ELSEVIER
SAUNDERS

Dermatol Clin 24 (2006) 85 – 100

DERMATOLOGIC
CLINICS

Garments As Solar Ultraviolet Radiation Screening Materials

Kathryn L. Hatch, PhD[a], Uli Osterwalder, MS[b,*]

[a]*Agricultural and Biosystems Engineering, University of Arizona, Tucson, AZ, USA*
[b]*Ciba Specialty Chemicals, Basel, Switzerland*

Although wearing clothing to protect one's skin from the harmful rays of the sun is not new practice, this practice is of recent increasing interest. This article discusses 1) three types of protection (sunburn, precancerous skin lesion development, and photoaging) that can be realized by covering the skin with fabric, 2) the process by which some garmets come to be labeled with information about ultraviolet (UV) radiation protection advantage, 3) the meaning of the information provided on product labels, 4) practical guidelines that can be used to decide which summertime garments having no stated sun protection information are the best for wearing out-of-doors, and 5) the pros and cons of using fabric and sunscreen lotions for sun protection. Although this article covers information that has been reviewed previously [1–4], it also conveys new information and takes a different approach to explaining about how garments act as solar radiation screening materials. This should provide clear answers to questions most frequently asked.

This article covers four main topics. The first topic is about the types of sun protection—sunburn protection, precancerous skin lesion development protection, and photoaging protection—that can be realized by covering the skin with fabric. New unpublished information is provided about photoaging protection to fabric-covered skin. The second topic centers on the process by which some garments come to be labeled with information about ultraviolet radiation protection advantage and about the meaning of the information provided on the product label. These are the garments that form a special classification of garments called sun-protective or UV-protective garments. By definition, sun-protective clothing is an item of personal apparel (including garments, hats, shoes, and fabric intended to be made into personal apparel) for which a claim of protective advantage against solar ultraviolet radiation is made [5]. A UV-protective textile is any textile whose manufacturer or seller claims that it protects from sunlight, including harmful UV light, claims the reduction of risk of skin injury associated with UV exposure, or uses a rating system that quantifies the amount of sun protection afforded [6]. There is no wording in these definitions that delineates/specifies a specific skin injury associated with UV radiation. The definitions are clear, however, that the claims are for UV radiation from the sun, not from other sources. Claims currently being made are for sunburn protection, but that wording rarely is used on product labels. The third topic is about guidelines individuals can use to assist in deciding which garments (that have no stated sun protection performance) would be the best selection for a summer day out-of-doors activity. The fourth topic compares and contrasts the use of fabric and sunscreen lotions for sun protection effectiveness. Finally, the article summarizes the concepts.

Types of protection

This section describes test methods used to quantity the sunburn protection provided to skin by covering it with fabric. It also describes results of

* Corresponding author. Ciba Specialty Chemicals, Klybeckstrasse 141, R-1045.2.12, CH4002, Basel, Switzerland.
E-mail address: uli.osterwalder@cibasc.com
(U. Osterwalder).

0733-8635/06/$ – see front matter
doi:10.1016/j.det.2005.09.005
derm.theclinics.com

experiments in which fabrics differing in sunburn protection capability were used to investigate the capability of fabric to prevent or slow the occurrence of precancerous skin lesions or skin photoaging.

Sunburn protection

The fundamental evidence that fabric protects against erythema is the condition called farmer's tan. The areas of skin not covered by fabric, often the lower arms and the neck, are the first to tan (darken) or burn (redden). There are two major methods to assess the amount/degree of sunburn protection provided by various fabrics: the in vivo method and the in vitro method.

In vivo method

The in vivo method is one that closely parallels the method used to assess the effectiveness of sunscreen lotions, that is to determine the sun protection factor (SPF) of the lotion. The major difference is that fabric is placed on the skin surface rather than spreading sunscreen lotion over the skin surface. Fabric SPF can be determined with Eq. 1:

$$\mathrm{SPF} = \frac{\begin{array}{l}\text{Radiation dose to produce}\\ \text{just perceptible erythema}\\ \text{under fabric covered skin}\end{array}}{\begin{array}{l}\text{Radiation dose to produce}\\ \text{just perceptible erythema}\\ \text{of uncovered skin}\end{array}} \qquad (1)$$

In vitro method

The in vitro method is also called the instrumental method, because a spectrophotometer is used. This method has an in vivo component to it. The two major steps in this procedure are transmittance testing and calculations based on the transmittance data collected. To obtain transmittance data, a fabric swatch is placed in a spectrophotometer equipped with an integrating sphere. The procedure is to direct a beam of radiation composed of one wavelength in the UV light and of known quantity perpendicular to the surface of the fabric swatch and to measure the amount of radiation transmitted through the fabric. The sending of beams of radiation continues until all wavelengths in the UV range (or in some tests the wavelengths at 2 or 5 nm intervals) have been directed to the fabric face and transmittance data collected. Once the transmittance data have been collected (usually by measuring the UV transmittance of several swatches of the same fabric to take into account variation in fabric uniformity), they are used to calculate percent transmittance values (percent UVA, percent UVB, or a total percent transmittance value), a fabric–ultraviolet protection factor (UPF) value, or a percent penetration value (1/UPF).

Percent transmittance

The calculation of total UV percent transmittance for a fabric is the ratio of the amount of radiation transmitted to the amount of radiation directed perpendicular to the fabric swatch surface. The calculation of the percentage of UVB transmitted through the fabric is the same, except only the data from the UV rays in the UVB region are used. Likewise, the calculation of the percentage of UVA transmitted involves only the data when UVA was directed at the fabric surface. Percent transmittance data do not take into account that certain wavelengths in the UV range are more responsible for skin damage than others. A fabric that allows a high proportion of UVA may be quite effective in preventing sunburn, as sunburning is linked to UVB radiation.

Fabric–ultraviolet protection factor value. The calculation of a UPF value is accomplished by combining the transmittance data with data collected that established the relative power of UV wavelengths to cause the skin to redden. These latter data, data collected using human subjects, are given in the erythemal action spectra [7]. The importance of using the erythemal action spectra data in a protection calculation is that fabrics that allow a greater portion of the most powerful skin reddening rays to be transmitted will receive a numerical value lower than a fabric that allows less of the powerful skin reddening rays through, even when both fabrics transmit the same amount of radiation. UPF can be calculated as in Eq. 2:

$$\mathrm{UPF} = \frac{\sum_{\lambda=290}^{400} E(\lambda)\cdot S(\lambda)\cdot \Delta\lambda}{\sum_{\lambda=290}^{400} E(\lambda)\cdot T(\lambda)\cdot S(\lambda)\cdot \Delta\lambda} \qquad (2)$$

where $E(\lambda)$ is the relative erythemal spectral effectiveness, $S(\lambda)$ is the solar spectral irradiance ($W\ m^{-2}\ nm^{-1}$), $\Delta\lambda$ is measured wavelength interval (nm), and $T(\lambda)$ is average spectral transmittance of the specimen.

The definition of UPF is that it is the ratio of average effective UV radiation irradiance transmitted and calculated through air to the average effective

UVR irradiance transmitted and calculated through fabric. The UPF value calculated therefore indicates how much longer a person can stay in the sun when fabric covers the skin as compared with the length of time in the sun without fabric covering to obtain same erythemal response. The endpoint is generally just perceptible skin reddening. Specific details on how to conduct transmittance testing, and use the transmittance data to calculate a UPF value for the fabric tested can be found in the following standard documents developed by committees within national, regional, or international standard setting organizations:

- ***AS/NZS 4399 (1996):*** Sun protective clothing evaluation and classification [5]
- ***American Association of Textile Chemists and Colorists 183-2000:*** Transmittance or blocking of erythemally weighted ultraviolet radiation through fabrics [8]
- ***BS 7914 (1998):*** Method of test for penetration of erythemally weighted solar ultraviolet radiation through clothing fabrics [9]
- ***EN 13758-1 (2001):*** Textiles—solar UV protective properties. Part 1: method of test for apparel fabrics [10]

Penetration/weighted transmittance. Another expression of sunburn protection is penetration or erythema weighted transmittance. It is calculated as the inverse of UPF (1/UPF). The significance of 1/UPF is that the resulting value lies between 1 and 0 (or 100% and 0%). The interpretation is that the lower the percent or the closer to zero the value is, the greater the sunburn protection provided by the fabric. In contrast, the UPF value has virtually no upper limit to indicate the protection provided.

