Park *Fashion and Textiles* (2023) 10:3
https://doi.org/10.1186/s40691-022-00319-3

Fashion and Textiles

RESEARCH

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Characteristics of cotton fabric dyed with *Euphorbia* extract at different concentrations of cellulosic nanoparticles (CNP)

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Abstract

As the perception of the consumer's environment and the toxicity of synthetic dyes that is harmful to humans, interest in natural dyes is also increasing in the textile dyeing industry. This study performed an alternative to metal mordants and used cellulose nanoparticles (CNP) as a natural mortant for dyeing cotton fabrics with natural dyes extracted from *Euphorbia*. The characteristics with and without CNP mordant were investigated in the experiment. The effects of natural cellulosic mordants were analyzed through color, fastness, color, fastness, air permeability, antibacterial rate, UV protection, and total hand value (THV). As a result, the light fastness has been shown to significantly increase, but the improvements in terms of the wash, perspiration, and rubbing fastness were negligible. In addition, when CNP was added to cotton dyeing, there was no difference change in air permeability, but THV was significantly improved to 5 or more, and the UV protection and bacteria reduction rate were excellent. These results are attributed to the groundwork for studies on other types of natural dyes in the future and, by establishing the benefits of CNP, this study significantly contributes to the improvement of the end-products of dyeing.

Keywords: Total hand value, Color depth, UV protection, Cellulose nanoparticle, CNP

Introduction

The textile industry mainly uses synthetic dyes; consequently, several substances that are harmful to the human body are discharged during the dyeing process. Moreover, there exist several problems such as environmental pollution due to the wastewater generated after dyeing (Kim, 2008). Natural dyeing is also perceived as an eco-friendly fashion element according to consumer trends that value emotional and cultural values, and is steadily growing as a high value-added industry (Park et al., 2010). While naturally dyed products are positively recognized for their non-allergenic, deodorizing, and antibacterial properties (Heo et al., 2008; Park & Han, 2015), there are still many issues that need to be resolved, such as the complex overall dyeing process due to repeated dyeing and washing, difficulty in mass production, low fastness (Sadeghi-Kiakhania & Safapour, 2015; Shahid et al., 2012), human health risk and deterioration of fiber properties due to the metal mordants used to promote weak binding between the dye and fiber polymers, and environmental pollution due to the wastewater generated after dyeing (Park et al., 2008). However, despite these difficulties, various methods have been recently reported to improve the natural dyeing of cellulose fabrics, such as mordant, plasma and chitosan treatment, grafting, microwave, etc. (Buyukakinci et al., 2021; Haji, 2020; Haji et al., 2018, 2020; Tayyab et al., 2020).

Meanwhile, cellulose is the most abundant natural organic compound on Earth, the main component constituting the cell walls of higher plants such as cotton, hemp, and wood, and billions of tons are produced annually through plant photosynthesis (Kim & Yoon, 2016). Recently, Cellulose nanoparticles (CNP) have been widely used in composite materials, electronic devices, and membranes (Ma et al., 2014) and in the field of textile dyeing, CNP is used in cotton synthetic dyeing for effective coloring and enhancement of the physical properties (Liyanapathiranag et al., 2020).

Euphorbia humifusa (locally called as silk grass) is an annual herbaceous species containing white latex, which is easily found on roadsides or fields (Choi, 2010). It is main components are quercetin (Fang et al., 1993), a glycoside belonging to the flavonoid family, tannin, and phenolic substances (Heo et al., 2008). Quercetin is produced by hydrolyzing rutin (the most commonly distributed flavonoid glycoside) with acidic aqueous solutions or enzymes.

The handle, which means the subjective emotional assessment of a textile material obtained through human touch and sight, is a means of deciding the intrinsic performance for the fabric's final use and is an overall expression determined by various mechanica l characteristics. The mechanical properties of a fabric may be affected not only by the material, yarn structure, and fabric shape but also by processing methods, including processing agents and dyeing. As such, many attempts are being made to change the handle and use these for its intended purpose (Jeon et al., 2003).

In this study, to investigate the value of using *Euphorbia humifusa* extract (*Euphorbia*) as a natural dye, which is an easily available material, but has not been used in cotton dyeing, a hydrogel-type CNP was added and dyed. Then, the mechanical handle, color depth, fastness UV protection, antimicrobial rate, and air permeability change were analyzed.

