



UV-blocking cotton fabric design for comfortable summer wears: factors, durability and nanomaterials

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Abstract The ultraviolet rays from sunlight pose a natural hazard to human health and can cause serious health problems. Some medical artificial lights also emit ultraviolet radiation. Unprotected human skin exposed to ultraviolet (UV) light can cause serious health problems, including skin aging, photosensitivity (rash), erythema (redness of the skin), and melanoma (skin cancer). To protect human skin from UV radiation, UV-blocking or protective products are used. According to medical professionals, UV protection products must be safe, chemically inert, non-irritating, non-toxic, and resistant to light, and completely block the replication of UV rays. Sunscreen cream/lotion products are used for UV protection, but these products cannot provide complete protection.

According to experts, one of the most efficient strategies to avoid sun damage is to wear protective gear. Researches are going on the manufacture of smart textiles that can be deployed as a protective shield with an adornment look to wear. Therefore, researchers have paid great attention to the development of fibers with anti-ultraviolet function. This review discusses the upshot of UV radiation on textile materials in particular cotton fabrics. It also describes the correlation between ultraviolet protection factor (UPF) and the physicochemical and structural properties of cotton fabrics. This review focuses on the manufacturing of UV protective cotton fabrics by applying UV absorbers and nanoparticles, their application process, and effects.

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Introduction

The Sun is the largest source of ultraviolet radiation. As a result of the depletion of the ozone layer, UV rays cannot be absorbed by O₃ and therefore, enter the surface of the earth. Besides the ozone layer depletion index, UV rays transmittance varies with the longevity of daytime, season, latitude, and altitude. These geological factors affect the increase in the transmittance of UV rays. For example, the transmittance of ultraviolet B (UVB) rays increases with each degree decrease in latitude. Therefore, meteorological factors such as fog, clouds, and pollution have an impact on lowering the transmittance of UV rays (Manaia et al. 2013; Frederick 2015; Bais et al. 2018). The UV rays are not strong enough to affect deep biodiversity, but they can cause mutations in species composition, and species with poor protection can get harmed at an early stage of their life. UV radiation promotes the deterioration of both natural and synthetic polymers (Kocić et al. 2019). In the case of humans, the power of penetration of UV radiation is very low. Therefore, it cannot dive deep into the organ, except for the layers of the skin. Two beneficial outcomes of ultraviolet radiation (UVR) on humans include the stimulation of vitamin D production and the treatment of skin infections such as psoriasis and eczema (Parisi and Wilson 2005). It does, however, have certain severe health consequences, like skin cancer. UV is a type of electromagnetic wave radiation with a wavelength of 100–400nm. These UV rays are classified as ultraviolet A (UVA) (320–400 nm), ultraviolet B (UVB) (280–320 nm), and ultraviolet C (UVC) (100–280 nm). UVA rays have a longer wavelength and are quite safe. UVB harms the skin and eyes of humans. Despite the fact that UVB is absorbed by the ozone layer to a degree of 95%, it can still reach the atmosphere of the Earth. UVC is the most dangerous and deadly ray, with a shorter wavelength that is utterly absorbed by the atmosphere of the Earth before reaching the surface (Kerr and Fioletov 2008; Fioletov et al. 2010; Kang et al. 2011; Barnes et al. 2019). UVB is thought to be the primary cause of sunburn, tanning, wrinkling, aging of the skin, and skin cancer. UVA is taken into

account harmless, but recent research has indicated that it can be potentially harmful in the long run (Xu and Fisher 2005; Marionnet et al. 2014; Knollmann-Ritschel and Markowitz 2017).

The most efficient strategy to reduce the detrimental accomplishments of UVRs would be to avoid sun exposure altogether, which is clearly impractical or undesirable. Therefore, it is recommended to wear UV-blocking clothing, sunglasses, and sunscreen that limit exposure to sunlight at noon when maximum UV rays enter the surface of the earth (Gies et al. 2018; McKenzie and Lucas 2018). Even if the textile material itself is susceptible to limited degradation due to UVRs, the light protection of textiles can be very considerable against the harmful effects of solar UVRs (Andrady et al. 2015). Clothes are the most effective tool for protecting the skin from the harmful rays of the sun. Previously, such protective clothing was developed taking into account the thickness and therefore the absorption coefficient of certain textile materials (Wilson and Parisi 2006; Zaratti et al. 2014). Studies have shown that the sequels to sun disclosure and the depletion of the ozone layer have the highest ratings in summer. During the summer season, New Zealand, Australia, South, and Eastern Europe experience the highest level of UV radiation in the world (Laperre and Gambichler 2003). In order make these protective cloth users friendly and high comfort, studies have come up with some magnificent solutions to make these clothing as protective and cozy at the same time. Among all other natural fibers, cotton is the most popular fabric in the hot season because of its hygroscopicity, air permeability, biodegradability, lack of static electricity, and so on. It is a plentiful natural fiber made up almost entirely of cellulose (about 88–96%) (Mahbubul Bashar and Khan 2013). Cotton has the highest moisture regain properties in both slack and tight fabric dyeing, which also indicates the comfort of cotton fabric (Çil et al. 2009). Several factors are considered during the development of UV protective clothing. Factors that influence the UPF of fabrics are structures, materials, dye, and yarn morphology, UVR absorbing additives, moisture absorption, and fabric deformation. UPF values above 40 (rating 40+) and 50 (rating 50+) are entertained as the ultimate sun-blocks (Gambichler et al. 2001; Duan et al. 2011; Mishra et al. 2014). UPF is higher in fabrics with closer and tighter structures, higher GSM (weight per unit area), or thickness (Aguilera et al. 2014; Louris et al. 2018). The UPF values are also influenced by the

materials used. Synthetic yarns perform better than natural fibers in terms of UV performance (Gies et al. 1998; Aguilera et al. 2014). UVR is absorbed more by darker hues, leading to greater UPFs (Hustvedt and Crews 2005; Aguilera et al. 2014). UPF is also affected by yarn morphology. Yarns with a more wavy filament structure have a structure that allows for increased UV transmission (Singh and Singh 2013). The UV protection efficacy of clothes can be improved by using fabric with UVR absorption compounds (Gies et al. 1998).

Although many studies have been conducted on the development of UV protective textiles, there is still a lack of comprehensive reviews that provide a clear conception of UV protective cotton clothing that can be worn comfortably in the summer season. In this comprehensive review, the development of UV protective cotton fabric is focused on. This review discusses the UV protection factor of cotton fabric and the factors to consider while making UV protective clothing. It also describes the use of UV absorbers and nanoparticles for UV protection. In this review, the nanoparticle synthesizing process is also discussed to apply them onto the fabric. Finally, this review presents the current situation and future directions for further developments.

UV protection of textile materials

The potency of UV blocking is evaluated by the UV protection factor of UVA and/or UVB. UV transmittance through a fabric, both direct and diffuse, is a vital component in determining UV protection of the fabric (Gambichler et al. 2002; Dubrovski and Golob 2009). The UV protective textile should have reflecting and absorbing properties that it can head off UV rays to reach the skin. The vital property of a protective textile is determined by its transmittance (Parisi et al. 2000; Gabrijelčič et al. 2009). Fabric structures for both woven and knit fabrics are essential factors for UV transmission modification. Figure 1 shows the effect of UV radiation on textile materials.

