yarn number increased. However, it was found that there is no significant effect on the UV protection of the L/A treated hemp fabrics.

Keywords: Hemp, Yarn number, Liquid ammonia treatment, Physical properties, Crease recovery

Introduction

In the situation of the intensive growth of world population and the lack of comfort and ecological fibers, solutions may be found in the return to almost forgotten natural fibers, such as hemp fibers [1]. Hemp (Cannabis sativa L.) is most likely the first plant cultivated by mankind for its textile use [2]. Recently, the interest in hemp is focused on its use as a raw material for the environmental friendly clothing [3-5]. The hemp fiber has been known to have unique characteristics compared to other fibers. As a textile fiber, hemp possesses a range of extraordinary properties such as antimicrobial properties, extremely quick absorption of humidity accompanied with quick drying, good thermal and electrical properties, outstanding tenacity and lack of allergenic effects, biodegradability and protection against UV radiation [6-9]. However, there are some drawbacks in the properties of hemp fabrics such as high stiffness, easy creasing with poor recovery, and rough handle, which limits wider applications of hemp fibers as clothing materials. In this respect, to improve the hand and physical properties of hemp and cellulose fabrics, many researchers have extensively employed liquid ammonia (L/A) treatment [10,11]. It is well known that the crystallite form, cellulose I of native cotton is transformed to cellulose III by the NH_3 treatment. Ammonia penetrates cellulose relatively easily and reacts with the hydroxyl group after breaking the hydrogen bonds. Therefore, the L/A treatment can impart wrinkle recovery, soft handling and mechanical properties to cellulose fabrics [12-17]. Nevertheless, no studies have been published on the crease recovery, drying ratio, washing shrinkage, wicking speed, and UV blocking of woven hemp fabric prepared with fine spun yarns utilizing L/A treatment.

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The aim of this work is to investigate the effects of yarn number and L/A treatment on the physical properties, such as, crystal structure, crease recovery, drying ratio, washing shrinkage, wicking speed, UV protection, and SEM morphologies of hemp woven fabrics prepared with fine spun yarns.

Experimental

Materials

Desized and scoured 100 % hemp woven fabrics used in this study obtained from Dream Hemp Co. Yarn number of the hemp fabrics are N_m 24, 36, 48, and 60, the counts of warp and weft yarns in the fabrics are equal. The fabrics were treated in liquid ammonia for 2 sec at −33.4 °C under tension-free condition. The specifications of the samples are shown in Table 1.

Characterization

X-ray diffraction patterns of the fibers were measured with a Bruker D 8 Discover of GADDS (Germany). The operating conditions were Cu-Kα radiation, voltage 40 kV, current 40 mA, inclinometer revolution speed 3 °/min, and scan from 5-40 ° of 2θ. The degree of crystallinity was calculated by the following equation:

Table 1. Specifications of the samples used in this study

Yarn number (N_m)	Weave	Fabric count		Fabric weight (g/m^2)	Thickness (mm)
		Ends/in	Picks/in		
24	Plain	63	52	200	0.52
36	Plain	68	54	145	0.44
48	Plain	85	70	139	0.43
60	Plain	92	69	103	0.30

$$\text{Crystallinity} = \frac{I_c}{I_a + I_c} \times 100 \quad (1)$$

where, I_c is the integrated diffraction intensity of the crystalline region, and I_a is the integrated diffraction intensity of the amorphous region based on $2\theta = 18^{\circ}$.

The crease recovery of the treated hemp fabric was measured with Monsanto crease recovery angle tester (Han Won Soway Co.) in both the warp and weft directions by KS K 0550. The specimen for crease recovery measurements was typically cut according to a special standard rectangular shape, and each test was repeated ten times to obtain the average. The crease recovery was calculated by using the following equation:

$$\text{Crease recovery (\%)} = \frac{\theta}{180} \times 100 \quad (2)$$

where θ is the recovery angle.

The washing shrinkage of the treated hemp fabric induced by cold water immersion was obtained according to the KS K ISO 7771.

$$\text{Shrinkage (\%)} = \frac{L_0 - L_s}{L_0} \times 100 \quad (3)$$

where L_o is the distance between the datum lines before washing and L_s is the distance between the datum lines after washing.