Experimental

Materials

The plain-woven 100% cotton fabric was used for the experiment (Density—warp 43 $cm^2 \times$ weft 25 cm^2; weight—126.5 g/m^2; thickness—0.351 mm). The cotton fabric was scoured at 100 °C for 30 min with 2% NaOH aqueous solution (liquid ratio 1:50, o.w.f.), washed with water sufficiently, and dried naturally at 20–22 °C for 18 h. The *Euphorbia Humifusa* was purchased from Haesung Corporation Ltd. in Yeongcheon (Korea), naturally dried, and used in its original state. Asian Nnanotech Co., Ltd. supplied the CNP (CNP: Water = 1: 99, pH 5.9), and 1% CNP was provided as white hydrogel. All reagents used in the experiment, including NaOH (Daejung Chemicals & Metals Co., Korea), were used as received.

Extraction of *Euphorbia*

An extract was made from the *Euphorbia* purchased in a dry state by collecting only the leaves and stems, crushing them, placing batches 500 g into a net, and heating them at 100 °C for 120 min (1:20 o.w.b). The extracted dye solution was used immediately (pH 4.9).

Dyeing and treatment with CNP

The cotton were dyed with the *Euphorbia* extract as follows. The first dyeing process involved placing a 1 L beaker on a hotplate with a stirrer, adjusting the dye solution concentration (o.w.f.) at a liquid ratio of 1:100, and dyeing the cotton at 80 °C for 60 min and subsequently drying it at room temperature for 18 h. After repeating this process under the same conditions, the cotton was finally washed with distilled water and dried sufficiently at room temperature. During the dyeing, the CNP concentration was adjusted to 0, 0.05%, 0.1%, 0.5%, and 1% (o.w.f.) and simultaneously added to the *Euphorbia* extract.

Color analysis

To determine the color depth, after conditioning at 50% relative humidity for 48 h prior to testing, the color of the cotton treated with 0, 0.05, 0.1, 0.5 and 1% CNP was colorimetrically evaluated by computer color matching system (CCM, COLOR-EYE 3100, Macbeth®, USA). The conditions were set to D65 illuminant/10° standard observation in 350–700 nm. The relative color depth at the maximum absorption wavelength was assessed by the Kubelka–Munk equation: $K/S = (1 - R)^2/2R$, where R, K and S are the decimal fractions of the reflectance, coefficient of light absorption and scattering for dyed fabric at λmax, respectively. The color difference (ΔE) based on L^* (Lightness, 100 white to 0 black), a^* (+Redness to −Greenness), b^* (+Yellowness to −Blueness), and H^* (hue angle) was determined using the modified CIELAB2000 formula equation (Hong et al., 2006).

Air permeability test

After scouring and dyeing, the air permeability of the fabric was cut so that the sample area was 20 cm^2, and in accordance with KS K ISO 9237: 1995, a compact type air permeability meter (AP-3603, Daiei kagaku seik MFG. CO. Ltd. Kyoto, Japan) was used to pass air vertically at a pressure of 100 Pa, and the amount and flow rate of air permeated through the area of the fabric were measured.

KES-FB measurement

The mechanical properties of the cotton fabrics by adding CNP were measured under high sensitivity conditions using the Kawabata Evaluation System (KES-FB, Kato Tech. Co. Ltd., Japan). As shown in Table 1, the characteristic values and measurement conditions of the analysis included tensile (EM, LT, WT, RT), bending (B, 2HB), shear (G, 2HG, 2HG5), compression (LC, WC, RC), surface (MIU, MMD, SMD), and the thickness (T) and weight (W) per unit area of the samples under a compressive load. The primary hand value (PHV) was calculated as per KN-203-LDY by measuring the KOSHI (stiffness, a comprehensive expression of resilience, elasticity, and plasticity felt when holding the fabric in the hands), NUMERI (smoothness, the fabric's texture when touched by

Table 1 Characteristic values of basic 16 mechanical properties of fabrics

Parameters	Description	Unit
EM	Extensibility	%
LT	Load-extension ability	None
WT	Tensile energy	g cm/cm^2
RT	Tensile resilience	%
B	Bending rigidity	gf·cm^2/cm^2
2HB	Hysteresis of bending moment	gf·cm/cm^2
G	Shear stiffness	gf·cm/degree
2HG	Hysteresis of shear force at shear angle of 0.5°	gf·cm
2GH5	Hysteresis of shear force at shear angle of 5°	gf·cm
LC	Compression-thickness, compressibility	None
WC	Energy in compression	gf·cm/cm^2
RC	Compression resilience	%
MIU	Coefficient of friction	None
MMD	Mean deviation of MIU	None
SMD	Geometrical roughness	%
T	Thickness of the fabric	mm
W	Mass of the fabric	mg/cm^2

hand), and FUKURAMI (fullness and softness, a comprehensive expression of the profound feel and compressive elasticity felt when holding the fabric in the hands). Based on the results, the total hand value (THV) was calculated as per KN-302-W-dress.

