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UV PROTECTION OF COTTON – THE INFLUENCE OF WEAVING STRUCTURE

Due to the depletion of the ozone layer, shorter but high energy UV–B rays and longer energy UV–A rays causing known skin aging and recently the formation of skin malignant neoplasm are reaching the surface of earth. The paper deals with the influence of different fabric construction on ultraviolet skin protection expressed as the ultraviolet protection factor (UPF). It is well known that clothing provides some protection against damage by ultraviolet radiation, but it highly depends on fabric construction, especially for longer exposure to sun light. Fabric openness or porosity is a key parameter influencing ultraviolet (UV–R) transmission. The effect of fabric density and cover factor using twelve woven fabrics from the same cotton fibres and yarn count, but different in type of weaving and fabric density were investigated. UPF and UV–A and UV–B transmission were measured using a transmission spectrophotometer Cary 50 Solarscreen (Varian) according to the AATCC Test Method 183–2000.

The solar radiation that reaches the Earth's surface is a spectrum in the range of 280 nm to 3000 nm, consisting of ultraviolet (UV), visible (VIS) and infrared (IR) radiation. UV–Radiation (UV–R) is divided into UV–A (from 400 to 320 nm), UV–B (from 320 to 280 nm) and UV–C (below 280 nm). The ozone layer absorbs short UV–C rays, but the consequence of the depletion of the ozone layer is that high energy UV–B rays and UV–A rays are reaching the Earth's surface. Even though UV–A rays are necessary for vitamin D synthesis, longer exposure to UV–A and UV–B rays can cause acute and chronic reactions and damages such as erythema (sunburn), sun tanning, photocarcinogenesis and "photoaging", as well as known skin aging and, recently, the formation of skin malignant neoplasm [1–11].

It is well known that clothing provides some protection from ultraviolet radiation [11–20]. Fabric, as other materials, can reflect, absorb and scatter solar wavelengths.

The UV protecting ability of garments and sun–screening textiles depends on a large number of factors, such as the type of fiber, porosity, density, moisture content, type and concentration of dye, FWA and UV protective agents, if applied. UV protection highly depends on fabric construction, especially for longer exposure to the sun. Fabric thickness, openness or porosity are the key parameters that influence ultraviolet transmission.

It is well known that fabrics treated under wet conditions, such as scouring and bleaching, undergo some structural changes reflected in higher density but in lower porosity. For this purpose, in the present investigations, the cotton fabrics were scoured. Therefore, it was of interest to study the influence of different fabric construction on ultraviolet skin protection expressed as the ultraviolet protection factor (UPF).

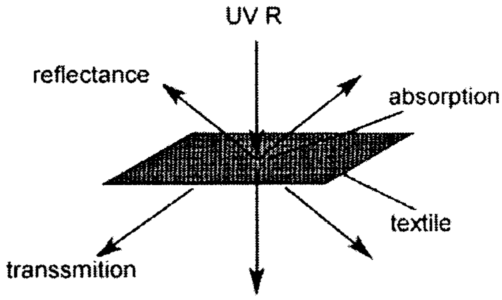

Figure 1. UV–Radiation on textile fabric

Our research focused on the effect of fabric density and cover factor using twelve woven fabrics from the same raw cotton, yarn count but different in type of weaving and fabric density. The surface mass and air permeability were determined by ISO standards, and the ultraviolet protection factor (UPF values) and UV–A and UV–B transmission of the fabrics were measured using a transmission spectrophotometer Cary 50 Solarscreen (Varian) according to the AATCC Test Method 183–2000.

Ultraviolet protection factor, UPF

Solar UV protective properties of apparel fabrics can be measured according to different standard methods [16–20], but all of these are based on the determination of the ultraviolet protection factor (UPF). The UPF is the ratio of the average effective UV radiation (UV–R) irradiance transmitted through air to the average effective UV–R irradiance transmitted through the fabric. It can be calculated using equation 1:

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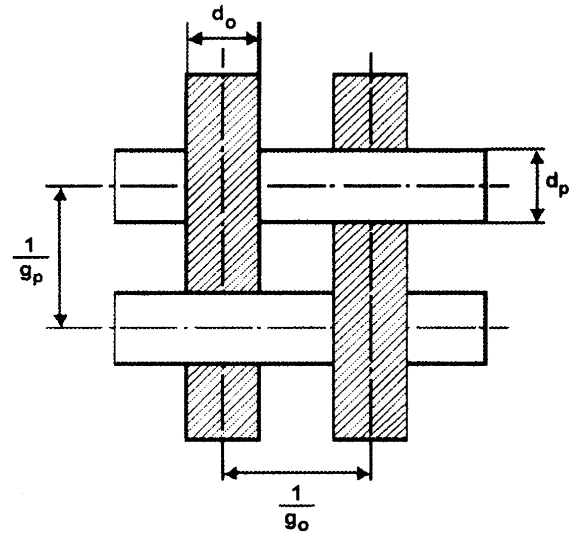


Figure 2. Fabric element

$$UPF = \frac{\sum_{\lambda=290}^{400} E(\lambda) \cdot S(\lambda) \cdot \Delta\lambda}{\sum_{\lambda=290}^{400} E(\lambda) \cdot T(\lambda) \cdot S(\lambda) \cdot \Delta\lambda} \quad (1)$$

where:

$E(\lambda)$ = the relative erythemal spectral effectiveness

$S(\lambda)$ = solar spectral irradiance [W m^{-2} nm^{-1}]

$\Delta\lambda$ = the measured wavelength interval [nm]

$T(\lambda)$ = the average spectral transmittance of the specimen

The ultraviolet protection factor indicates how much longer the person can stay in the sun with the fabric covering the skin as compared with uncovered skin to, obtain the same erythemal response.

Fabric percent cover (P_t)

The geometric pointer to scale density of the fabric (woven, knitted) produced with yarn of different fineness usually is the cover factor or percent cover of warp (P_o), weft (P_p) or fabric percent cover (P_t) [13]. The fabric percent cover (P_t) is defined as the ratio of the projected fabric surface area covered by yarns (warp and weft) to the total fabric surface area (Fig. 2) [21].

The percent cover can be calculated according to (2–4):

$$P_o(\%) = g_o \cdot d_o \cdot 100; \quad (2)$$

where P_o (%) = the percent cover of warp,

g_o = the warp density, d_o = the warp thickness

$$P_p(\%) = g_p \cdot d_p \cdot 100; \quad (3)$$

where P_p (%) = the percent cover of weft,

g_p = the weft density, d_p = the weft thickness

$$P_t(\%) = P_o + P_p - P_o \cdot P_p \cdot 100; \quad (4)$$

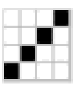
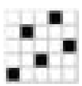
where $P_t(\%)$ = the fabric percent cover.

EXPERIMENTAL

For the purpose of this study twelve woven fabrics were produced in three weaves (Figure 3). Each weave had a variation of warp (g_o) and weft (g_p) density (Table 1). All the fabrics were made using cotton yarn, warp fineness Tt_o = 17x2 = 34 tex and weft fineness Tt_p = 30 tex. The fabrics were alkali-scoured in a bath containing NaOH and anionic surfactant, neutralized and rinsed till pH 7 was achieved.

The yarn thickness was measured using the photoelectrical method and recalculated from 10000 measurement results for every mm of yarn [21]. The fabric surface mass, m was determined according ISO

Table 1. Weaves, labels, density and surface mass of the raw and scoured woven fabrics

WEAVE	LABEL	RAW			SCOURED		
		g_o [thread/cm]	g_p [thread/cm]	m [g/m^2]	g_o [thread/cm]	g_p [thread/cm]	m [g/m^2]
plain P 1/1 	P1	32	18	175,33	33	20	187,00
	P2	16	20	121,07	18	24	131,87
	P3	21	16	126,00	22	18	136,47
	P4	24	16	141,11	25	18	156,67
twill K 1/3 Z 	K1	32	23	189,80	34	26	204,73
	K2	16	25	136,93	18	25	151,47
	K3	21	20	139,73	23	23	153,47
	K4	24	16	134,73	25	18	147,80
satin A 1/4 (2) 	A1	32	27	202,53	34	29	215,07
	A2	16	25	132,53	18	27	142,47
	A3	21	20	138,47	23	22	151,40
	A4	24	16	133,27	26	18	145,47