The UV transmission factor of woven and knitted fabrics is associated with the cover and gauge of the fabric; closer and tighter structures with fewer pores result in less transmission (Wilson et al. 2008). UV rays that contact textiles are partially reflected, absorbed, and transmitted over the fibers and interstices, and the optical porosity of a fabric inhibits its probability to

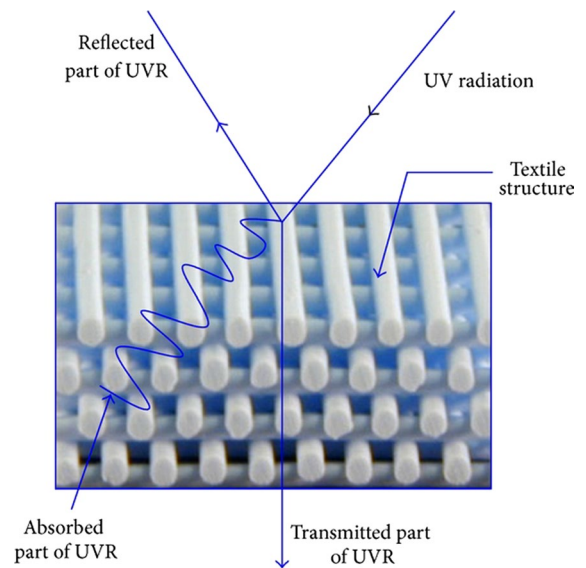


Fig. 1 UV radiation effect on textile materials (Singh and Singh 2013). Published under a CC-BY license, Hindawi

furnish UVR protection (Saravanan 2007; Kocić et al. 2019). According to Krste Dimitrovski et al. (Dimitrovski et al. 2010), the UV protection level of fabric can be determined by its designs and constructional parameters. The transmitted UV radiation in textiles is made up of two constituents: a diffuse component that is affected by the absorption qualities of the fabric and an unchanging component that passes directly through the gaps between the yarns. Changes in the construction parameters of textile materials can be used to reduce UV transmission. The right combination of the thickness, areal density, and weave of woven or knitted fabric, as well as the yarn type (mono or multifilament) and fineness, offers the possibility of UV-protective textiles. The chemical properties of the fiber and the construction parameters of the fabric influence the UPF (Majumdar et al. 2010, 2012; Wong et al. 2013).

Standard for measuring UV protective factors

The UV protection factor (UPF) is a significant statistical tool of the protection provided by UV ray protection products such as sunscreen or clothing, and it is considered to be an excellent representative of *in vivo* methods for determining the photo protection (Laperre et al. 2001). The corollary of UPF is the sun

protection factor (SPF). The core difference between UPF and SPF is that SPF is measured by human tests, whereas UPF is measured by instruments (Hustvedt and Crews 2005; Grifoni et al. 2009). To measure the UPF based on transmitted radiation, the international scientific community has established Equation (1).

$$UPF = \frac{\sum_{290}^{400} E_{\lambda} \times S_{\lambda} \times \Delta_{\lambda}}{\sum_{290}^{400} E_{\lambda} \times S_{\lambda} \times T_{\lambda} \times \Delta_{\lambda}} \quad (1)$$

Where,

E_{λ} is the solar UVR spectral irradiance (in $W \cdot m^{-2} \cdot nm^{-1}$)

S_{λ} is the relative erythemal effectiveness according to the Commission Internationale de l'Éclairage (CIE) (Webb et al. 2011).

Δ_{λ} is the bandwidth (in nm)

T_{λ} is the spectral transmission through the textile is the wavelength (in nm)

Based on this UPF calculation method, UV protective excellence has specific categories of international standards. The higher the rating indicates the better the protection. For better understanding, we can give examples like if an uncovered fair skin starts showing redness or erythema under the sun exposure at 10 minutes then under the protection of UPF rating 20 will increase the time by 20 times, which means 200 minutes. UPF ratings 40+ or 50+ are considered as excellent protection. The method mentioned in Table 1 has gained widespread acceptance as a laboratory-based test procedure (Stankovic et al. 2009). The UV Protection Factor rating categories according

to AS/NZS, ASTM, and European standards are shown in Table 1.

Factors considered for fabric construction for UV protection

Nature of fiber

Natural fiber has a great impact on the UPF of fabric. Due to the variations in ultraviolet transparency, the chemical nature of the fibers has an effect on UPF. Fibers with a large conjugated aromatic polymer system were found to be more effective in blocking UV radiation (Daoud and Kong 2004; Paul et al. 2010). Researchers have found that hydrophobic fibers, like polyester, have a high UV light transmittance protection ratio. The presence of a benzene circle in polyester may help it obtain a specious property of UV protection (Gorensek and Sluga 2004; Shim et al. 2009; Pan and Sun 2011). Benzene exhibits very strong light absorption properties. The minimal comfort properties made polyester the least used fabric during the summer. Natural fiber-made fabrics are more comfortable and are mostly used instead. Among all other natural fibers, cotton is the most widely used fabric in summer and hot weather. Most of the researchers and scientists who are interested in UV protection of natural fibers have their attention on cotton fabric. Natural fibers, such as cotton, silk, and linen, absorb less ultraviolet radiation than synthetic fibers. Spectroscopic studies of 'WB Achwal' show that cotton has relatively high UV transmission in the range of 280–400nm. Bleached cotton has a high level of permeability to ultraviolet radiation. Gray cotton shows higher UPF properties. The presence of natural pigments, pectin,

Table 1 UV protection factor rating categories according to AS/NZS, ASTM, and European standards (Gambichler et al. 2006; Stankovic et al. 2009; Harrison and Downs 2015; Downs and Harrison 2018; Louris et al. 2018)

Protection	AS/NZS 4399:1996 & ASTM D6603			EN 13758-2:2003		
	% UVB Transmittance	UPF Range	UPF Ratings	% UVB Transmittance	UPF Range	UPF Ratings
Excellent	Less than 2.5	Above 40	40, 45, 50, 50+	Less than 2.5	Above 40	40+
Very good	4.1–2.6	25–39	25, 30, 35	3.3–2.5	30–40	30
Good	6.7–4.2	15–24	15, 20	5.0–3.4	20–29	No value

and waxes in gray cotton acts as ultraviolet absorbers. Flax, hemp, ramie, and jute are examples of natural fibers that are strong UV barrier raw materials. They include colors, lignin, waxes, and pectin, all of which function as natural UV radiation absorbers (Zimniewska and Batog 2012; Subramaniyan et al. 2013). Researchers have observed a high UPF naturally-pigmented cotton fabric (Hustvedt and Crews 2005). A fabric composed of a mixture of polyester and cotton would be much more protective than one made solely of cotton. Furthermore, for warm-weather clothes, a combination of polyester and cotton would give higher absorbency and comfortability at the same time (Bajaj et al. 2000; Osterwalder et al. 2000; Stott 2010). In the case of cotton fabrics, it is obvious that greige fabrics (raw) have superior UVR protection, regardless of fabric construction (Sarkar 2007; Jansen et al. 2013). The ability of a cloth to block UV radiation is also affected by its fiber chemistry. Fibers containing a large conjugated aromatic polymer system were shown to be more effective at UV blocking (Xin et al. 2004). The chemical modification of the fiber influences the UPF. An inclusion complex was developed by the reaction of β -cyclodextrin (β -CD) with 4-hydroxy benzophenone (4-HBP), since β -CD acts as a host molecule for 4-HBP. The complex was added up to a finishing bath comprising citric acid (CA) and sodium hypophosphite (SHP) as a catalyst to provide the anti-crease and ultraviolet (UV) protection properties of the cotton fabric. The best concentration for both the UPF and anti-crease qualities was found to be 0.25 g of β -CD and 4-HBP. The UPF and the wrinkle recovery angle increase when the concentrations of CA and SHP increase. The finished fabrics show an excellent durability against 30 successive washing cycles (El Tahlawy et al. 2007; Abidi 2018). The sunscreen ingredient octyl methoxycinnamate was integrated into cyclodextrin cavities and covalently bonded to cloth fibers in another investigation. Tencel, a cellulosic fabric, was grafted with β -cyclodextrin molecules via a monochlorotriazinyl- β -cyclodextrin process (β -CDMCT). The finished fabric showed better photoprotective characteristics than the unmodified textile material even after repeated washings (Scalia et al. 2006a, 2006b).

Yarn properties

The UPF of the fabric is inversely proportional to the yarn count. Fabrics constructed from finer yarns have a finer composition (Sarkar 2004). For fabrics with finer yarns, it may also be a result of higher porosity in the fabric. However, according to another analysis, with increasing yarn fineness, the UPF increases first and then decreases (Dubrovski and Brezocnik 2009; Chattopadhyay et al. 2013; Gorjanc et al. 2014). The cross-sectional structure of the fiber can influence the UPF of textiles. According to optical theory, the cross-section of fiber has an impact on light transmittance and reflectance. Triangular configurations outperform other forms in single yarns with cube, rectangular, and rectangle cross-sections, while the round one has the least UV protection impact (yu et al. 2015; Yu et al. 2017). Yarn twist is a crucial element in determining the core and surface characteristics of the fabric, as well as the porous structure. As a result, it has a great influence on UV transmission through the fabric. Due to the increased fiber density caused by high-twist yarns, the UVR transmittance through them is reduced (Stankovic et al. 2009). The yarn hairiness may also influence the UV protection properties of the textiles. However, further studies are needed to determine the impact of yarn properties on UV shielding of cloth (Stankovic et al. 2009).