Comparison of sun protection factor and ultraviolet protection factor values

Theoretically, the UPF and SPF value for any fabric should be the same, given the same incident spectral distribution on the fabric specimens used. As Menter and Hatch [3] concluded after reviewing studies in which swatches of the same fabrics were used in in vivo and in vitro tests, however, statistically identical results do not result. It is possible, however, that the development of a standard in vivo procedure that takes into account the results of UPF/SPF comparison studies might lead to a procedure in which in vivo results would be correlated more perfectly with in vitro results. Additionally, it has been shown (Fig. 1) that a good correlation between the UPF and SPF values can be achieved, provided the garment is covering the skin uniformly [11].

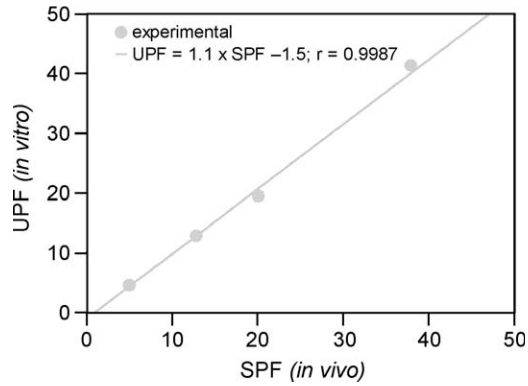


Fig. 1. Regression correlation curve between UPF and SPF. (*Data from* Osterwalder U, Rohwer H. Improving UV protection by clothing—recent developments. Recent Results Cancer Res 2002;160:62–9.)

Precancerous skin lesion protection

Two dermatologists [12,13] have reported cases in which either the appearance of or number of skin tumors on the patient's body seemed directly related to type of clothing worn. In 1991, Bech-Thomson and colleagues [12] reported that their xeroderma pigmentosum patient had marked improvement in skin condition after she started and continued to wear leather and denim skirts that transmitted little UV. In 1998, O'Quinn and Wagner [13] observed that their male patient (Fig. 2), who worked outside almost every day, had markedly fewer skin cancers under the yoke areas of his shirt than under other areas of his shirt. They concluded that the skin was more protected by the double layer of fabric forming the yoke (front and back) than by the single layer of fabric forming the body of the shirt.

It was Menter and his research team [14,15] who conducted two studies to determine the ability of fabric to reduce the production of skin tumors. In other studies, hairless albino mice were used. In the study described here, the skins of the mice were not photosensitized. In the other study they were. Sk-1 hairless albino mice—whose skins either were covered with a fabric with an SPF of greater than 30, a fabric with an SPF of 6.5, or not covered (the control)—were irradiated with UV radiation using a dose regimen seven-fold higher than that used to produce squamous cell cancer in unprotected hairless mice. The outcome of the experiment illustrated by photographing one of the mice in each group and presented in Fig. 3, was that the fabric with an SPF of greater than 30 protected against premalignant lesions better than the fabric with an SPF of 6.5. There was no protection improvement, however, by the fabric with

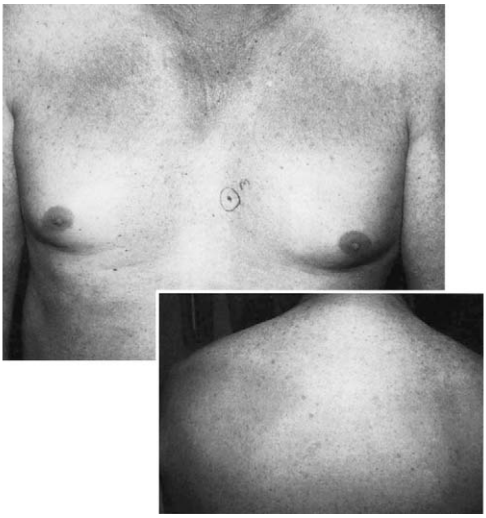


Fig. 2. Precancerous skin lesions under various sections of a shirt. (*From* O'Quinn RP, Wagner RF. Unusual patterns of chronic photodamage through clothing. Cutis 1998;61: 269–71; with permission. © 1998, Quadrant HeathCom, Inc.)

an SPF of 6.5 compared with the control. One would expect that fabrics with higher SPF/UPF values to provide more protection against the development of precancerous tumors, because it is primarily UVB radiation that is involved in skin cancer development.

Photoaging protection

The possible reduction of photoaging of skin by covering it with fabric was just recently studied [16]. Over a 3-month period, skin of volunteers of Asian origin were protected by two different fabrics or left bare. Specifically, the fabrics were:

1. ***Non–UV-enhanced fabric:*** Cotton T-shirt fabric TF 437W, tubular, 124 g/m2 (Test Fabrics Incorporated, Middlesex, New Jersey)
2. ***UV-enhanced fabric:*** Cotton T-shirt fabric TF437W treated with three washes in household washing machine (Miele Deluxe Electronic W724) at 40C (cotton program) with a common laundry detergent containing 0.25% of the UV-cutting agent (UVCA) Tinosorb FD (Ciba Specialty Chemicals Incorporated, Basel Switzerland)

The UPF values of the unwashed and UVCA-washed fabrics were determined as UPF 4 and UPF 13 respectively, using the Australian standard [5]. Biophysical parameters of skin color, skin moisture content, skin wrinkling, and skin elasticity were determined as a function of exposure to UV radiation. Irradiation was performed three times a week for 12 weeks with less than one mean effective dose monthly adjusted (effective dose UVA 320–400 nm [24–26 J/cm^2], UVB 280–320 nm [0.04–0.06 J/cm^2]) using a Multiport 601 150W Solar Light Simulator (Solar Light Company, Philadelphia, Pennsylvania).

Skin-darkening protection

Darkness of skin was assessed using a Minolta CM-508i Chromameter (Konica Minolta, Hannover, Germany) yielding the color in L-a-b coordinates. As shown in Fig. 4, fabrics can efficiently prevent tan-

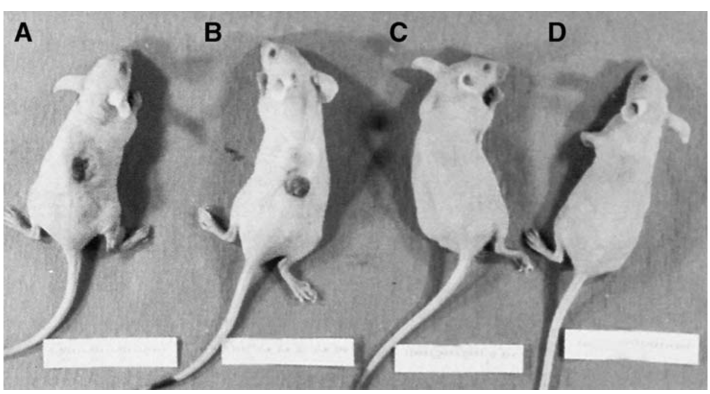


Fig. 3. Clinical appearance at 24 weeks of Sk-1 hairless mice irradiated with solar-simulating (SSR) for 12 weeks. (*From* Menter JM, Hollins TD, Sayre RM, et al. Protection against UV photocarcinogenesis by fabric materials. J Am Acad Dermatol 1994;31:711–6; with permission.) (*A*) A mouse from the group irradiated with 5960 J/cm^2 SSR in absence of fabric, with squamous cell carcinoma (SCC). (*B*) A mouse from the group irradiated with 3460 J/cm^2 SSR through typical fabric (SPF 6.5 ± 1.0). Note development of SCC. (*C*) A mouse from the group irradiated with 3460 J/cm^2. (*D*) Normal unradiated control mouse.