The drying rate was measured by the vertical strip method according to the following procedure: the fabrics were conditioned for 12 h under standard atmospheric conditions of 20 and 65 % RH (W_0). They were immersed in distilled water and then centrifuged for 1 min at 3000 rpm (W_2). After then, they are kept in the standard atmospheric conditions and weighted every 10 min (W_1). The drying ratio was calculated by the following equation:

$$\text{Drying ratio (\%)} = \frac{W_2 - W_1}{W_2 - W_0} \times 100 \quad (4)$$

The ultraviolet (UV) protection properties of the samples were evaluated according to test methods for ultraviolet blocking and ultraviolet protection factor of textiles (KS K 0850) using a UV transmittance analyzer (Labsphere Co. USA). The light source used in the test is Xenon Arc, A-type ultraviolet rays (UV-A) with a wavelength of 315-400 nm, and B-type ultraviolet rays (UV-B) with a wavelength of 290-315 nm. The UPF (Ultraviolet Protection Factor) value was used here to evaluate the UV protection capacity of textiles, which is defined by Australian/New Zealand Standard [18]. The UPF value was calculated according to the following equations (5), (6), (7), and (8).

$$\text{UV protection (\%)} = 100 - \textit{UV transmittance} \text{ (\%)} \quad (5)$$

$$\text{UV-A transmittance} = \frac{T_{316} + T_{320} + \ldots + T_{396} + T_{400}}{18} \quad (6)$$

$$\text{UV-B transmittance} = \frac{T_{290} + T_{296} + \ldots + T_{310} + T_{316}}{6} \quad (7)$$

$$UPF = \frac{\sum_{290\text{nm}}^{400\text{nm}} E_\lambda S_\lambda \Delta_\lambda}{\sum_{290\text{nm}}^{400\text{nm}} E_\lambda S_\lambda T_\lambda \Delta_\lambda} \quad (8)$$

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

The surface and cross-section of all the samples were observed morphologically by scanning electron microscopy (Jeol, JSM-6700F) at a beam voltage of 20 kV at room temperature. All the specimens were coated with gold using an ion sputter coater (Jeol, JFC-1 100E).

Results and Discussion

Figure 1 shows the X-ray diffraction patterns of hemp fabrics after L/A treatment. The major diffraction peaks of (002), (101), and $(10\bar{1})$ planes at $2\theta = 22.6^{\circ}$, 14.6° and 16.7° of the untreated hemp showed the crystalline forms of cellulose I. Peak at $2\theta = 20.7^{\circ}$ by $(002)/(10\bar{1})$ planes in the patterns of the treated hemp is a characteristics for cellulose III and the peak at $2\theta = 11.7^{\circ}$ by (101) planes is a characteristics for cellulose I. It is generally well known that the cellulose I crystalline form of native cotton is transformed to

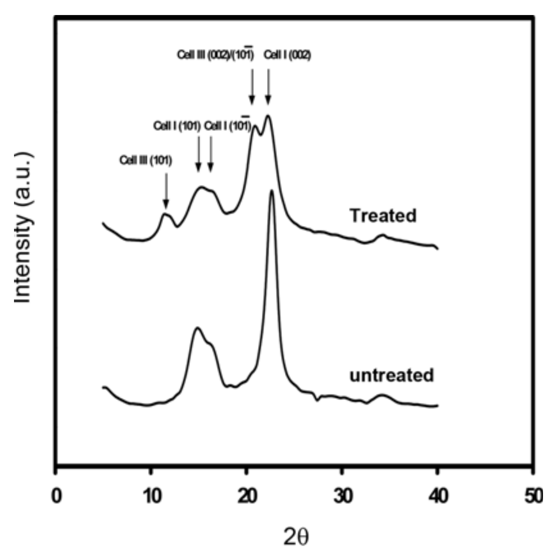

Figure 1. X-ray diffraction patterns of hemp fabrics after L/A treatment.