Fabric structure

Sun protective knitted and woven fabrics must have higher cover factor properties. Higher cover factors mean higher UV protection. The primarily constructional parameters of the fabric are determined by its weave/knit design, yarn count, and thread density. Yarn crimp, fabric cover factor, fabric porosity, fabric thickness, fabric mass, and fabric mass density are the secondary constructional parameters. Generally, woven fabric has a higher UV protection rate compared to knit fabric (Kathirvelu et al. 2009; Alebeid and Zhao 2017). The woven fabric has frequent inter-lacements with yarn. Comparatively knit fabric has more open structure, the porosity further increases due to stretching (Bajaj et al. 2000). Porosity and the cover factor are quite related, as both measure the tightness of the weave and the knitting (Stankovic

et al. 2009; Behcet and Halil Rifat 2010). Tighter fabric structures with smaller pores occupied more percentage of the area and created more opaque UV radiation. The fabric cover factor is proportional to its weight per unit area; a heavier fabric allows the least UV transmission, as it has a smaller space between the yarns. This gives the advantage of blocking more radiation (Sarkar 2004). The UPFs for fabrics of various densities are mentioned in Fig. 2. The designed cotton fabric can give good UV protection (UPF > 15) when the air permeability is high, and it can give excellent UV protection (UPF > 40) when the air permeability is low (Majumdar et al. 2010)(Stankovic et al. 2009).

Satin, twill, and plain weaves among woven structures give better UV protection than sateen weave because of its higher cover factor (Gabrijelčič et al. 2009). Twill and satin materials provide an excellent UPF at 70–80% tightness (Dubrovski and Golob 2009). In addition, the UPF of the different tightness weaves varied, with satin coming out on top, followed by twill and plain weaves among the three weaves important points to consider (Dubrovski and Brezocnik 2009; Khan et al. 2020). In knit construction, the double knit fabric shows higher UV protection than the single knit structure. The interlock fabric provides the highest level of UV protection, right ahead to the 1×1 rib structure, full Milano, and full cardigan (Kan 2014). Because their UPF ratings were less than 15, the plain weave and sateen weave fabrics cannot be considered to provide any level of protection based on the previously established classification parameters. The UV protection of the undyed twill weave fabric is rated as good, with a UPF of 19.2. The UPF values of undyed fabrics can be addressed using the fiber composition and the structure of the fabric (Sarkar 2004).

Fig. 2 UPFs for fabrics of various densities. Reproduced with permission (Zimniewska and Batog 2012). Copyright © 2012, Elsevier

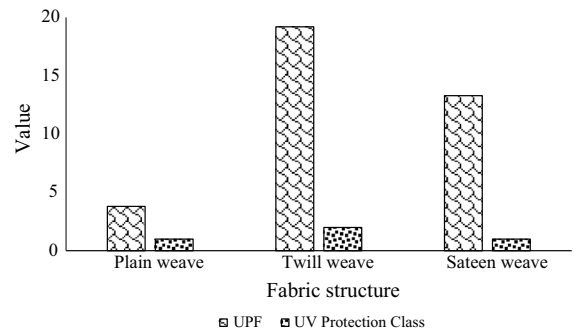
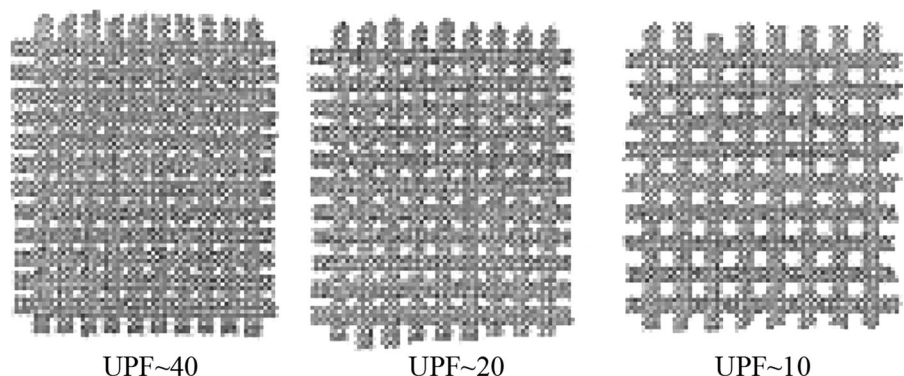


Fig. 3 UPF and UV protection class of undyed cotton fabrics for different structures

The structure and UPF of the undyed cotton fabrics are demonstrated in Fig. 3.

The UPF of undyed materials was greatly increased by dyeing with natural colorants, particularly for fabrics like plain weave and sateen weave, which had no protective properties in their original state. The amount of protection provided after dyeing was determined by the concentration of colorant in the fabric. The UPF values increased as the percentage depth of the shade increased within the same fabric type (Sarkar 2004). The UPF values, protection class, and color strength of different weave cotton fabric dyed with natural colorants at different concentrations are shown in Table 2.

Bleaching and dyeing effect

Pretreatment of the fabric is done to remove natural, applied, and obtained impurities, and coloring particles. Certain UV blocking agents are often removed or reduced in the fabric, yarn, and fiber structure. The

Table 2 UPF, and protection class of different weave cotton fabrics treated with natural colorants at different concentrations [UV protection class indicators: No class: 1; Good: 2; Very good: 3; Excellent: 4] (Sarkar 2004)

Fabric structure	Dyes	UPF	UV protection class
Plain weave	2% madder	11.1	1
	4% madder	15.8	2
	6% madder	16.6	
	2% cochineal	28.5	3
	4% cochineal	34	
	6% cochineal	36.6	
	2% indigo	43.1	4
	4% indigo	Above 50	
	6% indigo		
Twill weave	2% madder	Above 50	4
	4% madder		
	6% madder		
	2 % cochineal		
	4% cochineal		
	6% cochineal		
	2% indigo		
	4% indigo		
	6% indigo		
Sateen weave	2% madder	Above 50	4
	4% madder		
	6% madder		
	2% cochineal		
	4% cochineal		
	6% cochineal		
	2% indigo		
	4% indigo		
	6% indigo		

removal of hydrophobic impurities from the fabrics is known as bleaching.

The bleached cotton significantly provides less UV protection than the unbleached cotton (Gabrijelčić et al. 2009; Ibrahim et al. 2009). Bleaching cotton textiles massively increases their transmittance and reduces their UV protection, according to studies. The presence of wax, pectin, and natural coloring particles in unbleached cotton exhibits more UPF than bleached cotton itself. Because of the bleaching agent and consequently low UV absorbance, even the most tightly woven and maximally coated samples have inadequate UPF (Gabrijelčić et al. 2009; Samant

et al. 2020). Bleaching techniques, as well as the addition of optical brightening, fluorescent, and whitening agents, have an effect on transmission (Downs and Harrison 2018). Optical brightening chemicals, also known as fluorescent whitening agents, are poor chemical compounds that absorb and re-emit light at various wavelengths. They make white persons appear to be "whiter than white" (Sarkar 2007). Optical brightening compounds included in laundry detergents enhanced the effectiveness of UV radiation blocking of cotton clothing and cotton/polyester blends, according to the study (Algaba and Riva 2002; Riva and Algaba 2006; Abidi et al. 2007; Wang et al. 2010).