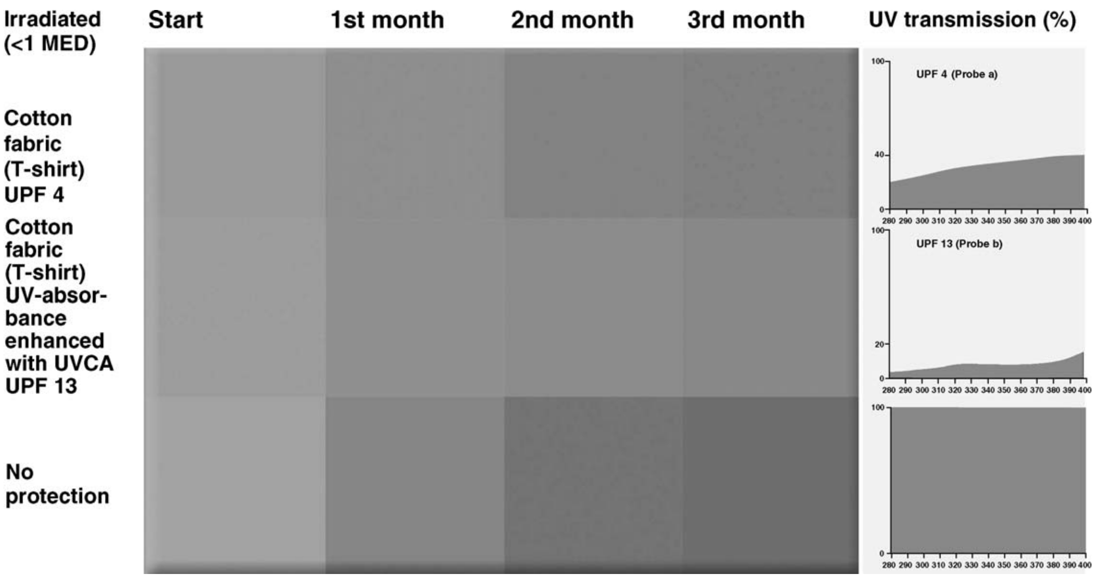


Fig. 4. Pigmentation of fabric-covered and -uncovered skin over a 3-month period of sun exposure.

ning. Tanning can be seen as a surrogate for various other kinds of photodamage. There is significantly better protection by the UPF-13 fabric as compared with the UPF-4 fabric. As can be seen in the figure, there was also adequate (ie, balanced) UVA protection in these studies. With inferior UVA protection as is the case with some types of sunscreens, one would expect more tanning. To completely avoid any sign of tanning (skin pigmentation), UPF greater than 15 is required under the regime of irradiation used in the study.

Skin moisture retention protection

Skin exposed to sun has reduced moisture content. To determine whether skin covered with fabric reduced the degree of skin moisture loss, skin moisture content was determined before and after irradiation using a Corneometer (Courage + Khazaka Electronic GmbH, Köln, Germany) skin conductivity/capacitance instrument. The results in Fig. 5 show that the skin moisture content drops considerably with UV irradiation. With fabric protection, the degree of skin moisture loss was reduced to some extent, but not entirely. Again, the UPF-13 fabric had a significantly better protection effect than the UPF-4 fabric. To avoid moisture loss or even increase the moisture content of the skin, however, a protective cream has to be applied.

Wrinkle protection

Wrinkles are an important sign of photoaging. In this phase of the study, wrinkling was measured by surface profilometry (ie, analysis of the shadow patterns). As seen in Fig. 6, a significant increase in wrinkling occurred on the uncovered site over the 3 months of UV exposure used in this study. When fabric covered the skin during UV exposure, the formation of wrinkles was avoided. In the case of the protection by the UPF 13 fabric, a slight but significant reduction of the wrinkles was detected after 3 months.

Skin-elasticity protection

Skin elasticity was determined by a cutometer. A tube with integrated light barrier measures by means of repetitive suction skin extension and rebound time

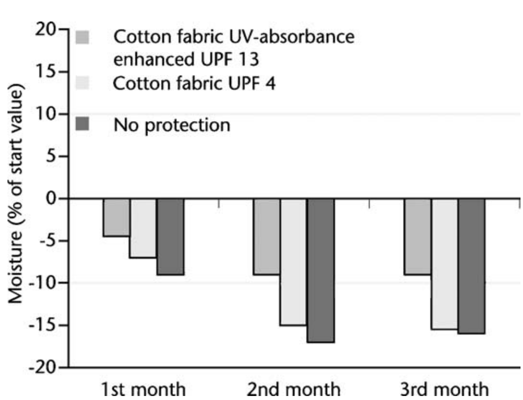


Fig. 5. Change in skin moisture–content of skin covered and not covered by fabric over a 3-month period of sun exposure.

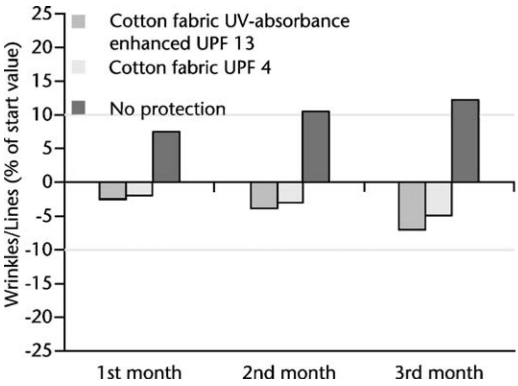


Fig. 6. Formation of wrinkles as a result of sun exposure over a 3-month period.

of the skin. As seen in Fig. 7, without protection skin elasticity drops significantly over the irradiation regime of 3 months. This effect was reduced to some extent when fabric covered the skin. Again, the UPF 13 fabric protected significantly better than the UPF-4 fabric, but some loss in skin elasticity occurred. This can be avoided completely or even be improved with a protective cream.

Conclusions

In all of these experiments, covering the skin with fabric was beneficial to reducing skin photoaging. The skin was less changed in color, had fewer wrinkles, was more elastic, and more hydrated. Repeating these experiments with fabrics with identical UPF values, however, may not give the same results. Identical results would be obtained only if the absorption spectra of the fabrics were identical, or the absorption in the UVA was identical. The higher UPF value fabric in the study was one containing a compound known to have excellent UVA absorption and possibly was one that absorbs the most harmful of the photoaging rays.

Garments sold with a sunburn-protective claim

The labeling of sunburn protective fabrics usually is accomplished using one of the following labeling standards developed by a committee within a national, regional, or international standard setting organization:

- ***AS/NZS 4399 (1996):*** Sun protective clothing evaluation and classification [5]
- ***ASTM D6603-00:*** Standard guide for labeling of UV-protective textiles [6]
- ***BS 7914 (1999):*** Children's clothing, requirements for protection against erythemally weighted solar ultraviolet radiation [17]
- ***EN 13758-2 (2003):*** Solar UV protective properties—classification and marking of apparel [18]

Labeling standards

Labeling standards differ from those that define a process for determining the UPF/SPF for the swatches (fabrics), because they direct the conversion of the fabric UPF values generated in in vitro testing to a single label UPF value, which in turn determines a classification category of the fabric/product. Labeling standards provide different directions for determining label information including the state of the fabric (eg, new or laundered) at the time of transmittance testing, so it is important to look for the standard number on the product label.

Differences in basis of claims

One of the active debates about classifying garments as UV-protective is whether classification should include:

- only those garments made of fabrics having or exceeding an agreed to minimal level of sunburn protection and covering at least an agreed to minimum skin surface area; and
- those garments made of fabric having or exceeding an agreed-to minimal level of sunburn protection with no requirement for area of garment skin coverage

Both bases for making a claim have been adopted. AS/NZS 4399:1996 was issued by Standard Australia/

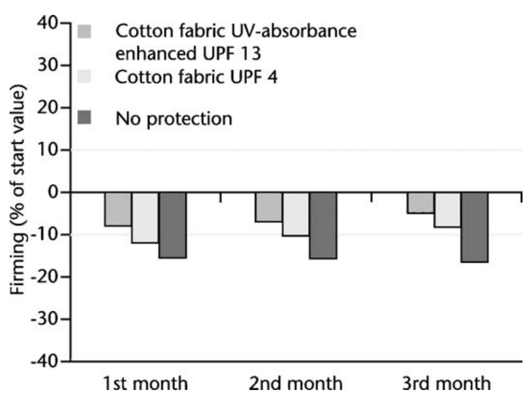


Fig. 7. Changes in skin elasticity as a result of sunlight exposure over a 3-month period.

New Zealand and titled "Sun protective clothing evaluation and classification" [5]. ASTM D6603-00 was issued by ASTM International and titled "Standard guide for labeling of UV-protective textiles" [6], require only that the fabric meet minimum protection levels. The BS 7914 (1999) standard issued by the British Standards Institute and titled "Children's clothing," [17] and EN 13758-2 issued by the European Committee for Standardization under the title "Solar UV protective properties—classification and marking of apparel" [18] require garment classification and minimum fabric UV-protective levels.

Another critical difference in basis of claims that a garment/fabric is sunburn protective lies in the condition of the fabric swatches of the fabric at the time of testing. The ASTM 6603 labeling document [6] specifies that the fabric swatches must be prepared for testing. What this means is that fabric is subjected to 40 launderings and many hours of UV radiation exposure. If the fabric will be used in swimwear, it also must be subjected to chlorinated pool water. Procedures for these exposures are specified in ASTM 6544—the preparation of textiles before ultraviolet transmittance testing [19]. The rationale for this swatch preparation step is to ensure that the lowest amount of protection during a normal life of the fabric is used in making the sunburn protection claim. In other words, the wearer of the garment is assured that the label amount is the least to be expected.