Table 2. The degree of crystallinity of hemp fibers treated with L/A

Treatment	Degree of crystallinity (%)
Untreated	66.1
L/A treatment	57.4

cellulose III by L/A treatment [13,19]. However, in this study, it was found that the crystal structure of hemp treated with L/A treatment transforms from cellulose I to the mixtures of cellulose III and I. This result is also similar to that of ramie fabrics treated with L/A treatment [17].

Table 2 shows the degree of crystallinity of hemp fibers treated with L/A. The degree of crystallinity of hemp fibers treated with L/A is 57.4 %, while that of the untreated fabrics is 66.1 %. Accordingly, the degree of crystallinity of hemp fiber after L/A treatment was decreased by 13.2 %. This is because the orientation of cellulose molecular chain in the crystalline region was disordered due to the influences of good penetration and intra-crystalline swelling of hemp cellulose by L/A treatment and as a result, the amorphous region of the treated hemp was accordingly increased [19].

Figure 2 shows the effects of yarn number and L/A treatment on the crease recovery of hemp woven fabric. The crease recovery of the untreated hemp fabric was 88-92 ^{o}, and that of the treated hemp fabric was 145-166 ^{o}. When the fabric was treated with L/A treatment, its crease recovery significantly improved by about 57-78 % compared with the untreated. This result may be due to the swelling of fibers in the fabric by the L/A treatment. Therefore, it is obvious that the improvement of crease recovery is due to the modification of the internal structure in the crystalline and amorphous regions by the L/A treatment. However, the effect of yarn number was negligible.

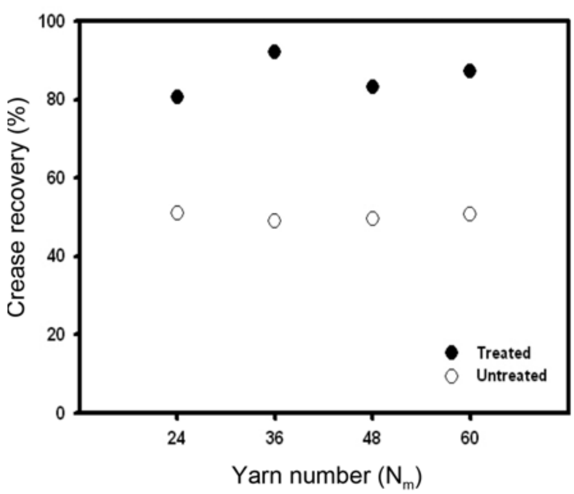

Figure 2. Effects of yarn number and L/A treatment on the crease recovery of hemp fabrics.

Figure 3 shows the dimensional shrinkage of hemp fabric treated with L/A. The washing shrinkage of fabric treated with L/A showed less than 0.4 %, while that of the untreated fabric showed about 0.7-1.7 %. The effects of intra-crystalline swelling and orientation behavior of non-crystalline region in hemp fiber are remarkably reflected in their shrinkage reduction by L/A treatment. The washing shrinkage of the treated fabrics was not affected by yarn number, but that of untreated fabrics was decreased as the yarn number increased. The dimensional stability of untreated hemp fabric prepared with the fined yarn was superior to that with the coarsed yarn.

The effects of yarn number and L/A treatment on the wicking speed of hemp fabric are shown in Figure 4. The wicking speed of the untreated hemp fabrics was 29-71 mm/10 min, while that of the treated fabrics was 49-87 mm/10 min. It can be seen that the wicking speed of the fabric after L/A treatment was greatly improved by about 19-42 % compared to the untreated. This is because the wicking speed of the fabrics can be higher due to removal of impurities in the fiber by L/A treatment. Figure 5 shows the effects of L/A treatment and yarn number on drying ratio of hemp fabrics. After the L/A treatment, the drying ratio of the treated fabric as increasing yarn number from Nm 24 to Nm 60 was slightly increased more than the untreated at drying