Ultraviolet protection capabilities of textile materials substantially depend on the type of pigment and dyestuff, the depth of the dyeing, the group of absorptives in the dyestuff, the uniformity and additive (Bajaj et al. 2000; Saravanan 2007; Riva et al. 2009; Alebeid et al. 2015; Wong et al. 2016a). When UV protection can be obtained by using dyes and pigments, it is not so wise to choose a heavy fabric for summer conditions. Darker colors of the same fabric type (black, navy, dark red) absorb UV radiation significantly more powerfully than light colors for equivalent weaves with UPF in the ranges of 18-37 and 19-34 for cotton and polyester, respectively. The UPF rating of some dyes, such as direct, reactive, and vat dyes, is greater than 50 (Bajaj et al. 2000; Grifoni et al. 2011). Several direct dyes increase the UPF of bleached fabric by a large amount, which is determined by the relative UVB absorbance of the dyes. The UPF of natural dyes varies from 15 to 45, depending on the mordant utilized (Gupta et al. 2005; Kim 2006; Kamel et al. 2007; Bonet-Aracil et al. 2016; Islam et al. 2021a, b, c; Liman et al. 2021; Rahman Liman et al. 2021). Cellulosic fabrics transmit UV-A and UV-B equally, according to the research, with a transmittance ratio (TA/TB) of 0.9. And if the same fabric is dyed with reactive dye, the UPF increases from 4.7 to 5.0-14.0, depending on the concentration, which is not enough to meet the minimum standards (Oda 2011; Emam and Bechtold 2015; Wong et al. 2016b). Cellulosic fabrics dyed with some vinyl sulphone dyes and monochlorotriazine dyes exhibit the reduction of UV ray transmission from 24.6% to 10-20% and 27.8% to 8-22% for UVA and UVB collectively. The UPF increases synergistically when these dyes are mixed together. For

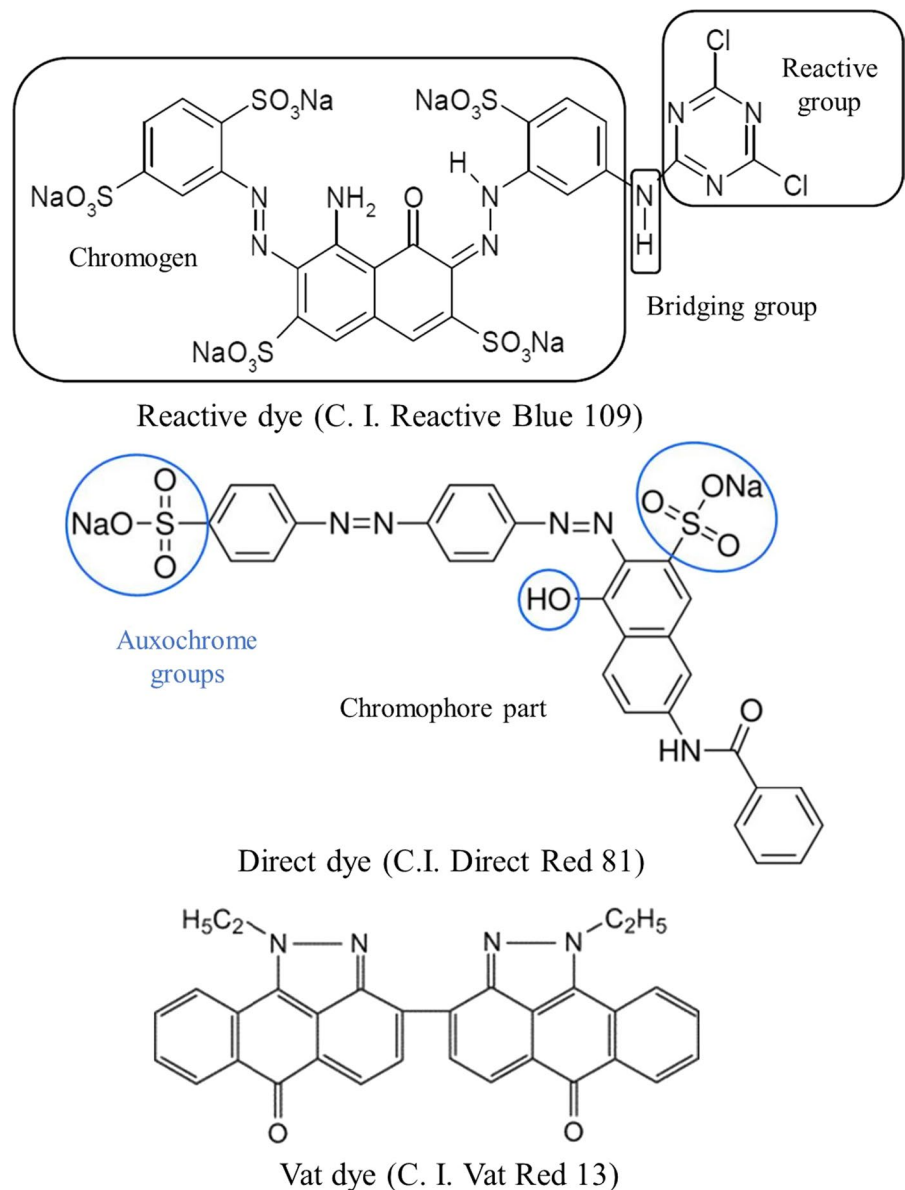
polyester/cotton blends, some dispersed reactive mix combinations may provide long-lasting UV defense with a UPF of 50+ (Alebeid and Zhao 2017). The structures of some dyes with good UV absorption are shown in Fig. 4.

UV radiation is absorbed by several dyes. According to studies, the darker the shade of a specific color, the greater the protection. In general, navy, black, and olive tones offer more protection than light pastels and, as a result, have a higher UPF rating. The influence of color on the UPF of cotton fabrics with identical weaves and weights is shown in Fig. 5. This

should only be used as a reference, as different fabrics may have different properties.

The naturally coloured cottons demonstrated considerably higher UPF values than conventional cotton (Hustvedt and Crews 2005). The natural dye produced from henna leaves can be used to produce outstanding UV-protective cotton fabric. The dyeing temperature and time were found to be important factors in improving UV protection (Alebeid et al. 2015). Feng et al. developed ultraviolet protective cotton fabric using Rheum and Lithospermum erythrorhizon. The materials coloured with natural dyes exhibited good

Fig. 4 Molecular structures of C. I. Reactive Blue 109. Reproduced with permission (Pal 2017). Copyright © 2017, Elsevier; C.I. Direct Red 81 (Walger et al. 2018). Published under a CC-BY license, MDPI and C. I. Vat Red 13. Reproduced with permission (Golob and Ojstršek 2005). Copyright © 2005, Elsevier



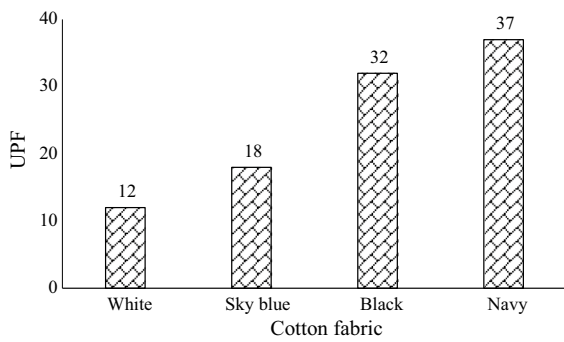


Fig. 5 UPF of different identical cotton fabrics

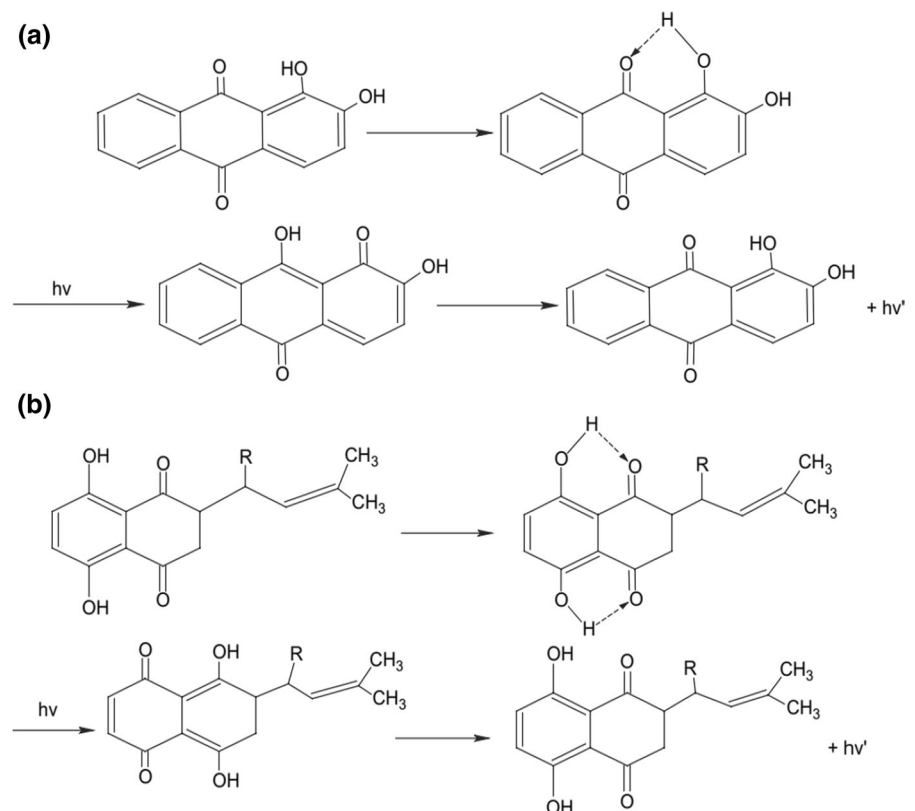
ultraviolet protection characteristics, according to the results of the experiments. They were able to absorb around 80% of UV radiation (Feng et al. 2007). When natural dyes are exposed to UVR, they can undergo a photochemistry reaction, as seen in Fig. 6. Salah investigated the antibacterial activity and UV protection properties of cotton fabrics treated with aqueous extract from banana peel and discovered that the mercerized cotton fabrics had excellent antibacterial

activity, high dye uptake, and high UV protection properties compared to control and unmercerized cotton (Salah 2013).