Garment skin coverage and label UPF minimums

BS 7914 applies to children's garments [17] and EN 13758-2 [18] applies to garments for individuals of all ages. Both standards require that clothing designed to offer protection to the upper body will at least completely cover the upper body, clothing designed to offer protection to the lower body will completely cover at least the lower body, and clothing designed to offer protection to both the upper and lower body will at least completely cover the upper and lower body. Definitions of upper and lower body in these standards include garments with elbow-length sleeves, pants, and skirts extending to the knees to be classed as solar UV-protective. The two standards differ in setting the garment fabric's sunburn protection level. EN 13758-2 requires more than UPF 40 and BS 7914 a penetration of 2.5% or less.

According to both AS/NZS 4399 [5] and ASTM D 6603 [6], the fabric comprising the garment must have a label-UPF rating of 15 for it to be classed as solar UV-protective. An important phrase here is *label UPF*. This is different than *swatch UPF value*. As outlined earlier, transmittance testing of swatches gives the amount of each wavelength of radiation that passes through the fabric, that is, is transmitted. These values are combined with weights, numbers that reflect relative differences among the wavelengths to cause skin reddening. The multiplication and addition in the equation lead to a single UPF value, a value for the swatch of fabric that was tested. The labeling documents instruct that the amount of variation in the swatch UPF values can alter the UPF value, which is a straight average of the swatch UPF values. High variations lead to a lowering of the label UPF value.

Classification categories

UPF garments/fabrics are placed into classes based on the calculated label UPF value [5,6]. The good protection class is composed of fabrics with label UPF values of 15 to 24, the very good protection class is composed of fabrics with label UPF values of 25 to 39, and the excellent protection class of fabrics with label UPF values of 40 to 50 and 50 + (the highest value permitted on a label).

Manufacturers and certifiers

Fabric and garment manufacturers who wish to label their garments or a line of their garments as being sun protective tend to do so using a label (hangtag) of a certifier. For example, in Australia/New Zealand, the certifier is the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). In the United States, the major certifier for some years was the American Sun Protection Association (ASPA). In Europe, a certifier is the International Testing Association for Applied UV Protection. Another certifier is the Skin Cancer Foundation, which provides a certification seal for those products that meet its certification requirements. Certifiers may use the standards produced by national and international standard-setting organizations. Often they set their own testing and labeling procedures and standards. The certifier's name usually appears on the garment label.

Garment choice

Garments include swimwear (styled with at least elbow-length sleeves and knee-length shorts), long-sleeved shirts (often pastel or white) usually with collars, long skirts, driving sleeves, and pants. The fiber content of the fabric of many of these garments is 100% nylon or 100% polyester. Because fiber content is required as marketplace information, individuals can determine if the sun protective garment is made from these fibers [20]. Nylon and polyester, especially the latter, have high UV absorbance [21] that can be enhanced with the addition of titanium dioxide (TiO_2) particles [22,23]. Often the styling of garments made with polyester or nylon fabric includes vents so that the garment is cooler to wear, the vents permitting insensible perspiration to have a way to escape (because water vapor has a difficult time diffusing through the fabric itself) and thus for body cooling to take place. Two factors prevent the diffusion of moisture through the fabric. First, there is insufficient space between the yarns in the fabric, because the straight smooth filament yarns pack closely together leaving insufficient void space for water molecules to diffuse. Second, moisture cannot diffuse through the fibers (these are hydrophobic fibers). The feeling can be likened to wearing plastic wrap. Worthy of note is a recently developed nylon fabric made with BASF fibers that is cotton-like by touch and has high UPF value because of the inclusion of finely dispersed TiO_2 particles within the fibers [24].

Other garments for which a claim of UV protection is made are those made with cotton fiber or rayon fiber (both fibers are composed of cellulosic polymers). Again, fabric fiber composition is required product information [20]. These fibers have poor UV absorbance [21], but their UV absorbance can be improved significantly by finishing the fabric with optical whitener and UV-absorbing compounds so that UPF ratings of 15 to 50+ can be obtained. These UPF values qualify the fabric as UV-protective and allow the manufacturer to make a claim in the marketplace. The most used commercial modification to date for cotton fiber is the addition of a UV-absorbing compound, a compound specifically developed to enhance UV absorption [25–29]. The compound does not interfere with moisture transport through the fiber or fabric. The most used modification for rayon fibers is to incorporate TiO_2 in the fiber, with best improvement in UV absorption when the new microsized TiO_2 particles are incorporated [22,23]. Two recent experimental treatments [30,31] hold promise for enhancing the UV protection of cotton fabrics. One treatment is applying a thin layer of titanium using a sol gel application method [30], and the second is applying nano-scale titanium hydrosol in combination with fluorescent whitening agent [31].

Purchasers

Purchasers of garments sold with a UV protective claim know the level of sunburn protection provided in the fabric at the time of purchase and during a reasonable length of use. The garments tend to be more expensive than similar styled garments for which a sunburn protection claim is not made. The higher cost covers expenses for transmittance testing, product labeling, and development of the chemical compounds to enhance the UV-absorbance of the fabric.

Individuals who become sunburned with short periods of sunlight exposure are encouraged to purchase and wear sunburn protective clothing. This group includes fair skinned, red-headed individuals. Individuals who sunburn slowly but spend long periods of time in the mid-day sun (working, gardening, and playing sports for example) also are encouraged to wear labeled sunburn protective clothing mainly because they know the degree of built-in protection.

Individuals who have other photosensitive conditions may be helped by wearing sunburn protective clothing, but this clothing would need to have ability to highly absorb UVA and also certain visible wavelengths. UPF values do not reveal that this is the case. As Menter and Hatch point out [3], exposure to UVB radiation has a relatively minor role in triggering the skin response of photosensitive individuals. It is exposure to UVA and visible rays that are responsible for their photosensitivity condition.

Garments sold without a claim

Most, if not all, summertime outerwear garments in a person's closet probably were purchased without consideration of how UV protective they are. Some of these garments, if transmittance tested, would show UPF values of at least 15. In fact, the results of four studies undertaken during the 1990s [32–35] show that 50% to 80% of summertime fabrics have UPF values of 15 or greater (Fig. 8). Between 20% and 40% of the garments in these studies had UPF values of 40 or greater.

The question is "How can individuals make best choices for UV protection among garments they own or among garments they are considering as additions to their own or children's wardrobe"? Or rephrased, "What fabric features (selection criteria) likely place a fabric in the 15 UPF classification or higher"? This section discusses the answer by first discussing useful selection factors and then often recommended but not practical selection factors.

Useful selection factors

Useful selection factors are those that are visually obvious, whether there is product information

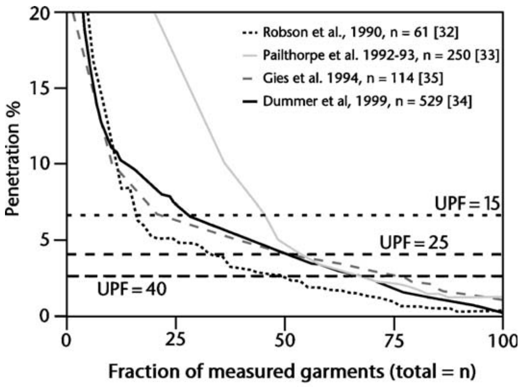


Fig. 8. Fraction of summertime fabrics having various UPF values. (*Data from* Refs. [32–35].)

that assists, or if the garment owner knows the laundering history of his/her garments or his/her children's garments.

Garment style

Garments that cover or shade the greatest skin area are better choices. These include hats with wide all-around brims, shirts with collars and long sleeves, trousers with long legs, and skirts that are knee length or longer. For many individuals, this is just too much fabric, too confining and not appropriate to the occasion. This is the time to complement garment selection with sunscreen lotion.

Double fabric layers and fabric thickness

Shirts that have a yoke, as do cowboy-style shirts, can be constructed with a single or double layer of fabric in the yoke area. For UV protection to the shoulder and upper torso, purchasing and wearing a double yoke garment would be the better choice. This is illustrated in Fig. 2, which shows the skin condition of a man who wore shirts with a double layer of fabric in the yoke area. Note that the dark area on the man's back is where there was a single layer of fabric and the lighter areas where the double layer of a fabric in the shirt yoke reduced the penetration of UV radiation [13]. Fabric thickness, a reflection of the amount of fiber in a given fabric area, is one concentration measure. Given two fabrics differing from each other only in thickness, the thicker fabric would have the higher UV-absorbing ability.