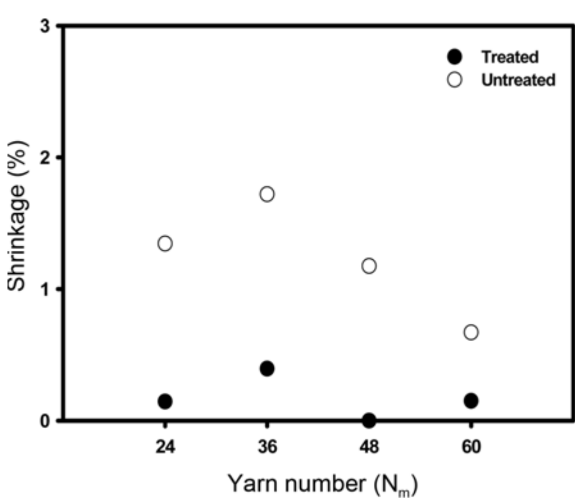

Figure 3. Effects of yarn number and L/A treatment on the shrinkage of hemp fabrics.

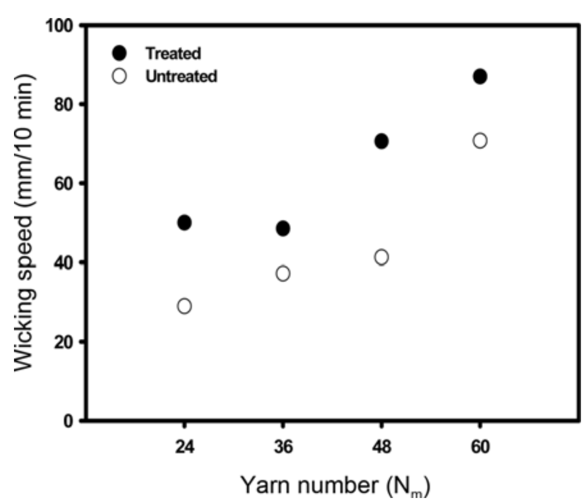

Figure 4. Effects of yarn number and L/A treatment on the wicking speed of hemp fabrics.

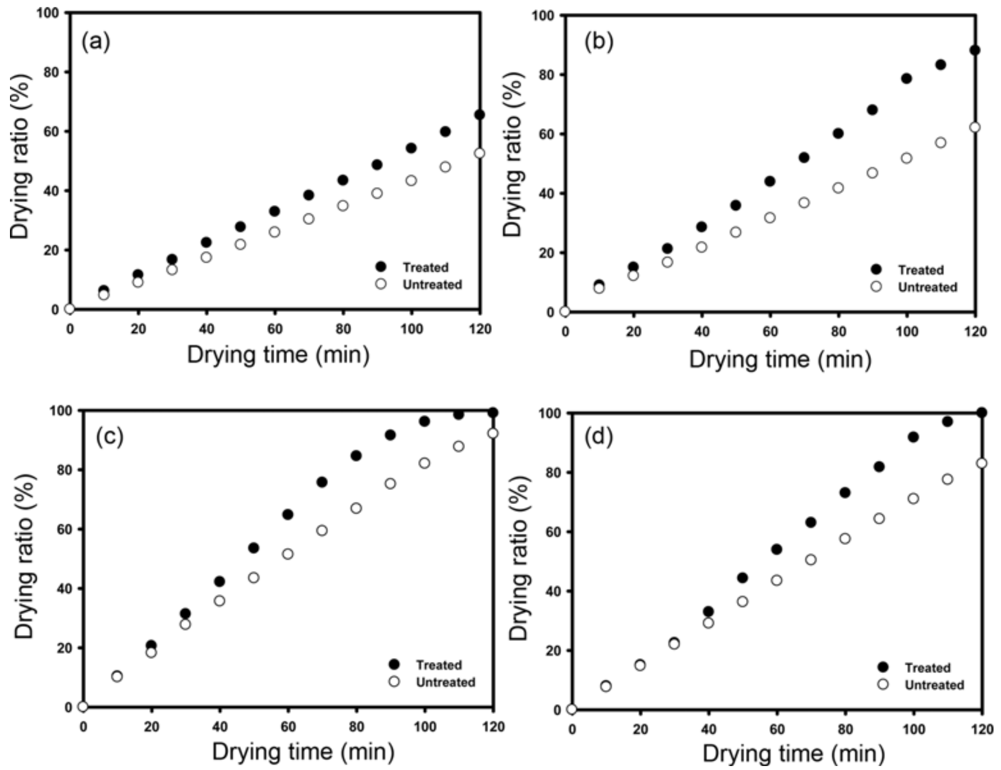

Figure 5. Effects of yarn number and L/A treatment on the drying ratio of hemp fabrics; (a) Nm 24, (b) Nm 36, (c) Nm 48, and (d) Nm 60.