Fastness test

The light fastness was analyzed in comparison with standard blue dye after irradiating the test piece with light for 20 h based on KS K ISO 105-B02: 2014 Xenon arc test. The color fastness to washing was measured based on the KS K ISO 105-C06: 2014. Fastness to perspiration was measured based on KS K ISO 105-E04 013. Rubbing fastness was evaluated for dry and wet rubbing in accordance with KS K ISO 105-X12: 2016.

UV protection test

The UV protection properties were measured within a wavelength of 290–400 nm according to KS K 0850:2014. The UV blocking rate was calculated using Eq. (1) for the amount of UV light transmitted compared to the input amount, and the UV index was calculated as the ratio of the average UV light transmitted through the sample to the average UV light transmitted without the sample, as in Eq. (2).

$$\text{UV transmission rate (\%)} = \frac{T}{B} \times 100 \tag{1}$$

$$\text{UV blocking rate (\%)} = 100(\%) - \text{UV transmission rate(\%)} \tag{2}$$

where, T: UV transmitted through the fabric and B represents UV transmitted without the fabric.

Table 2 Stock solution of cellulose nanoparticles (CNP) with and without *Euphorbia*

Euphorbia	CNP (%)	*L**	*a**	*b**	*c**	*h**	pH
Without	1	32.67	0.06	− 1.55	1.55	272.2	5.9
With	0	27.29	0.60	1.48	1.60	67.79	4.9
	0.05	26.32	0.86	1.85	2.04	64.97	4.9
	0.1	26.40	0.90	1.95	2.15	65.14	4.9
	0.5	26.54	1.02	2.26	2.48	65.77	4.9

*L** lightness, *a** +red ~ −green, *b** +yellow ~ −blue, *c** chroma, *h** hue, *pH* acidity

Table 3 Color characteristics of cotton dyed with *Euphorbia* at different cellulose nanoparticles (CNP) concentration

Sample	*L**	*a**	*b**	*c**	*h**	Surface color
Scoured	90.68	- 0.23	4.64	–	–	–
Dyed	79.99	0.12	14.01	14.01	89.52	
Dyed with 0.05% CNP	73.39	1.25	16.75	16.79	85.72	
Dyed with 0.1% CNP	74.55	1.37	16.94	17.00	85.39	
Dyed with 0.5% CNP	72.58	1.40	16.19	16.25	85.06	
Dyed with 1% CNP	74.10	1.19	17.43	17.47	86.09	

Antibacterial rate test

For antibacterial properties, *Staphylococcus aureus* ATCC 6538 and *Klebsiella pneumoniae* ATCC 4352 were cultured in the test specimen and control specimen according to KS K 0693:2016, and after 18 h, the reduction rate (%) was measured and expressed.

Results and Discussion

Stock solution of CNP

CNP is in a hydrogel state, with water in a 1:99 ratio and the color of the stock solution is opaque and creamy white with an *L** of 32.67. However, as shown in Table 2, the stock solution of the dye solution has an *L** value of 27.29, but as the amount of CNP increases, the *L**, *a**, *b**, and the color and saturation also increase, and the dye solution becomes slightly darker even if there is no significant change in color. In addition, the pH of the CNP stock solution was weakly acidic, but it became acidic after CNP was added to the dye solution.