Fabric fiber composition

Fabrics may be composed of just one fiber (eg, 100% cotton, 100% polyester, 100% wool, or 100% silk). Other fabrics are blends of fibers (eg, 65% polyester and 35% cotton). Fiber composition is required to be stated on a textile product label, and fibers are known to differ in UV-absorbing ability.

Crews and colleagues [21] determined how fibers ranked relative to each other in regard to UV absorbance. This approach is in contrast to earlier studies in which fabrics of various fiber compositions were ranked and fabrics that differed in other important characteristics such as thickness (eg, wool fabrics are much thicker than cotton fabrics). The results of the experiment [21] established fibers could be classified in three distinct groups:

Group 1: polyester, which is the best UV absorber
Group 2: wool, silk, and nylon
Group 3: cotton and rayon (cellulosic fibers), which are the poorest UV absorbers

What is discouraging about these results is that the favorite fibers, cotton, rayon and flax (linen) for summer wear, are at the bottom of the list. What is encouraging is that garments one has in his/her possession, perhaps the favorite ones having this fiber composition may be excellent choices. This is because of the presence of optical whitening compounds on these fabrics.

Laundering history of cellulosic fiber fabrics

Knowing the number of times a garment made from 100% cotton, 100% rayon, 100% flax (linen), or from blends of these fibers with each other or with polyester have been laundered is helpful information in making a good choice of garment to wear out in the sun. Garments with these fiber compositions that have been laundered most are most likely the better choices. There are two major reasons; optical whitener is being deposited, and the fabric is shrinking with each wash.

Optical whitener accumulation

Optical whitening agents (OWAs), also known as florescent whitening agents and as brighteners, are included in almost every heavy-duty detergent product sold in the United States and in Europe. These OWAs are included, because they whiten and brighten fabrics. Compounds in this classification convert a portion of incident UV radiation to the visible blue wavelength and reflect the visible blue wavelength. More specifically, OWAs absorb UV radiation near 360 nm and re-emit it at about 430 nm. More visible light reaches an observer's eye from the surface of a fabric containing OWA than from an identical fabric without OWA. White fabrics containing OWA are said to be whiter and colored fabrics to be brighter compared with the same fabric without the OWA.

Secondarily, the presence of OWAs on fabric enhances UPF value, because they absorb UV. Specifically, they absorb better in the UVA region than in the UVB region (where most compounds in the classification absorb poorly). Most compounds in this classification have an absorption weakness at about 308 nm, a wavelength that is a powerful producer of erythema.

Zhou and Crews [36] found after laundering cotton sheeting and cotton broadcloth 20 times in home laundering equipment using detergent containing OWA, that the 100% cotton sheeting showed a tenfold increase in mean UPF (initial fabric UPF 5.5 and after 20 washings UPF 57.1). The 100% cotton broadcloth showed about sixfold increase (after 20 washing UPF of 22). At 20 launderings, UPF still had not leveled off; more laundering may lead to even greater improvement, but not only because of the OWA. They noted that some of the UPF increase was because of shrinkage in the fabric. UPF values increased when the test fabrics were laundered under identical conditions except for the presence of OWA. Zhou and Crews [36] did not observe enhanced UPF values for the polyester or nylon fabrics they laundered 20 times with detergent containing OWA.

Reinehr and colleagues [37] compared whiteness values and UPF values of white and colored cotton fabrics before and after laundering the fabrics with a traditional OWA compound and with an OWA compound with improved absorption in the UV. Some fabrics had been prewhitened, so they could determine whether the addition of OWA in laundry had a detrimental effect on whiteness, which it did not.

Finally, Reinehr and colleagues [37] softened and added OWA to cotton fabric using two-rinse cycle fabric-softening products: one containing a cationic-OWA (OWA-4) and the other OWA-2. Two formulations were used; 0.3% and 2.7% on weight of after-rinse product of softening compound. The fabric swatches laundered with the higher concentration cationic-OWA softener had higher SPF values than the swatches laundered with the lower concentration (SPF of 30 compared with 12). The comparison treatment (OWA-2) resulted in an SPF of 5 at both concentrations.

Ultraviolet-absorber accumulation

UV-absorber compounds are available in select detergents and in a dedicated laundry product (a dedicated product whose sole intent is to enhance the UPF values of cotton and cotton blend fabrics). The name of the dedicated product is Rit SunGuard, manufactured by Phoenix Brands (Indianapolis, Indiana). It is distributed primarily to grocery stores in the United States. Laundry detergents containing UV absorbers are available in Europe, Asia, and Australia. Rinse-cycle fabric softeners (conditioners) containing UV absorber are available in Switzerland and Japan. Consumers should look for the Skin Cancer Foundation Certification Seal and Ciba Specialty Chemical company's butterfly logo on laundry product packages and wording such as *UV cut detergent*, *UV Shield*, *UPF 30+*, and *Sun Care* on the package to determine which products contain UV absorbers.

The classification of compounds called the UVCA class or UV-absorbing class is composed of compounds having chromophore systems that absorb very effectively in the UV region, enabling them to maximize the absorption of UVR while in situ on textiles. These compounds also contribute to fabric whiteness and brightness. Compounds within this class enhance the UPF values of cellulosic fabrics, cellulosic blended fabrics, 100% polyester fabrics, and 100% nylon fabrics when added to the fabric during mill finishing [25–29]. Such mill-finished fabrics usually are made into garments for which a claim of UV protection will be made. Their presence on those fabrics often is not revealed in labeling. Compounds in the UVCA class should not be confused with UV-absorbing compounds whose purpose is to slow the solar degradation of PA (polyamide/nylon) fiber or enhance light fastness of dyes on automotive PES (polyester/polyethylene terephthalate) fibers/fabrics.

Scientists working on the development of laundry products that include UV-absorbing compounds have shown that these products lead to significant improvement in UPF values of cotton fabrics that initially have little sunburn protection capability [38–43]. Of particular interest are two studies conducted by researchers outside the product development arena to determine differences in the amount of UPF enhancement that would result by home laundering the same fabrics with different laundry products.

Wang and colleagues [44] laundered a jersey fabric (initial UPF 4.7) and a print cloth fabric (initial UPF 3.1). They found that after five cycles of laundering in water only, the UPF of their jersey fabric increased to 7.1 and UPF of their print cloth increased to 4.2, which they attributed to fabric shrinkage. After five cycles of washing in American Association of Textile Chemists and Colorists detergent with OWA, the UPF value was 6.0 for jersey and 4.4 for print cloth. After washing the swatches once with detergent containing UVCA, the UPF for jersey was 11 and 7 for print cloth. By the fifth wash cycle, the jersey fabric had a UPF value of 23, and the print cloth had a value of about 12.

Kim and colleagues [45] laundered two white knit fabrics: a 100% cotton jersey (initial UPF of 14.2) and a 60% cotton–40% polyester pique (initial UPF of 23.4). After one laundering cycle with the Rit SunGuard product, UPF values were 81.4 ± 23.0 (jersey) and 39.6 ± 8.3 (pique). With Rit Whitener and Brightener product values were 30.5 ± 6.1 (jersey) and 36.6 ± 6.1 (pique). UPF values above 30 were obtained by the conclusion of the fifth laundering with Tide (Procter & Gamble, Cincinnati, Ohio) and with Wisk (Unilever, Englewood Cliffs, New Jersey). Specifically, the UPF values at this point were 43.3 ± 8.5 (jersey) and 39.7 ± 10.4 (pique fabric). There were statistically significant differences in UPF values for fabric type and for laundry product used in the wash. Adding just the Rit SunGuard product to laundry water resulted in the most rapid achievement of a UPF of 30+.

Fabric shrinkage

Cotton fabrics are subject to shrinkage when they are laundered, knit cotton fabrics tending to shrink more than woven cotton fabrics. Small amounts of shrinkage can lead to significant improvement in the UPF value of the fabric. This is because a fabric parameter textile scientists call fabric cover factor has a tremendous influence on UV transmission, that is directed transmission, rays that do directly through the fabric. They are not scattered as they go through the fabric, because they never interact with the fibers [46,47]. Fabric cover factor is discussed in the next section.