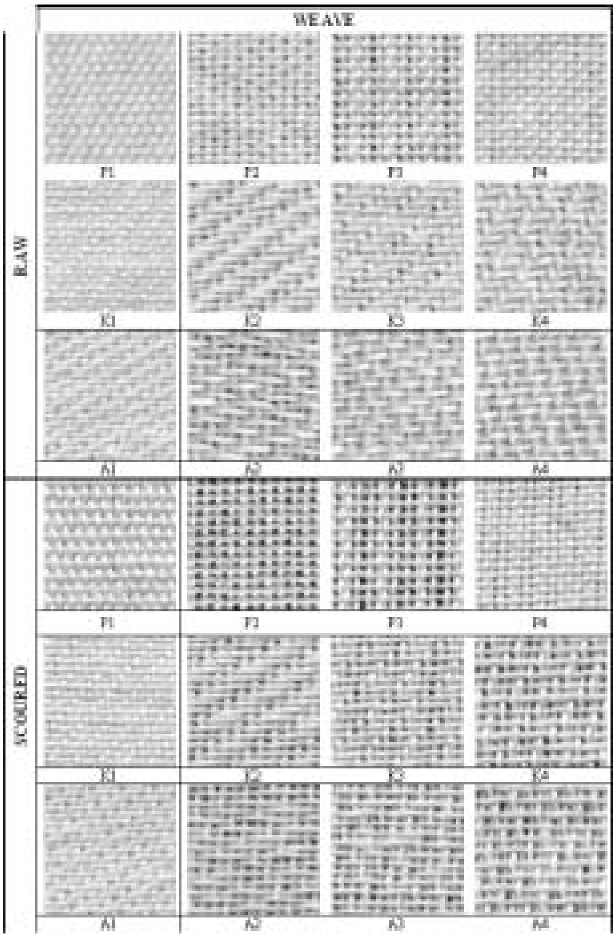


Figure 3. Fabrics 10x magnified

3801:1977 *Textiles – Woven fabrics – Determination of mass per unit length and mass per unit area*; air permeability, AP according to ISO 9237:2000 *Textiles – Determination of the Permeability of Fabrics to Air*. The UPF values and UV–A and UV–B transmission, $T(\lambda)_{UVA+UVB}$ were measured on a transmission spectrophotometer Cary 50 Solarscreen (Varian) according to the AATCC Test Method 183–2000 – *Transmittance for blocking of erythemaly weighted ultraviolet radiation through fabrics*.

RESULTS AND DISCUSSION

The cotton woven fabrics in this paper were alkali-scoured in order to investigate the influence of structural changes on UV protection. The results presented in Table 1 show an increase of fabric density. Even though impurities such as pectin, waxes etc. removed from the cotton during the scouring process, increase of the warp and weft density results in fabric surface mass increase. Figure 3 shows differences in the density of the fabrics.

Yarn thickness measurement (d_o, d_p) by the photoelectric method resulted in:

d_o = 0.4022 mm and

d_p = 0.3387 mm.

Table 2. Percent cover of warp (P_o), weft (P_p) and fabric percent cover (P_t) of the raw and scoured fabrics

LABEL	RAW			SCOURED		
	P_o [%]	P_p [%]	P_t [%]	P_o [%]	P_p [%]	P_t [%]
P1	128.70	60.97	111.20	132.73	67.74	110.56
P2	64.35	67.74	88.50	72.40	81.29	94.83
P3	84.46	54.19	92.88	88.48	60.97	95.50
P4	96.53	54.19	98.41	100.55	60.97	100.21
K1	128.70	77.90	106.34	136.75	88.06	104.39
K2	64.35	84.68	94.54	72.40	84.68	95.77
K3	84.46	67.74	94.99	92.51	77.90	98.34
K4	96.53	54.19	98.41	100.55	60.97	100.21
A1	128.70	91.45	102.45	136.75	98.22	100.65
A2	64.35	84.68	94.54	72.40	91.45	97.64
A3	84.46	67.74	94.99	92.51	74.51	98.09
A4	96.53	54.19	98.41	104.57	60.97	101.78

The cover factor [%] for the raw and scoured woven cotton fabrics was recalculated from these values according to equations 2–4. The percent cover of warp (P_o) and weft (P_p) and the fabric percent cover (P_t) of the raw and scoured fabrics are presented in Table 2.