Characteristics of color

In general, cotton is known that the dyeing process must be repeated in order to obtain a deep color because it is very difficult to natural dyeing. In this study, 0.05%, 0.1%, 0.5%, and 1% CNP were added to the *Euphorbia* to investigate its potential as a mordant. Table 3 shows the color values through *L**, *a**, *b**, *c**, and *h** of the dyed cotton fabrics and the colors of the dyed fabrics. Compared to dyeing with the *Euphorbia* alone, both the L^* and h^* values decreased when CNP was added. The a^* and b^* are red-yellow colors, and in particular, the yellowness of b^* is greater (+), thereby showing a stronger yellow color. The c^* was also higher, thereby increasing the saturation. Furthermore, the dye appeared to adhere more effectively to the fabric when the *Euphorbia* contained CNP. In particular, adding 0.5% CNP to the *Euphorbia* resulted in a more vivid color and the lowest L^*, highest a^*, and largest c^* values. The surface color visible to the eye looks darker when 0.05% is used, but there is no significant difference. These results showed the same results in mugwort dyeing (Park, 2020) However, additional research is needed to compare it with natural mordants such as alum or natural glaze.

Figure 1a shows the ΔE values of the fabrics dyed with different CNP concentrations (0, 0.05, 0.1, 0.5, and 1%). After scouring, the ΔE of the non-dyed fabric was 16.35. The ΔE value of the cotton treated with the extract and CNP was larger than that of the non-dyed cotton, indicating that the use of CNP improves dyeability. In particular, the ΔE value was the largest (21.36) when the fabric was dyed with the extract and 0.5% CNP, showing the best dyeability under these conditions. Figure 1b shows *K/S* value; the non-dyed fabric had an extremely low *K/S* value of 0.165 after scouring. The *K/S* value of the fabric dyed only with the *Euphorbia* was 2.88, and that of the fabric dyed with the extract and 0.5% CNP was higher with a value of 3.72, which was consistent with the color change trend mentioned earlier.

Characteristics of air permeability

The air permeability of scoured cotton and dyed cotton with or without adding 0.5% CNP were investigated. As the result, the air permeability of each sample shown to slightly decreased to 149.4 when 0.5% CNP was added to the *Euphorbia* compared to the scoured cotton (150.6) and dyed cotton without 0.5% CNP (152.6). The viscous CNP seems to have acted as a binder to better attach the dye to the fabric, which is consistent with the color and dye uptake trends mentioned above.

Mechanical properties of the *Euphorbia* dyed cotton with and without CNP

The mechanical properties of the fabric dyed with 0.5% CNP were evaluated by analyzing the tensile, bending, shear, compression, thickness, and weight characteristics. Table 4 shows the results.

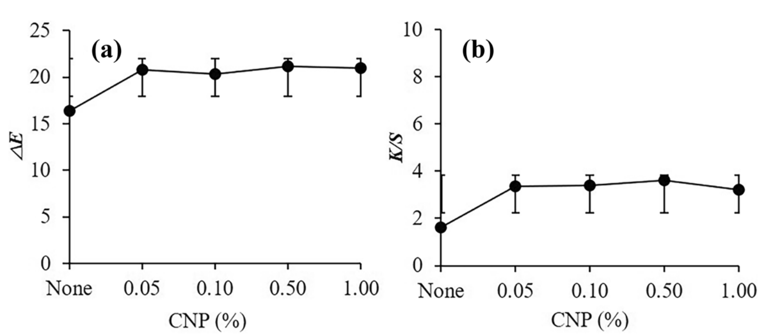

Fig. 1 Color difference and depth of cotton dyed with *Euphorbia* by different concentrations of cellulose nanoparticles (CNP). (**a**) ΔE (colordifference), (**b**) *K/S* value (color depth)

Table 4 Mechanical properties of cotton dyed with *Euphorbia* with and without cellulose nanoparticles (CNP)

Property	Parameter	Unit	Condition		
			Scoured	Dyed	Dyed with 0.5% CNP
Tensile	EM	%	14.30	13.48	13.57
	LT	–	0.62	0.66	0.66
	WT	g·cm/cm^2	22.25	22.25	22.50
	RT	%	29.68	25.83	27.65
Bending	B	–	0.07	0.08	0.08
	2HB	–	0.11	0.13	0.10
Shear	G	–	1.35	1.64	1.63
	2HG	–	3.28	4.47	4.39
	2HG5	–	5.44	6.73	6.97
Surface	MIU	–	0.20	0.20	0.17
	MMD	–	0.03	0.02	0.02
	SMD	μm	6.42	6.62	6.56
Compression	LC	–	0.34	0.29	0.26
	WC	gf·cm/cm^2	0.64	0.53	0.62
	RC	%	36.10	41.29	40.90
Thickness	T	mm	1.252	1.245	1.438
Weight	W	mg/cm^2	16.70	16.88	16.90