Often recommended, but not practical selection factors

Fabric cover factor, fabric depth of shade, and fabric hue are three selection criteria that can have a significant influence on the sun protection provided to fabric-covered skin. Dermatologists and others providing advice about UV protection by means of garments should not recommend that individuals use these selection factors, however. An explanation follows.

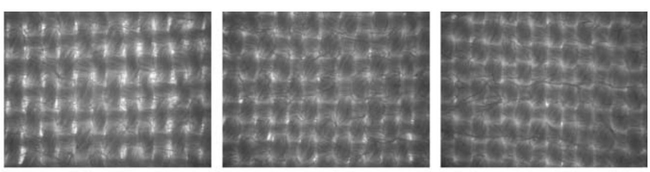
Fabric cover factor

Fabric cover factor is the proportion of a fabric surface area filled with fiber/yarn to the total fabric surface area. Scientists [21,26,27,48–51] quantify the cover factor of fabrics using either image analysis (the more commonly used method and that used to determine the cover factor of the fabrics in Fig. 9) or direct transmittance data.

When a fabric is placed on a white surface and the surface is magnified, as is the case in the photographs of the cotton fabric shown in Fig. 9, one sees that a portion of the white underlying surface is visible. The amount of white showing decreases from left to right. The measured fabric cover factors are 86%, 95%, and 98% [48]. The complementary relationship is called fabric porosity (or fabric optical porosity) and provides data about the percent of fabric surface area not filled by fiber. The porosity of the fabrics in Fig. 9 is therefore 14%, 5%, and 2%, respectively.

Cover factor is a highly important fabric parameter, because it determines the probability of a UV ray striking a fiber. The greater the probability that UV radiation directed at the fabric surface will strike a fiber and therefore be reflected or absorbed by the surface fiber or other fibers as it continues its journey through the maze of fibers comprising the yarn leads to decreased transmittance (higher UPF). Conversely, the higher the percent porosity of the fabric, the greater the probability that rays directed perpendicular to the fabric surface (as is the case in transmittance testing) will pass directly through the pores in the fabric (where there is no UV-absorbing material.

If one had a set of fabrics composed of fibers that absorbed all the radiation that struck them, but each fabric had a different cover factor, then the relationship between percent cover factor and SPF/UPF value would be as shown in Table 1 [33]. These



% Cover factor	86	95	98
% Porosity	14	5	2

Fig. 9. Comparison of cover factor of three cotton fabrics having identical yarn structures. (*From* Algaba I, Riva A, Crews PC. Influence of fiber type and fabric porosity on the UPF of summer fabrics. AATCC Review 2004;4(2):26–31; with permission.)

Table 1
Relationship between cover factor/porosity and sun and ultraviolet protection factor values

Cover factor (%)	Porosity (%)	Max theoretical fabric SPF/UPF
80	20	5
90	10	10
93.4	6.6	15
95	5	20
97.5	2.5	40
98	2	50
99	1	100
99.5	0.5	200

data show that UPF increases rapidly as percent cover factor increases in small increments. Again, the fibers in this set of fabrics absorb all the UV that strikes them. This is not usually the case.

What if one had a set of cotton fabrics (or rayon fabrics) that were identical except for percent cover factor? Algaba and colleagues [48] prepared such a set (see Fig. 9) and determined the cover factor of each; the values are 86%, 95%, and 98% from left to right. What would the UPF values of the fabrics be? The UPF of these fabrics (all below 15 UPF) does not reflect the numbers shown in the figure. The reason is that the fibers allow UV radiation to pass through them, so the effect of fabric cover factor is diminished. None of the fabrics would provide even minimum protection (at least as defined in the UV labeling standards).

Another reason not to recommend visual comparison of fabrics to determine relative cover factor, even when the fabrics may be made from fibers more UV-absorbing than cotton and rayon (the least UV-absorbing fibers), is because the comparison fabrics likely will differ in color; shade, even if the same hue; and thickness, all of which will effect the conclusion (ranking). The visual comparison method is to hold fabrics up to a light source, estimate the relative quantity of light passing through the fabric, and select the fabric letting the least amount of visible light through.

Osterwalder and colleagues [1] provide an explanation about why this is not a reliable procedure by showing diagrams of two fabrics with cover factors of 1.0%. One fabric was white (UPF 3.7) and the other black (UPF 48.2). Using the visual comparison method leads to subjects saying that the black fabric would be far less ultraviolet protective than the white fabric. The reason for this erroneous conclusion is that the eye sees more distinct spots of visible light coming through the black fabric than the white one because the light striking the fibrous area of the black fabric is being absorbed while the visible light striking the fibrous portion of the white fabric scatters and is transmitted through the fabric. The transmitted scattered light blurs the impression of the amount of light coming directly through the pores of the white fabric. Although they used two extremes (a white and black fabric), the same conclusions are reached under other scenarios.

Fabric depth of shade

The description of a fabrics color may be specified, in a nonscientific way, by its hue (eg, red, orange, yellow, blue, or green) and its depth of shade. This discussion begins with the wisdom of using fabric depth of shade to estimate fabric UPF. Fabric depth of shade is related to the lightness or darkness of the color (hue) of a fabric. For example, a red dye can be used to make fabrics ranging in shade from light pink to dark red, the shade differing because of the concentration of the dye in the fabric. Similarly, a black dye can be used to make fabrics ranging in shade from light gray to intense black. Although it is true that the darker the shade of fabrics dyed with the same dye, the higher the UPF of the fabric (provided the dye used has capability of absorbing in the UV region of the electromagnetic spectrum) [52], fabric depth of shade is an impractical selection factor for consumers to use, because the comparison probably will not be between or among fabrics that were dyed with the same dye. Because dyes, even those that dye the fabric to the same hue, differ in ability to absorb UV radiation, fabrics of the same hue and depth of shade will have different UPF values, sometimes dramatically different values.

Srinivasan and Gatewood [52] conducted a study showing how unreliable using hue and depth of shade comparison can be to estimate the UPF value of fabrics or attempt to rank fabrics on the basis of UPF values. It was not their intent to show this relationship, however. They chose a 100%-cotton bleached print cloth fabric (initial UPF 4.1) and a series of commonly used direct dyes, and then dyed swatches of the fabric with each dye to a pale shade and a dark shade. The amount of dye added to the pale shade swatches was ~0.5% OWF and ~1.0% OWF to the dark shade fabrics. When the UPF values for each swatch were determined, it was obvious that the fabrics containing more dye (dark shades) had higher UPF values than swatches containing less of the same dye (pale shades).

Fabric color: hue

Hue is the color of the fabric (eg, red, yellow, or blue). The question is whether one can relate fabric color (hue) to UPF. The answer is no. Consider the data in Table 2, columns 1 and 4. The UPF data in column 4 were calculated using the data in column 3 and knowing exactly the amount of dye that was added to the swatches. Note that the UPF values in column 4 are in descending order. Then note that fabrics of the same hue do not cluster together. For example, red fabrics with identical concentration of dye have UPF values of 51, 31, and 20. Of note is that the black fabric in this study did not have the highest UPF value, even though advice has been given to consumers that black fabrics are the best UV protection choices. Also to be noted is that most fabrics in the marketplace are not dyed with a single dye but a carefully chosen set of dyes to produce the fashion color, a situation that further complicates any chance of estimating the UPF values of colored fabrics, even those of like fiber composition or cover factor. Other data about the relationship of dye type and dye concentration on fabric to UPF values that support the previous conclusions and add additional knowledge about dyes and UPF can be found elsewhere [53,54].

Table 2
Direct dyes ranked for effectiveness in improving the ultraviolet protection factor of 4.1-UPF cotton fabric

Direct dye used to dye cotton fabric	Fabric UPF shade		Fabric UPF value when each fabric had the same dye concentration
	Pale[a]	Dark[b]	
Red 28	39	51.7	41
Black 38	30	40	34
Red 24	28	37	31
Green 26	22	29	26
Yellow 44	18	29	25
Blue 1	22	30	26
Yellow 106	19	28	25
Brown 154	23	31	25
Blue 86	16	19	24
Violet 9	21	29	24
Yellow 28	20	29	22
Red 80	17	25	20
Yellow 12	13	19	18
Blue 218	13	19	17
None	4.1	4.1	4.1

[a] Each fabric contains about 0.5% dye on weight of fiber.

[b] Each fabric contains about 1.0% dye on weight of fiber.

Data from Srinivasan M, Gatewood BM. Relationship of dye characteristics to UV protection provided by cotton fabric. Textile Chem Colorist Am Dyestuff Reporter 2000; 32:36–43.