Moisture and swelling effect

The UPF of the moist garment is slightly better than that of the same garments in the dry state. The presence of water molecules in the fabric's interstices decreases scattering and thereby increases its permeability to ultraviolet radiation. The UPF rating of the fabric decreases from 30% to 50% when it is wet. The capacity of textile fibers to protect against UV radiation varies depending on their structure and other additions (Tsunami and Wang 2010; Sayed et al. 2015). The UPF of textile materials is also impacted by the construction characteristics and wear circumstances of textile materials, as well as the moisture and additives used during production (Bajaj et al. 2000). Moisture has a strong impact on the form and hygroscopicity of the fibers, as well as on the conditioning time, resulting in swelling phenomena (Hearle and Morton 2008; Grishanov 2011). The UPF of a

Fig. 6 Illustration of a UV-absorptive scheme for the natural dyes: a. *Rheum* and b. *Lithospermum erythrorhizon*. Reproduced with permission (Feng et al. 2007). Copyright © 2007, Elsevier



fabric is affected by the relative humidity percentage or the moisture content of the fibers in two ways. Fibers swell as a consequence of moisture absorption, reducing interstices and thus the UV penetrance. The presence of water, on the other hand, decreases scattering effects because the refractive index of water is similar to that of the textile polymer, resulting in higher ultraviolet transmission compared to a lower UPF value (Bajaj et al. 2000). When a cotton garment is wet, it can emit up to 50% more UV rays than when it is dry. For sufficient and exceptionally good protection, ultraviolet radiation transmission should be less than 6% and 2.5% (Saravanan 2007).

UV absorbers

Colorless organic or inorganic compounds that absorb substantially in the UV range of 290–360 nm are termed as UV absorbers (Krizek and Gao 2004; Saravanan 2007; Das et al. 2010). UV absorbers operate as radical scavengers and quench singlet oxygen in the fibers, converting electrical excitation energy into heat energy. The high-energy, short-wave UVR stimulates the UV absorber to a higher energy state, and the energy absorbed can then be dissipated as longer-wave radiation (Das et al. 2010). Isomerization can occur, on the other hand, causing the UV absorber to fragment into non-absorbing isomers. UV absorbers, which are used in sunscreen lotions, physically block UVR (Aloui et al. 2007; Das et al. 2010). 2-hydroxybenzophenones, 2-hydroxyphenyl benzotriazoles, and 2-hydroxyphenyl-s-triazines seem to be the most important classes of ultraviolet absorbers. The most widely used UVB screens, 2-ethyl hexyl-4-methoxy cinnamate, have a high refractive index (RI) and contribute significantly to the skin RI matching (Smith et al. 2002; Shen et al. 2014). To avoid color deterioration or loss, an effective UV absorber must be able to absorb across the spectrum, remain stable against UVR, and disperse the energy absorbed (Wong et al. 2013). O-hydroxybenzophenones, O-hydroxy phenyl triazines, and O-hydroxy phenyl hydrazines are the most commonly used organic UV absorbers. The chemical structures of UV absorbers for cotton fabric are mentioned in Table 3.

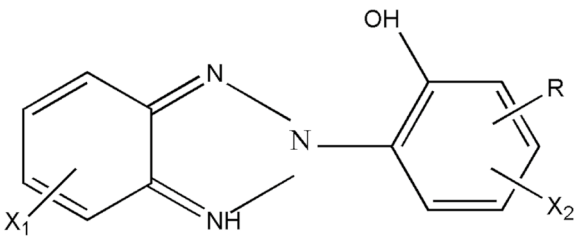
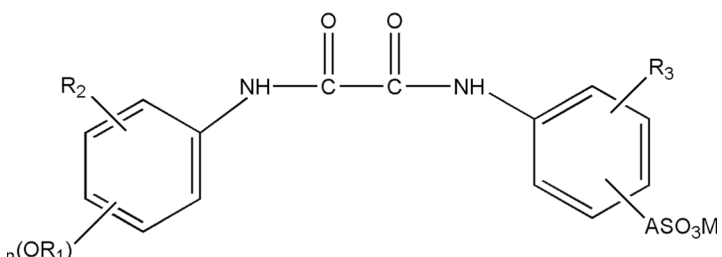
The orthohydroxyl group is known to promote absorption and ensure that the chemical is soluble

in alkaline solutions. UV absorbers often employed include 2-hydroxy benzophenones, 2-hydroxy phenyl benzotriazoles, 2-hydroxy phenyl-striazines, and compounds such as benzoic acid esters and hindered amines (Sekar 2000). The significant absorption of 2, 4 dihydroxybenzophenone near UV is due to conjugate chelation between the orthohydroxyl and carbonyl groups. Organic compounds, including benzotriazole, hydro benzophenone, and phenyl triazine, are commonly employed in coating and padding techniques to produce a wide UV protection (J. Rupp 2001). Synergistic effects can be achieved by using the right mixture of UV absorbers and antioxidants (Smith 2000; Hussain et al. 2012; Khan et al. 2017). Low energy levels, quick diffusibility, and low sublimation fastness characterize benzophenone derivatives. Orthohydroxyphenyl and diphenyltriazine derivatives have excellent sublimation fastness, and a self-dispersing formulation can be utilized in both pad-baths and print pastes for high-temperature dyeing (Kathirvelu et al. 2009).

UV absorbers applied to the spinning dope prior to fiber extrusion and dye bath in bath dyeing increase the light fastness and weatherability of spun-dyed fibers (Hearle and Morton 2008). UV absorbers to the extent of 0.6–2.5% are sufficient to provide UVR protection fabrics (Wong et al. 2006). Even so, recent findings have shown that these chemicals have limitations in terms of application due to toxicity, poor activity, and poor washing fastness.

The performance of two common UV absorbers, benzophenone, and its derivative 2, 4 dihydroxybenzophenone, was investigated in terms of UV protection factor (UPF), color fastness, tensile strength, handling, and other factors. The ability of two novel UV absorbers, avobenzone alone and in conjunction with octocrylene, to absorb UV radiation over a broader spectrum was also tested. Compared to benzophenone, the effect of UV finish with 2, 4 dihydroxybenzophenone was found to be more apparent; UPF ratings increased up to 200 with avobenzone alone and in conjunction with octocrylene. In the UV-A and UV-B ranges, the combination of innovative UV absorbers significantly reduced UV transmission to well below 1% (Chakraborty 2014). The influences of benzophenone, 2, 4-dihydroxy benzophenone, avobenzone,

Table 3 Chemical design of UV absorbers for cotton fiber. Reproduced with permission (Alebeid and Zhao 2017). Copyright © 2017, Taylor & Francis

UV absorber	Chemical design
Benzotriazole derivatives	 <p>R = Alkyl, Alkoxy, Sulfonate X₁ = H, Sulphonate, Halide, Sulphonate arylalkyl X₁ = X₂</p>
Oxalic acid dianilide derivatives	 <p>R₁ = Substituted or unsubstituted alkylbenzyl n = 0, 1, 2 R₂ = H, Halide, Alkyl, Phenylalkyl R₂ = R₂ (Identical or different) A = Direct bond or alkylene linkage M = H or alkali metal</p>

and avobenzene + octocrylene on UPF of white and reactive dyed cotton are shown in Fig. 7.

Nanoparticles for UV protection

Common textile finishing methods for imparting various properties to cotton fabric do not always to produce long-term results, and their effect is impaired after laundering or usage. Nanoparticles (NPs) have a larger surface area and energy; thus they can provide a large surface area for treated fabrics, resulting in a significant affinity for the fabric and a better endurance of the intended textile functionalities (Wong et al. 2006). The use of semiconductor and metal nanostructures in textile finishes has exploded in recent years due to their unique properties (Roe and Zhang 2009). In addition to UV

protection properties, researchers have found that cotton fabric treated with different nanoparticles is useful in a variety of applications, including hydrophobicity, antimicrobial, and self-cleaning (Wong et al. 2006; Gorenšek and Recelj 2007; Shateri-Khalilabad and Yazdanshenas 2013).