EM; Extensibility, LT; Load-extension ability, WT; Tensile energy, RT;Tensile resilience, B; Bending rigidity, 2HB; Hysteresis of bending moment, G;Shear stiffness, 2HG;Hysteresis of shear force at 0.5°, 2HG5; Hysteresis of shear force at 50°, LC; Coefficient of friction, WC; Mean deviation of MIU, RC; Geometrical roughness, MIU; Compression thickness, MMD; Energy for compression, SMD; Compression resilience, T; thickness, W; wight

Tensile properties are affected by the density of yarn, the number of warp and weft yarns, and crimp. The higher the EM, the better the stretch or extensibility. The EM of the dyed fabrics with and without CNP tended to decrease after dyeing. When 0.5% CNP was added, the EM value changed from 13.48 to 13.57, indicating a slight increase in extensibility. The smaller the load-extension ability (LT) value, the less fatigue due to pressure when wearing clothes, and the value increased 0.62–0.66 when dyeing with and without CNP, respectively, indicating a better fit in all conditions after dyeing. Tensile energy (WT) is the relationship between force and elongation, and the higher its value, the better the tensile strength. The WT after scouring and after dyeing without CNP were the same at 22.25, and increased to 22.5 after dyeing with CNP, but the difference was insignificant. The higher the tensile resilience (RT), the better the dimensional stability, and the value decreased from 29.68 to 25.83 and 27.65 when dyeing with and without CNP, respectively, showing a slight decrease in dimensional stability, but adding CNP to the extract also affected stability.

Bending is a property that determines various practical aspects of fiber aggregates. Bending rigidity (B) affects the sewing and handle, and the higher its value, the stiffer the material. The value increased from 0.07 to 0.08 when dyeing with and without CNP, respectively, resulting in a more flexible fabric. The smaller the hysteresis of bending moment (2HB), the higher the elasticity. The value increased from 0.11 to 0.13 after dyeing without CNP and was similar with CNP, indicating that adding CNP to the *Euphorbia* makes the fabric more elastic against bending.

Shear properties are related to the drape and have a significant influence on forming clothes. Shear stiffness (G) is related to the appearance and fit when wearing clothes. It was increased from 1.35 to 1.64 and 1.63 when dyeing with and without CNP, respectively, indicating an increase under all conditions after dyeing. The smaller the shear hysteresis (2HG), the more comfortable it is to wear. The value increased from 3.28 to 4.47 and 4.39 when dyeing with and without CNP, respectively, also increasing under all conditions after dyeing. The larger the G and 2HG values, the richer the garment's silhouette. The analysis results show an increase in both values, indicating a more voluminous look.

Compression properties are related to the resilience of the fabric. The smaller the compression linearity (LC), the better the compression. The value decreased from 0.34 to 0.29 and 0.26 when dyeing with and without CNP, respectively, resulting in better compression. In addition, the smaller the compression energy (WC), the smaller the resistance due to compression, and it increases in proportion to the compression thickness. Like compression linearity, the value decreased from 0.64 to 0.53 and 0.62 when dyeing with and without CNP, respectively. The lower the compression resilience (RC), the more difficult it is to recover elastically. The value increased from 36.09 to 41.29 and 40.9 when dyeing with and without CNP, respectively, indicating better shape stability against compression in all conditions when dyeing with the *Euphorbia*.

Surface properties are factors that affect the smoothness in relation to the physical properties of the fabric. These properties include the coefficient of friction (MIU), the standard deviation of MIU (MMD), and the standard deviation of the surface roughness (SMD), and the smaller their values, the smoother the surface. The MIU changed from 0.2 to 0.2 and 0.17 after dyeing with and without CNP, respectively, suggesting that the surface smoothness was improved by adding CNP. The MMD also decreased from 0.03 to 0.02 and 0.02 after dyeing with and without CNP, respectively, indicating that CNP has a significant effect on the smoothness of the fabric. On the other hand, the SMD increased from 6.42 to 6.62 and 6.56 after dyeing with and without CNP, respectively. In short, the analysis of the surface properties revealed that dyeing with CNP added to the *Euphorbia* enables a smoother fabric surface.