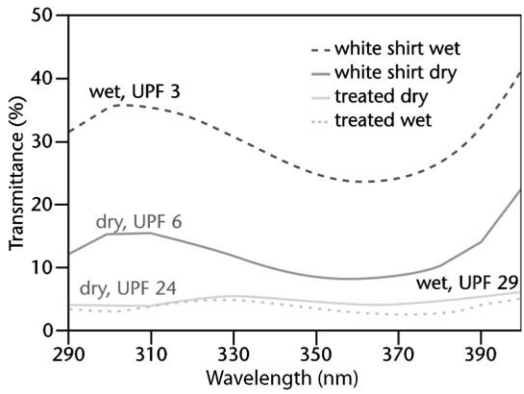


Fig. 10. Transmission of UV through unfinished and UVCA-treated fabric when dry and wet. (*Data from* Osterwalder U, Schlenker W, Rohwer H, et al. Facts and fiction on ultraviolet protection by clothing. Radiat Prot Dosimetry 2000;91:255–60.)

Cautions

Sun protection afforded by covering one's skin with fabrics can be reduced during wearing. Of major concern is a reduction in UPF when the fabric becomes saturated with water. This would be of the most concern for swimwear and garments worn by heavily sweating individuals. The amount of reduction can be minimal or substantial depending on the fiber content of the fabric and whether the fabric has been finished with UV-absorbing compounds or laundered with products containing these compounds [3,55–58].

In general, the UPF of white and pastel colored 100% cotton fabric decreases as the moisture content of the fabric increases. As these fabrics get wet, scattering is reduced, leading to an increase of UVR penetration/transmittance. In contrast, fabrics containing UV absorbers or dyestuff compounds do not have reduced UPF, because UV protection is provided almost exclusively by absorbance (Fig. 10). Although this has been said before, ranking fabrics for sun protection performance is not done easily and often will lead to mistakes in judgment about how much sun protection is a being provided.

Comparison of fabric with sunscreen lotions

Fabric can be a highly effective sun (ultraviolet radiation) screening material. Fabric SPF/UPF values can be as high as for sunscreen lotions. The major disadvantage of using garments as sunscreening materials is probably that most garments do not

Table 3
Comparison of garments and sunscreens

Comparison factor of garments vs. sunscreen	Comment
Cost	Sunscreen costs $\geq$ $1 per one full body application. Garments labeled as UV-protective are costly. Use of regular garments does not have an additional cost unless dedicated UV absorber is purchased and applied.
Replacement frequency	Sunscreen lotion needs replacement more frequently. Protective garments are long-lasting.
Simplicity in testing	Sunscreen is costly to test because it must be performed in vivo. Fabrics are easily tested.
Long-lasting and photostable	Sunscreen is temporary and must be reapplied. Garments keep their protective property over the whole day.
Even and sufficient application	Lotions require an even application to avoid having areas of inadequate protection. Individuals tend to underuse lotion so the protection stated on the product may not be achieved. Garments protect the area they cover.
Timing of application	Sunscreens must be applied 30 minutes prior to sun exposure. Garments may be donned at the last minute.
Waterproof-staying power on the skin	Sunscreen must be reapplied. Does not apply to normal textiles
Affected by wetting	Protection may be lessened when white fabrics are wetted, but not if protection effect is mainly due to absorption by dyestuff or UV absorber.
Skin tolerance	There are known reactions to certain ingredients in lotions. No known skin reactions from UV-absorbing compounds on fabrics.
UVA protection	UVA protection by lotions often insufficient and not photostable; no UVA issue with garments.
Sunburn protection	As a rule-of-thumb, sunscreens only provide ~1/3 of the labeled protection value [59] due to the lack of proper compliance. Protection is much more reliable in fabrics (compliance is not a factor).
Photoaging	Sunscreens are advantageous because of their active influence on hydration of the skin.
Transparency	Sunscreens preferred to covering the skin with fabric.

come labeled with a UPF value. But consumers can make reasonable judgments about relative sun protection performance and now have laundering options that lead to known levels of sun protection performance. Application of sunscreen lotions and garment selection lead to a good sun screening strategy. Each option has its advantages and disadvantages as outlined in Table 3.

Summary

Fabric serves as a UV radiation filtering material, because it is made from fibers that all have some UV reflecting and absorption ability, and because fabric often is colored, meaning it contains colorants (dyes and pigments) that likewise have varying degrees of UV-absorbing ability. Further, cotton and cotton blend fabrics (eg, cotton and polyester blends) and rayon (viscose) fabrics and rayon blend fabrics acquire a UV-absorbing compound, OWA (also known as a florescent whitener), or they many be finished in the mill with these compounds. The introduction of UVCA, compounds that increase the absorption of UV radiation of the fabrics to which they are applied, especially the absorption of the wavelengths most responsible for skin reddening (sunburning), has increased the ability of cotton and cotton blend fabrics to protect against UV radiation. Manufactured fibers can be enhanced by adding TiO_2. Other compounds recently studied may be applied to commercially available fabrics in the near future. Fabrics can protect against sun burning, development of precancerous skin lesions, and solar aging of the skin. UV protection labeling is about sunburn protection. New procedures will need to be developed for labeling fabrics intended to protect against other deleterious effects of the sun.

Another major point was that most cover-up garments, garments that cover the arms, legs and torso are UV protective, because the fabric from which they are made provides some UV protection to the skin. When a manufacturer decides to make a claim that a garment is UV protective, that manufacturer usually tests and labels the garment using a standard procedure, often one developed by a committee within a national, regional, or international standard setting organization. Individuals who are sun-sensitive are urged to purchase and wear garments for which a claim of UV protection is made. Using cover-up garments and sunscreen lotions is an effective combination for protection of the skin while outdoors on sunny and cloudy days.

References

[1] Osterwalder U, Schlenker W, Rohwer H, et al. Facts and fiction on ultraviolet protection by clothing. Radiat Prot Dosimetry 2000;91:255–60.

[2] Rupp J, Böhringer A, Yonenaga A, et al. Textiles for protection against harmful ultraviolet radiation. International Textiles Bulletin 2001;47(6):8–20.

[3] Menter JM, Hatch KL. Clothing as solar radiation protection. Curr Probl Dermatol 2003;31:50–63.

[4] Hatch KL. Fabrics as UV radiation filters. In: Shaath NA, editor. Sunscreens: regulations and commercial development. 3rd edition. New York: Karger Publishing; 2004. p. 557–72.

[5] Standards Association of Australia. Standard AS/NZS 4399: sun protective clothing: evaluation and classification. Homebush, Australia: Australian/New Zealand Standards; 1996. Available at: http://www.standards.com.au. Accessed October 28, 2005.

[6] American Society for Testing and Materials (ASTM International). Standard D 6603 – 00, Standard guide for labeling of UV-protective textiles. In: Bailey SJ, Baldwin NC, McElrone EK, et al, editors. ASTM standards, Vol. 7:03. 2004. p. 1187–91. Available at: http://www.astm.org. Accessed October 28, 2005.

[7] Commission Internationale de l'Eclairage. Research note. A reference action spectrum for ultraviolet-induced erythema in human skin. CIE J 1987;6:17–22.

[8] American Association of Textile Chemists and Colorists. Test method 183-2000: transmittance or blocking of erythemally weighted ultraviolet radiation through fabrics. In: AATCC technical manual. Research Triangle Park (NC): AATCC; 2004. p. 341–3.

[9] British Standards Institute. Standard 7914–1998: method of test for penetration of erythemally weighted solar ultraviolet radiation through clothing fabrics. Available at: http://www.bsi.org.uk. Accessed October 28, 2005.

[10] European Committee for Standardization. Standard EN 13758–1: textiles—solar UV-protective properties. Part 1: method of test for apparel fabrics. Available at: http://www.cenorm.be. Accessed October 28, 2005.

[11] Osterwalder U, Rohwer H. Improving UV protection by clothing—recent developments. Recent Results Cancer Res 2002;160:62–9.

[12] Bech-Thomson M, Wuld HC, Ullman S. Xeroderma pigmentosum lesions related to ultraviolet transmittance by clothes. J Am Acad Dermatol 1991;24:365–8.

[13] O'Quinn RP, Wagner RF. Unusual patterns of chronic photodamage through clothing. Cutis 1998;61:269–71.

[14] Menter JM, Hollins TD, Sayre RM, et al. Protection against UV photocarcinogenesis by fabric materials. J Am Acad Dermatol 1994;31:711–6.