The fabric percent cover also confirms fabric shrinkage during alkali-scouring. Exceptions are fabrics with the highest fabric density P1, K1, A1, because they already have the maximum number of threads and there is no interspace for shrinkage. As the shrinkage is higher, the fabric cover factor is larger. According to Table 2, plain–woven fabrics have the highest cover factor between the woven fabrics with the same number of threads. Twill and satin woven fabrics of the same density and yarn fineness are more porous than plain woven fabrics. Analyzing the slot through plain woven fabric, there are two warps and two wefts, which present the total thickness of four threads. Twill weave gives four wefts and two warps, which makes a total thickness of six threads. Satin weave has five wefts and two warps, which makes a total thickness of seven threads. That means that the filling factor for plain woven fabric is 4/4 = 1.00, for twill 4/6 = 0.67 and for satin only 4/7 = 0.57 presenting the fabric of lowest porosity. This is the same rule for fabric warp or weft direction.

For this reason, air permeability (AP) values depend on fabric weaves (Table 3). Shrinkage during scouring also caused lower air permeability. Plain–woven cotton fabric had the lowest air permeability value, while satin woven had the largest one.

The influence of woven cotton fabric structure on UV protection was investigated in this paper. UV protection was represented by the ultraviolet protection factor, UPF. The total UV–A and UV–B transmission expressed as $T(\lambda)_{UVA+UVB}$ was measured using a transmission

Table 3. Air permeability, AP, UV–A and UV–B transmission, T(λ)UVA+UVBand UPF values of the raw and scoured woven fabrics

LABEL	RAW			SCOURED		
	AP [l/h mm WC cm^2]	T(λ) UVA+UVB	UPF AATCC	AP [l/h mm WC cm^2]	T(λ) UVA+UVB	UPF AATCC
P1	16.36	4.16	56.96	8.67	3.96	62.85
P2	51.43	35.24	5.71	37.89	22.18	9.23
P3	60.00	28.18	7.22	36.00	13.40	15.72
P4	36.00	22.33	10.71	21.18	11.11	17.49
K1	15.00	2.55	111.10	9.23	3.54	113.52
K2	45.00	33.33	6.06	36.00	15.15	13.84
K3	60.00	23.85	8.53	27.69	12.86	16.09
K4	45.00	26.76	7.57	41.50	14.68	14.13
A1	12.41	1.99	140.52	9.47	1.81	166.15
A2	90.00	37.95	5.29	60.00	18.85	10.51
A3	72.00	21.37	9.50	51.43	12.49	16.84
A4	90.00	25.40	7.95	60.00	9.48	12.38

spectrophotometer Cary 50 Solarscreen (Varian), according to the AATCC Test Method 183–2000. The results are presented in Table 3. The mean UPF values for the raw and scoured cotton fabrics are shown in Figure 4.

Compared to raw cotton the UPF values of the scoured cotton fabric are higher (Table 3 and Figure 4), which is expected due to the fabric shrinking during the scouring process. All three woven fabrics with the highest density (P1, K1 and A1) give excellent UV protection. Additionally, UV protection depends on the weave of the woven fabric according to the UPF results. Twill and satin woven fabrics have lower density than plain woven ones, so their UVF are lower. It was important to analyze the UPF values of woven cotton fabrics of the same weave. Plain–woven fabrics P2 and P3 have almost the same number of threads, but they give different UV protection because of different waft and werp thickness, where the weft is 18% thicker than the warp. The UV protection of twill (K2 and K4) and satin (A2 and A4) woven fabrics show the same phenomena.

The UPF directly depends upon the UV–A and UV–B transmission of the fabric, the transmission depends upon the fabric cover factor. Correlations between the percent cover and the total transmission UV–A and UV–B were investigated and presented in Figures 5a–c.

The cover factor (percent cover) is important for UV–A and UV–B transmission and also for UV protection. All the trends for raw and scoured cotton fabrics are linear and similar, but the correlation factor depends upon the type of fabric weave.

Plain–woven raw and scoured cotton fabrics (Figure 5a) have a very high correlation factor, R = 0.98. Twill woven fabric has a slightly lower correlation factor, R = 0.92 (Figure 5b). The correlation is lower for satin woven fabrics, but for this weave a larger number of