time between 20 and 120 min. This is explained by the fact that the L/A treatment and the fine yarn reduces the quantity of water keeping in the fibers and it also increase the moisture drying ratio of fabric.

On the other hand, the UV-blocking of a fabric depend on a large number of factors, such as, fiber content, weaving pattern, porosity, moisture content, dye concentration, finishing processes, and the presence of additives.

Figure 6 and 7 show the effects of L/A treatment on the UV-A and UV-B protection of hemp fabric, respectively. The UV-A protection of the untreated fabric is 61.8-72.9 %, while that of the treated fabric is 75.1-86.1 %. The UV-B protection of the untreated fabric is 67.5-79.2 %, whereas that of the treated fabric is 82.9-90.4 %. As a result, the UV-A and UV-B protection of hemp fabrics treated with L/A treatment were higher by about 11-15 % than those of the

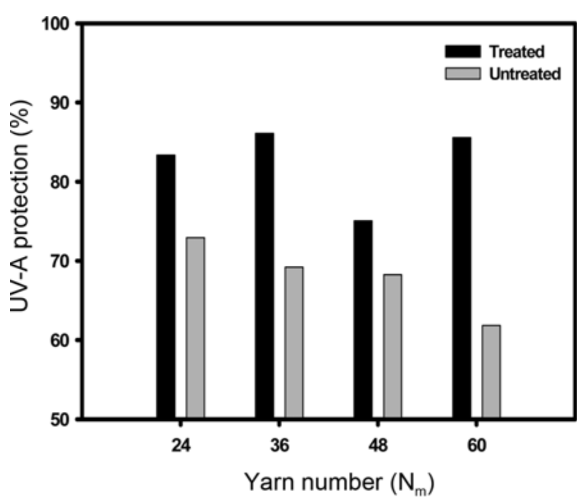

Figure 6. Effects of yarn number and L/A treatment on the UV-A protection of hemp fabrics.

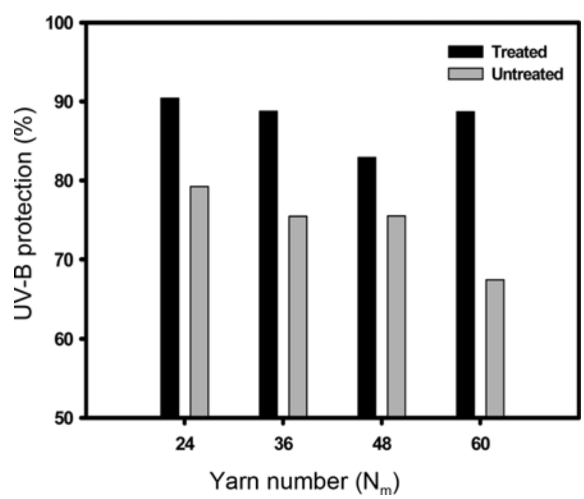

Figure 7. Effects of yarn number and L/A treatment on the UV-B protection of hemp fabrics.

untreated fabrics by L/A treatment. However, as the yarn number increased, the UV-A and UV-B protection of hemp fabrics without the L/A treatment was decreased and that of the treated fabrics was similar. The hemp fabrics were found to have higher UV-A and UV-B than either cotton (UV-A: 64.3 % and UV-B: 68.5 %) or rayon (UV-A: 61.3 % and UV-B: 65.0 %) [20]. In addition, Table 3 shows the effects of L/A treatment on the UPF values of hemp fabrics. The UPF