The thickness and weight are related to the practicality and hygiene of clothing. The thickness decreased from 1.252 to 1.245 mm when dyed without CNP, and slightly increased to 1.438 when CNP was added to the dyeing process. These results show that the thickness decreased simply due to the dyeing but also through the addition of CNP. In addition, the weight increased from 16.70 to 16.88 mg/cm^2 and 16.90 mg/cm^2 when dyeing with and without CNP, respectively, showing that dyeing and adding CNP affected weight increase. These results will affect the fabric's handle and lead to differences in the objective assessment of the fabric.

Handle evaluation

Handle evaluation was performed by measuring the KOSHI, NUMERI, and FUKURAMI and assessing the objective handle predicted according to the mechanical characteristics by PHV and THV. Figure 2 shows the results. KOSHI, which means stiffness, is a comprehensive expression of the resistance and resilience perceived when fabric is touched with the hands. The scoured cotton was 6.06, but the stiffness increased to 6.23 when

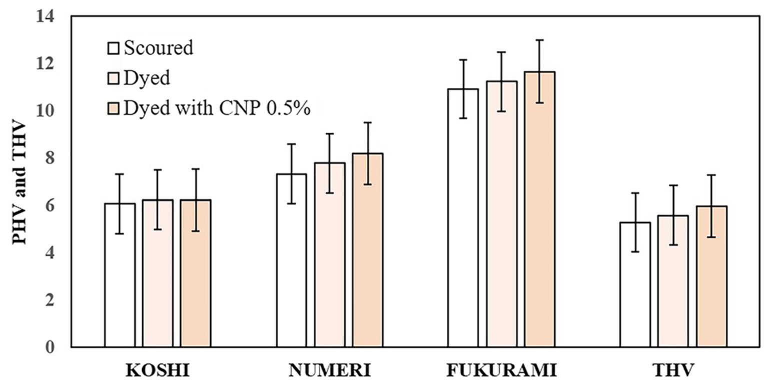

Fig. 2 PHV (primary hand value) and THV (total hand value) of cotton dyed with *Euphorbia* with and without CNP

Table 5 Colorfastness to washing, perspiration, rubbing and light of cotton dyed with *Euphorbia* with and without cellulose nanoparticles (CNP)

Sample	Washing		Perspiration				Rubbing		Light
	CC[a]	Stain	Acidic		Alkali		Dry	Wet	CC
			CC	Stain	CC	Stain			
Dyed	3	3–4	4–5	3	4–5	3	4–5	3	3
Dyed with 0.5% CNP	3	3	4–5	3	4–5	3	4–5	3	3–4

CC; color change

dyeing with and without CNP, respectively, indicating that the resilience and elasticity of the fabric improved. NUMERI is related to the surface properties that indicate the fabric's smoothness when touched by hand. The value increased from 7.32 to 7.77 and 8.17 when dyeing with and without CNP, respectively, indicating that adding CNP makes the fabric smooth. FUKURAMI is related to surface roughness, which expresses the fullness and softness felt when the fabric is held in the hand. It increased from 10.9 to 11.22 and 11.65 when dyeing with and without CNP, respectively, suggesting that the flexibility due to volume and compressive elasticity improved by adding CNP. The results show that the THV improved after *Euphorbia* dyeing compared to before, and improved even more by adding CNP.

Fastness to washing, perspiration, rubbing, and light

There are various methods for improving the fastness of cotton fabrics and the overall natural dyeability, but they are not easy. Table 5 shows the results of measuring the fastness to washing, perspiration, rubbing, and light according to the addition of CNP in cotton fabrics dyed with *Euphorbia*. There was no difference in the fastness to washing with or without CNP, as rating grades ranged between 3 and 4, and the effect of CNP on the fastness to sweat was also not significant. In general, naturally-dyed fastness to wet rubbing is not high, and the results in this study for fastness to dry and wet rubbing were both grade 3, showing no difference according to the addition of CNP to the dyeing process. The fastness to light was grade 3 when dyed only with the *Euphorbia*, but increased

Table 6 UV protection rate of cotton dyed with *Euphorbia* with and without cellulose nanoparticles (CNP)

Sample	UV Protection Factor (UPF)		UV Cut Ratio (%)	
	UPF (%)	Grade	UV-A	UV-B
Dyed	94.8	50+	98.5	99.0
Dyed with 0.5% CNP	99.2	50+	98.7	99.0

Table 7 Bacteria reduction rate of cotton dyed with *Euphorbia* with and without cellulose nanoparticles (CNP)

Sample	*Staphylococcus aureus*	*Klebsiella pneumoniae*
Scoured	66.7 (%)	58.3 (%)
Dyed	99.5 (%)	60.9 (%)
Dyed with 0.5% CNP	99.8 (%)	68.1 (%)

slightly to grade 3–4 after adding 0.5% CNP. The results above show that adding CNP to the natural dyeing of cotton fabrics has no significant effect on improving the fastness.