ZnO as UV protective nanoparticles

ZnO (zinc oxide) nanoparticle has unique photocatalytic, electrical, electronic, optical, dermatological, and antibacterial properties; due to these characteristics, ZnO is the most vastly studied material (Çakir et al. 2012; Barani 2014; Ibănescu et al. 2014). Many recent studies have found that cotton fabrics containing nano-ZnO provide better UV protection. The performance of ZnO nanoparticles as UV absorbers can be efficiently transferred to fabric materials by coating

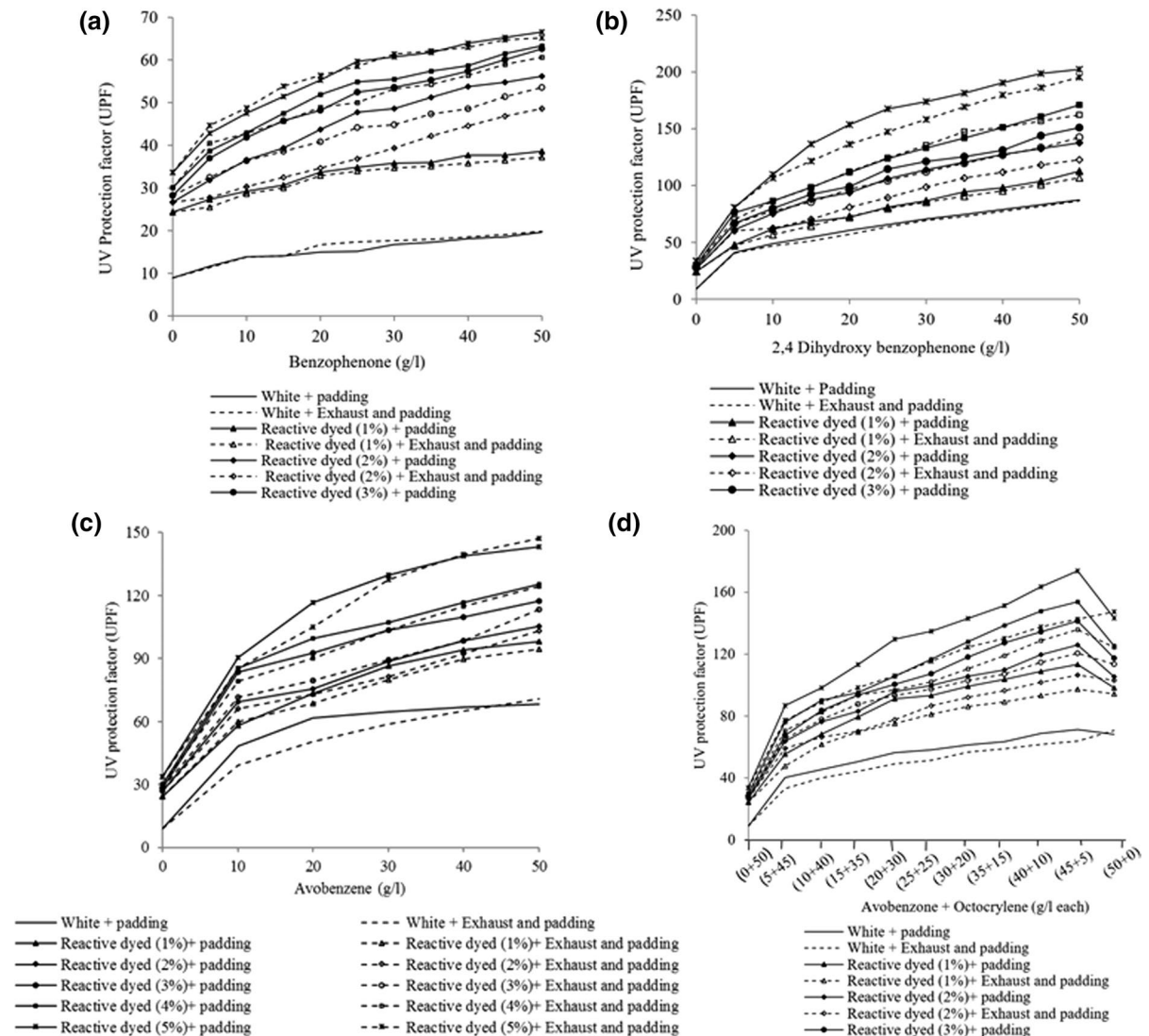
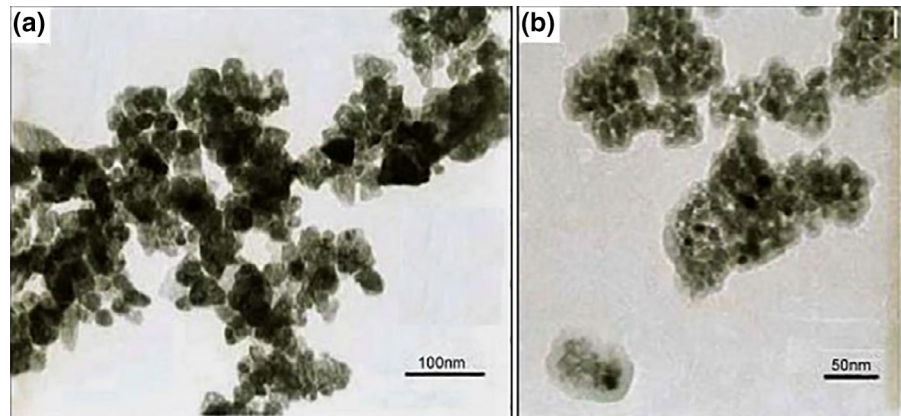


Fig. 7 Influence of (a) benzophenone, (b) 2, 4dihydroxy benzophenone, (c) avobenzone, and (d) avobenzone + octocrylene on the UPF of white and reactive dyed cotton (Chakraborty et al. 2014). Published under a CC-BY license

them with ZnO nanoparticles on the surface of cotton (Vigneshwaran et al. 2006; Becheri et al. 2008; Li et al. 2011; Abd Elhady 2012; Shateri-Khalilabad and Yazdanshenas 2013; Advances 2019). The nanoparticles must be diffused in a suitable solvent and a series of processes must be performed to enhance the stability of the ZnO nanoparticles and inhibit particle aggregation in order to manufacture UV-protective textiles (Kathirvelu et al. 2009; Lee 2009; El Shafei and Abou-Okeil 2011; Sivakumar et al. 2013). ZnO nanoparticles were produced using a solution of

ZnCl₂ and 2-propanol in the research conducted by S. Kathirvelu et al. As a result, samples made in an aqueous medium are larger than those produced in a more monodisperse propanol solution (see in Fig. 8). The results of the UV transmission and UPF values for the UVA and UVB ranges found that cotton samples containing ZnO nanoparticles provided greater protection than cotton samples manufactured using the synthesis 2 techniques. It should be remembered that the padding method of applying ZnO nanoparticles to fabrics will result in particle penetration into

Fig. 8 (A) water-synthesized samples (synthesis 1) and (B) samples synthesized in 1, 2-propanol solution (synthesis 2). Reproduced with permission (Kathirvelu et al. 2009). Copyright © 2009, NOPR



the yarn interstices. Since these nanoparticles may not remain on the surface of the fabrics, they might not quite be effective (Kathirvelu et al. 2009).