[15] Menter JM, Hollins TD, Sayre RM, et al. Protection against photodynamic therapy (PDT)-induced photosensitivity by fabric material. Photodermatol Photoimmunol Photomed 1998;4:154–9.

[16] Baschong W, Artmann C, Schaumann M, et al. Sun protection beyond sunburn—UV-protection in non-Caucasians. Presented at the American Academy of Dermatology 62nd Annual Meeting. Washington DC, February 6–11, 2004.

[17] British Standards Institute. Standard 7949–1999: children's clothing, requirements for protection against erythemally weighted solar ultraviolet radiation. Available at: http://www.bsi.org.uk. Accessed October 28, 2005.

[18] European Committee for Standardization. Standard EN 13758–2: textiles—solar UV-protective properties. Part 2: classification and marking of apparel. Available at: http://www.cenorm.be. Accessed October 28, 2005.

[19] American Society for Testing and Materials. ASTM D6544 – 00: standard practice for preparation of textiles prior to ultraviolet (UV) transmission testing. In: Bailey SJ, Baldwin NC, McElrone EK, et al, editors. ASTM standards, Vol. 7:03. 2004. p. 1152–5. Available at: http://www.astm.org. Accessed October 28, 2005.

[20] United States Federal Trade Commission. Textile Fiber Products Identification Act of 1960 and its amendments. Available at: http://www.ftc.gov. Accessed October 28, 2005.

[21] Crews PC, Kachman S, Beyer AG. Influences on UVR transmission of undyed woven fabrics. Textile Chemist and Colorist 1999;31:17–26.

[22] Wedler M, Hirthe B. UV-absorbing micro additives for synthetic fibers. Chem Fibers International 1999;49:72.

[23] Dransfield GP. Inorganic sunscreens. Radiat Prot Dosimetry 2000;91(1–3):271–3.

[24] BASF. No more sunburn! Clothing with sun protection for young and old. Available at: http://www.basf.de/science_around-us. Accessed October 28, 2005.

[25] Hilfiker R, Kaufmann W, Reinert G, et al. Improving sun protection factors of fabrics by applying UV absorbers. Textile Res J 1996;66:61–70.

[26] Reinert G, Fuso F, Hilfiker R, Schmidt E. UV-protecting properties of textile fabrics and their improvement. Textile Chem Colorist 1997;29:36–43.

[27] Jöllenbeck M. New UV absorbers for sun protective fabrics. In: Altmeyer P, Hoffmann K, Stücker M, editors. Skin cancer and UV radiation. Berlin: Springer Verlag; 1997. p. 382–7.

[28] Jöllenbeck M, Härri HP, Schlenker W, Osterwalder U. UV protective fabrics. In: UV-protective Fabrics. Proceedings of American Association of Textile Chemists and Colorists Functional Finishes and High Performance Textiles Symposium. Charlotte, North Carolina, January 27–28, 2000.
[29] Eckhardt C, Rohwer H. UV protector for cotton fabrics. Textile Chem Colorist Am Dyestuff Reporter 2000;32:21–3.
[30] Xin JH, Daoud WA, Kong YY. A new approach to UV-blocking treatment for cotton fabrics. Textile Res J 2004;72(2):97–100.
[31] New Xu P, Wang W, Chen S-L. UV blocking treatment of cotton fabrics by titanium hydrosol. AATCC Review 2005;5(6):28–31.
[32] Robson J, Diffey BL. Textiles and sun protection. Photodermatol Photoimmunol Photomed 1990;7:32–4.
[33] Pailthorpe M. Textile parameters and sun protection factors. In: Pailthorpe M, editor. Textiles and Sun Protection Conference Proceedings. Kensington (NSW): The Society of Dyers and Colourists of Australia and New Zealand; 1993. p. 32–53.
[34] Dummer R, Osterwalder U. UV protection factor of summer clothing in Switzerland and Germany. Dermatology 2000;200:81–2.
[35] Gies HP, Roy CR, Elliott G, et al. Ultraviolet radiation protection factors for clothing. Health Phys 1994;67: 131–9.
[36] Zhou Y, Crews PC. Effect of OBAs and repeated launderings on UVR transmission through fabrics. Textile Chemist and Colorist 1998;30:19–24.
[37] Reinehr D, Eckhardt C, Kaufmann W. Skin protection against ultraviolet light by cotton textiles treated with optical brighteners. In: 4th World Surfactants Congress-Asociacion Espanola de Productores de Sustancias para Aplicaciones Tensioactivas (Barcelona). Cambridge (UK): Royal Society of Chemistry; 1996. p. 264–76.
[38] Eckhardt C, Osterwalder U. Laundering clothes to be sun protective. In: Cahn A, editor. Proceedings 4th World Conference of Detergents: strategies for the 21st century. (Montreux, 1998). Champaign (IL): AOCS Press; 1999. p. 317–22.
[39] Rohwer H, Eckhardt C. Laundry additive for the sun protection of the skin. SÖFW J 1998;124:1241–4.
[40] Rohwer H, Osterwalder U, Dubini M. Enhanced textile sun protection within a few washes. 39th International Detergency Conference. Luxembourg, September 6–8, 1999.
[41] Rohwer H, Kvita P. Sun protection of the skin with a novel UV absorber for rinse cycle application. SÖFW J 1999;125:1–5.
[42] Spillmann N. Sun protection via laundry products—innovative science and creative effects to complete the circle of sun protection. In: Proceedings of the 5th World Conference on Detergents. (Montreux, 2002). Champaign (IL): AOCS Press; 1999. p. 42–197.
[43] Schaumann M, Rohwer H. UV absorbers for fabrics. Happi 2003;36(2):59–61.
[44] Wang SQ, Kopf AW, Marx J, et al. Reduction of ultraviolet transmission through cotton t-shirt fabrics with low ultraviolet protection by various laundering methods and dyeing: clinical implications. J Am Acad Dermatol 2001;44:767–74.
[45] Kim J, Stone J, Crews P, et al. Improving knit fabric UPF using consumer laundry products: a comparison of results using two instruments. Fam Consum Sci Res J 2004;33(2):141–58.
[46] Stanford DG, Georgouras KE, Pailthorpe MT. The effect of laundering on the sun protection afforded by a summer weight garment. J Eur Acad Dermatol Venereol 1995;5:28–30.
[47] Stanford DG, Georgouras KE, Pailthorpe MT. Sun protection afforded by a summer weight garment: the effect of wash and wear. Med J Austr 1995;162: 422–5.
[48] Algaba I, Riva A, Crews PC. Influence of fiber type and fabric porosity on the UPF of summer fabrics. AATCC Review 2004;4(2):26–31.
[49] Menzies SW, Lukins PB, Greenoak GE, et al. A comparative study of fabric protection against ultraviolet induced erythema determined by spectrophotometric and human skin measurements. Photodermatol Photoimmunol Photomed 1992;8:157–63.
[50] Sedlacek M. Development of an optical porosity meter for the analysis of UV protective clothing [diploma thesis]. Grenzach (Germany): FH Karlsruhe; 1998.
[51] Bommer B. Investigation of the UV protection factor of knit wear under stretch [diploma thesis]. Grenzach (Germany): FHBB Muttenz; 1999.
[52] Srinivasan M, Gatewood BM. Relationship of dye characteristics to UV protection provided by cotton fabric. Textile Chemist and Colorist American Dyestuff Reporter 2000;32:36–43.
[53] Veatch KD, Gatewood BM. Influence of light exposure on the UV protection of direct, reactive, acid, and disperse dyes on cotton and nylon fabrics. AATCC Review 2002;2(2):47–51.
[54] Gorenšek M, Sluga F. Modifying the UV blocking effect of polyester fabric. Textile Research Journal 2004; 74(6):469–74.
[55] Jevtic AP. The sun protective effect of clothing including beachwear. Aust J Dermatol 1990;31:5–7.
[56] Gambichler T, Hatch KL, Avermaete A, et al. Influence of wetness on the ultraviolet protection factor (UPF) of textiles: in vitro and in vivo measurements. Photodermatol Photoimmunol Photomed 2002;180: 29–35.
[57] Moon R, Pailthorpe M. Effect of stretch and wetting on the UPF of elastane fabrics. Australasian Textiles 1995;15:39–42.
[58] Jesson N. Textiles for sun protection: wet versus dry fabric protection against UV radiation. [dissertation]. Sydney (Australia): University of New South Wales; 1992.
[59] Diffey BL. Sunscreen isn't enough. J Photochem Photobiol 2001;64:105–8.