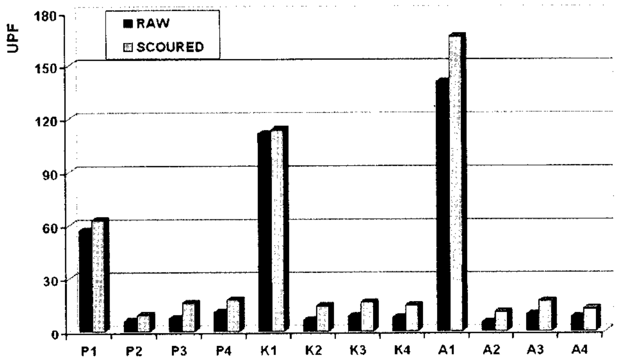


Figure 4. Mean UPF values of the raw and scoured cotton woven fabrics

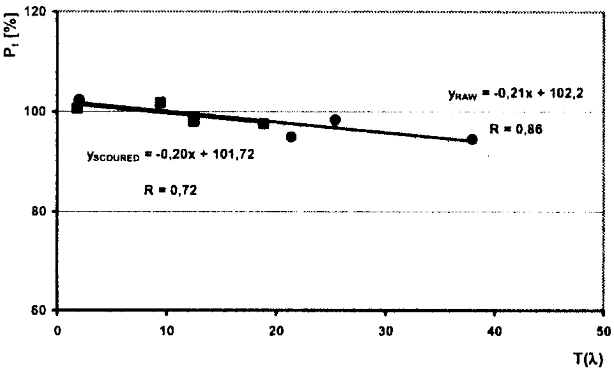


Figure 5. Correlation between UV–A and UV–B transmission through the fabric and fabric percent cover in a) plain, b) twill and c) satin woven fabrics.

satin fabrics with a wide range of fabric density is needed for discussion on the subject.

CONCLUSION

The UV protection of textile fabrics depends on the construction parameters. As higher fabric density results in a higher fabric surface mass and a higher fabric cover factor, UV–A and UV–B transmission decrease and UV protection increases. Woven fabrics shrink during alkali scouring, which results in increasing fabric density and cover factor and UV protection. Plain–woven cotton fabrics give better UV protection than twill and satin woven fabrics due to the higher filling factor. Not only the fabric type of weave, but also the warp and weft density, yarn structure and fineness, have an important role in UV protection.

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IZVOD

UV ZAŠTITA PAMUKA – UTJECAJ KONSTRUKCIJE TKANINE

(Naučni rad)

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Pojavom rupa u ozonskom omotaču olakšano je dopiranje i kraćih ultraljubičastih zraka visoke energije (UV–B) do površine Zemlje. UV–B zrake, kao uostalom i UV–A zrake, uzrokuju tamnjenje kože koje se stručno naziva starenje te u zadnje vrijeme sve češći zloćudan melanom kože. Poznato je da odjeća štiti kožu od ovih zraka jer je prepreka njihovoj transmisiji do kože. Međutim, na stupanj zaštite značajno utječe konstrukcija materijala poglavito kod dužeg izlaganja Suncu. Ovaj rad je fokusiran na istraživanje utjecaja gustoće i pokrivnog faktora (pokrivenosti) pamučne tkanine na zaštitu od UV zračenja. U tu svrhu istkano je 12 pamučnih tkanina iz istovrsnog vlakna, iste finoće pređe, ali različitog veza i gustoće tkanine. Pored parametara konstrukcije uzorcima tkanina izmjeren je faktor zaštite od ultraljubičastog zračenja (UPF), te transmisija UV–A i UV–B zračenja na transmisijskom spektrofotometru Cary 50 Solarscreen (Varian) prema standardnoj metodi AATCC Test Method 183–2000.

Pokazalo se da UV zaštita ovisi o strukturi tkanine. Veća gustoća tkanine, rezultira većom površinskom masom i većom pokrivenošću i popunjenošću tkanine, čime se smanjuje transmisija UV–A i UV–B zračenja. Smanjenjem transmisije povećavaju se UPF vrijednosti koje su indirektan pokazatelj povećanja UV zaštite. Alkalnim iskuhavanjem pamučnih tkanina dolazi do njihovog skupljanja čime se povećava gustoća tkanine, njena pokrivenost, a time i UV zaštita. Tkanine u platno vezu zbog većeg faktora popunjenosti pružaju bolju UV zaštitu od tkanina u drugim vezovima. Osim vrste veza važnu ulogu u UV zaštiti imaju gustoća osnove i potke, te vrste i finoća pređe.

Ključne riječi: Pamučne tkanine • Struktura tkanine • Poroznost • UV zaštita •

Key words: Cotton fabrics • Weaving structure • Density • Porosity • UV protection •