Electrospinning was utilized in another study to investigate the influence of ZnO nanoparticle accumulation on polypropylene nonwoven fabrics (Lee 2009). The solution of polyurethane in DMF and the addition of zinc oxide nanoparticles at various concentrations to the solution produce electrospinning solutions. Depending on the degree of ZnO content (0–2 wt%), UPF increased from 2 to 50+ (see in Fig. 9). Wang et al. used the sol-gel finishing process to create dumbbell-shaped ZnO crystallites with a size greater than 500 nm on cotton fabric. Using a dip-pad-cure technique, clear solutions of zinc acetate and triethenamine in 2-methoxyethanol, equal to 3 percent by the weight of ZnO, were added twice to cotton fabrics and then cured at up to 400°C. Curing at temperatures above 150°C resulted in a UPF value

of >400. After five laundering cycles, this approach offered consistent fastness (Wang et al. 2005). Yadav et al. used zinc nitrate and sodium hydroxide as precursors and soluble starch as a stabilizing agent to make ZnO using a wet chemical process. Around 75% of the incident UV ray was blocked by 2% nano-ZnO on cotton fabric (Yadav et al. 2006). Noorian et al. employed a bi-component metal oxide to improve UV protection in textiles and polymers. $\text{Cu}_2\text{O}/\text{ZnO}$ nanoparticles were produced in situ on the cotton fabric surface to improve UV protection. According to the findings, the use of $\text{Cu}_2\text{O}/\text{ZnO}$ nanoparticles on cotton fabric provides significantly better UV protection than using ZnO and Cu_2O nanoparticles alone. They claim that ZnO nanoparticles have higher UV absorption and reflectance than Cu_2O nanoparticles, which protect treated cotton fabric, and that both can shield fibers together by forming a thin layer of particles on the fabric surface in situ (Noorian et al. 2015).

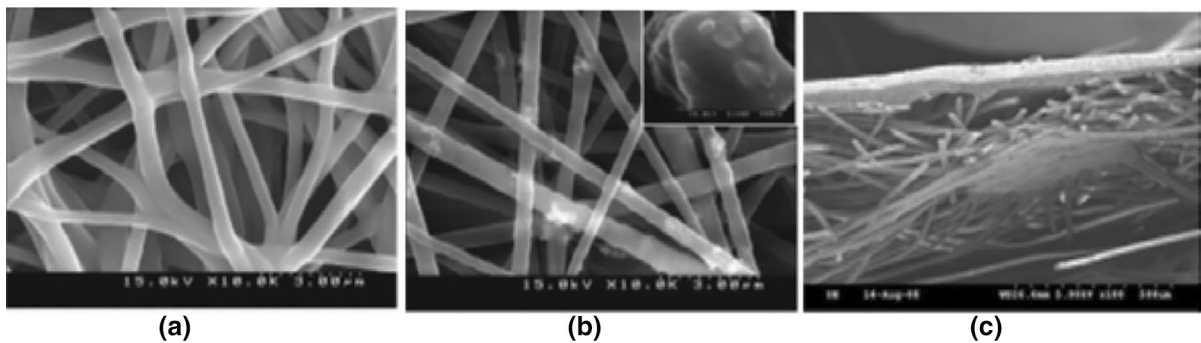


Fig. 9 SEM of electrospun polyurethane nanofiber web (A), electrospun polyurethane/zinc oxide nanocomposite fiber web (B) cross-sectional view of a nanocomposite fiber (inset),

and cross-sectional view of a layered fabric system (C). Reproduced with permission (Lee 2009). Copyright © 2009, Springer nature

Lu et al. recommended that cotton fabrics be treated with encapsulated ZnO in polystyrene. Although a grainy coating on the fibers provided a high UPF value, after 10 home washings, the UPF value decreased significantly from 86.6 to 15.3 (Lu et al. 2006). Fig. 10 shows a ZnO-PS based nanosphere with carboxylic surface functional groups, as well as the attachment of a ZnO-PS based hybrid nanosphere to cotton through an esterification reaction between the cotton –OH groups and the ZnO-PS based hybrid nanosphere –COOH groups. A primary hydroxyl group is found at C6 in a cellulose moiety of cotton fabric, whereas secondary hydroxyl groups are found at C3 and C2 (Seth et al. 2020).

Becheri et al. synthesized ZnO nanoparticles from ZnCl₂ and NaOH in a homogeneous phase process in H₂O or C₂H₆O₂ at high temperatures and then applied them to cotton and wool fibers. The UV transmittance of the textiles was lowered from 90% to 20% (Becheri et al. 2008). Mao et al. developed ZnO nanoparticles directly in situ on SiO₂-coated cotton fibers using a hydrothermal mechanism (Mao et al. 2009). Hydrothermal techniques have been recognized as a favorable and easy control approach for the creation of crystalline nanoparticle metal oxides with a limited size distribution, excellent crystallization, few agglomerates, and phase purity (Ledwith et al. 2004). Cotton fabric was pretreated with SiO₂ sol to optimize wash and light color fastness (Mahltig and

Textor 2006). The cotton was coated with needle-shaped ZnO nanorods with a diameter of 24 nm after hydrothermal processing. The UV-blocking quality of the coated fabrics was excellent, with a UPF value of over 50. However, after 5 launderings, the UPF dropped to half what it was before (Fig. 11) (Mao et al. 2009). Another study discovered that cotton fabric functionalized with biosynthesised NP ZnO had a higher efficacy in blocking ultraviolet light (UV) (Asmat-campos et al. 2021).

Cotton fabrics treated with ZnO nanoparticles demonstrated significant UV protection (87.8 UPF), hydrophobicity (155), and zone of bacterial inhibition against *E. coli* and *S. aureus* (25.13, 0.05 mm and 30.17, 0.03 mm, respectively). This study used zinc acetate as a precursor to green synthesis of ZnO nanoparticles from *Acalypha indica* leaf extract (Karthik et al. 2017). When the cotton fabric was treated with AuNPs/ZnONPs, it demonstrated a significant increase in UV protection. Even after 15 washings, the imparted functional qualities showed outstanding preservation. The antibacterial activity of the activated fabric samples is significantly improved against both *S. aureus* and *E. coli* (Ibrahim et al. 2016). In another study, aminopropyltriethoxysilane was used as a silane cross-linker to anchor zinc oxide nanoparticles to a pristine cotton fabric surface, which was then modified using hexadecyltrimethoxysilane, a silane hydrophobe. With a water contact angle of

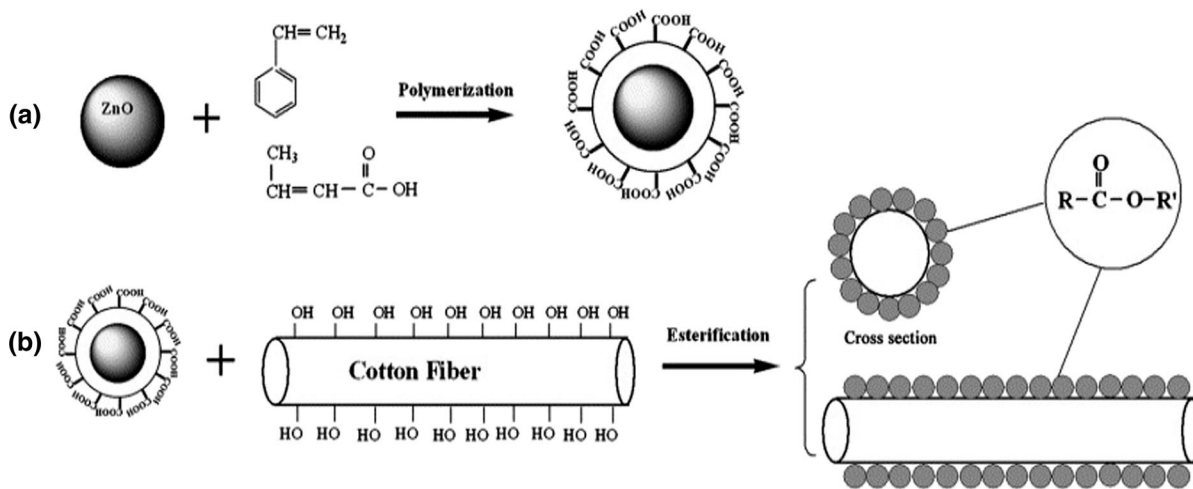
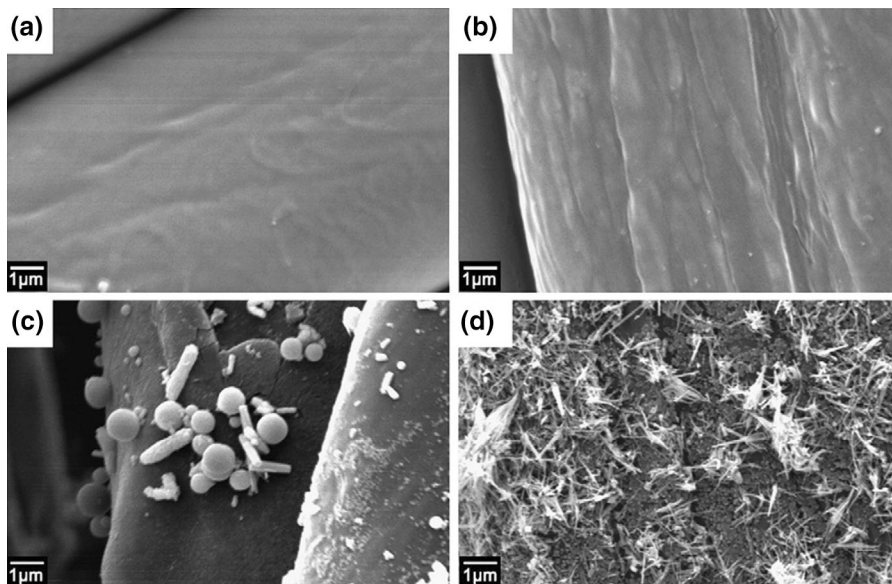