UV protection rate

Cotton fabrics generally provide better UV protection properties compared to thin silk fabrics. Table 6 shows the UV protection rate of scoured cotton and the fabrics dyed with or without CNP. The UV protection rate was slightly increased from 94.8 to 99.2% by adding 0.5% CNP to the dyeing process. The UV protection index was as high as 50+ in cotton, showing that the UV protection rate is very good. The UV-A increased from 98.5 to 98.7% by adding 0.5% CNP, but there was no difference in both cases in terms of UV-B (99.0%). As described above, in the case of cotton fabrics dyed with Euphovia, excellent UV protection properties were obtained regardless of whether CNP was added. It is believed that the effect of CNP in hydrogel state on UV protection is not as great as that of dyeing, and it is also presumed that there will be an effect such as the thickness or texture of the cotton fabric.

Antibacterial properties

Flavonoid compounds have antibacterial, anti-inflammatory, anti-allergic, and physiologically active functions that reduce oxidation in our bodies (An et al., 2006; Park & Han, 2015). Table 7 shows the antibacterial properties of cotton fabrics dyed with 0.5% CNP. It shows that adding CNP results in higher antibacterial properties against *Staphylococcus aureus*. Dyeing with CNP improved the antibacterial properties against *Staphylococcus aureus* and *Klebsiella pneumoniae* from 66.7% and 58.3% to 99.8% and 68.1%, respectively. This is because a stronger bond can be formed by adding CNP to the *Euphorbia* containing flavonoid compounds. That is, as described above, by adding weakly acidic CNP with a pH of 5.9 to the *Euphobia* extract, rutin, the main component, was hydrolyzed to quercetin, and it was able to bind with the dye. It is expected that these results may also have an effect on the antibacterial properties. Since CNP itself is 100% cellulose, antibacterial properties cannot be discussed. However, as in the antibacterial results, it was found that even if CNP was added, the dyeing property was improved, but the antibacterial property was not decreased.

Conclusions

This study measured the color and dye uptake, analyzed the fastness to washing, perspiration, rubbing, and light, and compared air permeability, evaluated the mechanical properties, and compared the UV protection and antibacterial properties to assess the function, dyeability, and mechanical properties of cotton fabrics dyed with *Euphorbia* using CNP. The main findings are as follows.

Dyeing with *Euphorbia* using cellulose nanofibers improved color and dye uptake. The ΔE and K/S values were also significantly different and higher. The air permeability was slightly decreased when using the *Euphorbia* and CNP together. In terms of mechanical properties, adding CNP resulted in better tensile properties, and improved elasticity and elastic recovery. The shear properties showed enhanced volume, and the compression characteristic suggested excellent shape stability. Through analyzing the surface properties, it was found that adding CNP led to a smoother surface. Both the thickness and the weight also increased. The objective handle assessment, the THV values according to the primary hand values increased to 5.28, 5.58, and 5.96 in the untreated, dyed, and dyed samples with CNP, respectively. In addition, the fastness to washing, sweat, and rubbing was not affected by CNP, and the fastness to light was improved by 0.5 in the cotton fabric dyed with CNP. The UV protection property was high regardless of the addition of CNP, and the antibacterial properties were excellent in all conditions after dyeing but were improved even more when adding CNP. Accordingly, it can be seen that the addition of CNP to the cotton contributes to the improvement of dyeability and mechanical properties. Therefore, this study investigates whether CNP can be utilized for dyeing in the future, and the use of CNP is a CNP-induced finishing process to improve the comfort of cotton fabrics rather than a success point of dyeing.

Author contributions

The author conceived the work, prepared the samples and performed the experiments. YP conducted the sequence alignment and drafted the manuscript. The author read and approved the final manuscript.

Authors' information

Youngmi Park is a professor at the Yeungnam University.

Funding

This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Korea government (MSIT) (No. NRF-2021R1A2C1012802).

Availability of data and materials

The data sets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

Received: 27 May 2022 Accepted: 10 October 2022
Published online: 25 January 2023

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