Table 3. Effect of L/A treatment on the UPF of hemp fabrics

Yarn number (N_m)	24	36	48	60
Untreated	4.53	3.87	3.84	2.96
Treated	9.33	8.74	5.37	8.67

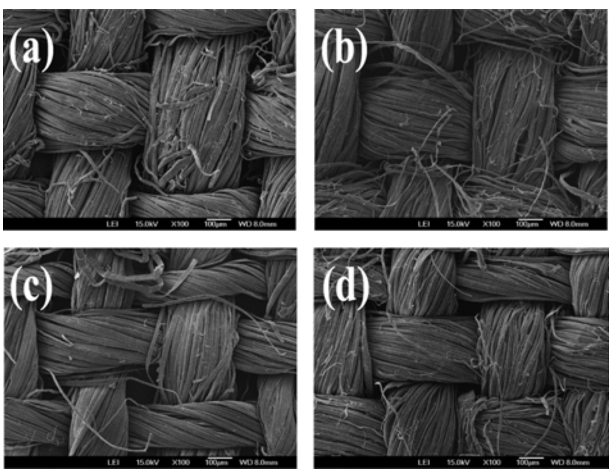

Figure 8. SEM images of the surface morphology of untreated or treated hemp fabrics with L/A; (a) untreated N_m 24, (b) treated N_m 24, (c) untreated N_m 48, and (d) treated N_m 48.

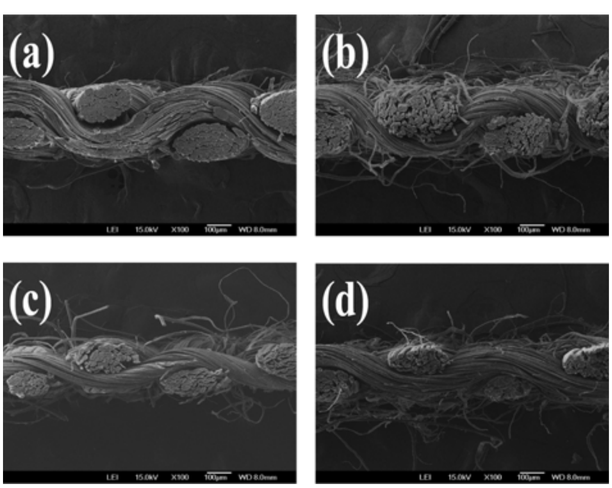

Figure 9. SEM images of the cross-section morphology of untreated or treated hemp fabrics with L/A; (a) untreated N_m 24, (b) treated N_m 24, (c) untreated N_m 48, and (d) treated N_m 48.

of the L/A treated fabrics is about 5-9, while that of the untreated fabrics is below 5. Therefore, as can be seen from Table 3, UPF values of the L/A treated fabrics were greater than the untreated. However, there is no significant effect on the UV protection of hemp fabrics with such low UPF values.

SEM image has proved to be useful for morphology of fabric. Figure 8 shows the surface morphology of untreated or treated hemp fabrics. The yarn space of fabric was significantly compacted after L/A treatment from the gap between two yarns. Figure 9 shows SEM images of the cross-section of untreated or treated hemp fabrics. It was identified that the fibers became more separated to individual fibers and more bulked after L/A treatment.

Conclusion

The effects of yarn number and L/A treatment on the physical properties of woven fabrics prepared with 100 % hemp spun yarns were investigated. It was found that the crystal structure of hemp fiber after L/A treatment was changed from cellulose I to the mixtures of cellulose III and cellulose I. The degree of crystallinity of hemp fabric treated with L/A was decreased by about 13.2 % compared with that of the untreated. Especially, the crease recovery of hemp fabric treated with L/A was improved more than that of the untreated. The washing shrinkage of fabric treated with L/A decreased when compared with that of the untreated, while the washing shrinkage of hemp fabric prepared with the fined yarn was higher than that of hemp fabric prepared with the coarsed yarn. The wicking speed and drying ratio of the hemp fabrics treated with L/A were larger than those of the untreated as yarn number increased. In addition, if the L/A treatment contributed to the reduction of UV transmission and the increase UPF of hemp fabrics, however, there is no significant UV protection effect.

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