Fig. 10 Schematic showing a ZnO-PS based hybrid nanocoating on cotton fabrics. (a) ZnO-PS nanosphere with carboxylic surface functional groups; (b) esterification reaction of cotton –

OH groups and ZnO-PS hybrid nanosphere –COOH groups to connect the ZnO-PS hybrid nanosphere to cotton. Reproduced with permission (Lu et al. 2006). Copyright © 2006, Elsevier

Fig. 11 SEM images of cotton (A) before modification, (B) after soaking in the SiO₂ solution, (C) after chemical deposition of ZnO, and (D) after hot H₂O treatment at 100°C for 2.5 h. Reproduced with permission (Mao et al. 2009). Copyright © 2009, Elsevier



154°, a water shedding angle of 2°, antibacterial activity of up to 98%, and UV-blocking ability more than 200 times that of pure cotton, this dual-silanization technique produces highly functional fabrics with superhydrophobicity. The materials are extremely resistant to abrasion, ultrasonic washing, immersion in various pH solutions, and UV irradiation when used as is (Agrawal et al. 2019).

TiO₂ as UV protective nanoparticles

TiO₂ (titanium dioxide) is widely used in photocatalytic processes rather than any other semiconductor, including ZnO, SnO₂, ZrO₂, Fe₂O₃, and TiO₃, since it is chemically and thermally stable and non-toxic (Roessler et al. 2002; Akhavan Sadr and Montazer 2014; Karimi et al. 2014). Special properties of TiO₂ nanoparticles such as higher stability, long-lasting, safe, and broad-spectrum antibiosis, have paved the way for new applications as an appealing multifunctional material (Roessler et al. 2002; Bae et al. 2003; Abidi et al. 2009). All these properties make TiO₂ nanoparticles useful in a variety of applications, including self-cleaning, antibacterial, UV-protection, and environmental purification (Han and Yu 2006; El-Naggar et al. 2016; Ahmad et al. 2019). Three well-known crystalline forms for TiO₂ are anatase (which has a wavelength of 388 nm), rutile, and brookite (Park and Kim 2005). Anatase is metastable at lower temperatures, according to Reidy, Holmes,

and Morris, and is particularly suitable for catalysis and photo-catalysis along with its greater surface area (Reidy et al. 2006). Anatase titanium dioxide has excellent catalytic activity than rutile, according to another research (Fu et al. 2005). As titanium dioxide is irradiated with light that has higher energy than that of its band gaps, electron hole pairs form at the surface, causing redox reactions. As a consequence, electrons in TiO₂ jump from the valence band to the conduction band, resulting in the formation of electron (e⁻) and electric hole (h⁺) pairs on the photo-catalyst surface. Negative electrons and oxygen form O₂, while positive electric holes and water form hydroxyl

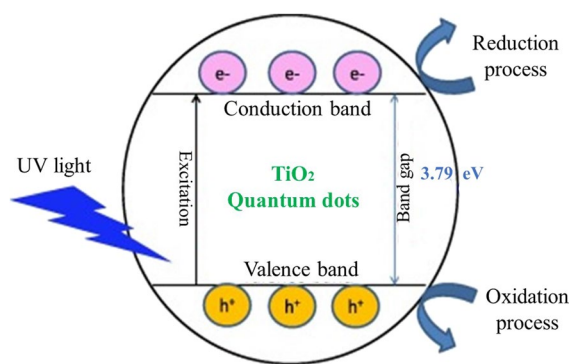


Fig. 12 The mechanism of photocatalytic activity of TiO₂ quantum dots (QDs). Reproduced with permission (Gnanasekaran et al. 2015). Copyright © 2015, Elsevier

radicals (see in Fig. 12) (Wong et al. 2006; Dastjerdi et al. 2010).

For the synthesis of TiO₂ nanoparticles, a variety of techniques have been used. Sol–gel processing is one of the most popular processes (Keshmiri et al. 2004). The anatase form of the TiO₂ nanoparticles was produced using the sol–gel technique. The pH of the solution and the rate at which isopropoxide is supplied are thought to affect particle size. Titanium dioxide nanoparticles have been used to achieve anti-bacterial, self-cleaning, UV protection, hydrophilic or ultrahydrophobic characteristics, and color degradation in textile effluent (Daoud et al. 2005; Mahmoodi et al. 2006).

According to a report, because of its large specific surface area and high surface energy, nanoscale TiO₂ has a strong affinity for fabrics. When used as a solar UV protector, however, the blue change of the nano-absorption TiO₂ edge is disadvantageous because it decreases UVA absorption (Yang et al. 2004). According to Zheng et al., treating cotton fabrics with nano-TiO₂ sols can lead to improved UV resistance. For cotton fabrics treated with nano-TiO₂ sols, the following finishing method is recommended: 40 % nano-TiO₂ sols, two dip-two pads with 70% wet pickup, drying at 50°C for 5 minutes, and curing at 165°C for 3 minutes (Zheng et al. 2011). Abidi et al. treated the cotton fabric with TiO₂ nano sol, which gave the cotton fabric excellent UVR protection, particularly in the UVB [290–315 nm] area. The establishment of covalent bonds between the (OH) groups of cellulose and the (OH) groups of the titania network resulted in excellent durability of the treatment in repeated home laundering (Abidi et al. 2007).

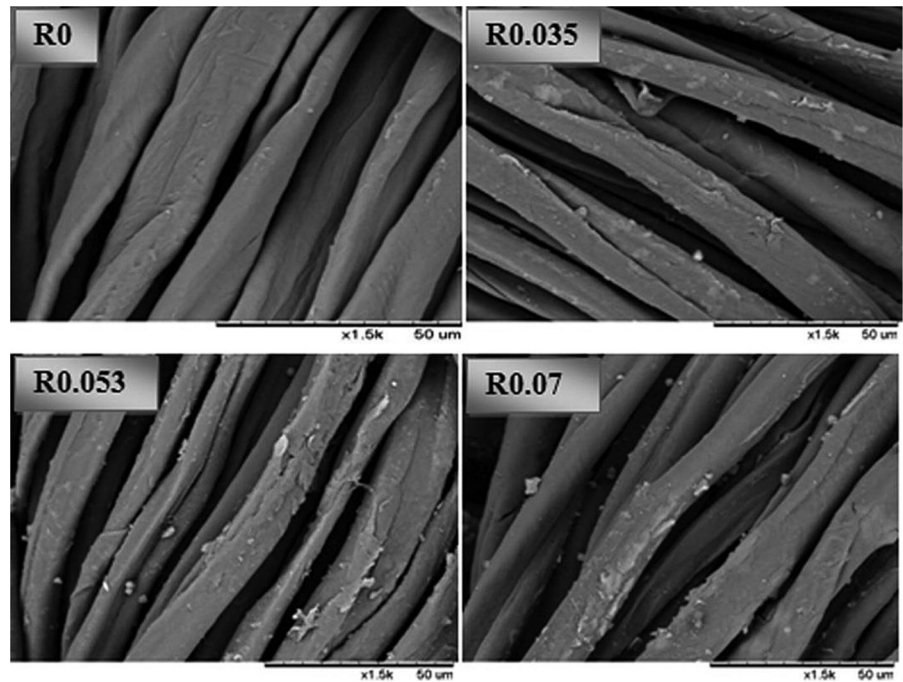
The cotton fabrics coated with TiO₂ nanoparticles were found to be resistant to domestic washing by Roshan et al. The UPF values remained similar even though the load of nanoparticles on the fabric surface decreased after washing, indicating the performance of the technology. The linking agent strategy produced better results for both undyed and dyed samples compared to the sol–gel method. Similarly, it has been observed that the rutile crystalline phase is more useful for UV protection in existing textile mill gear, making it industrially feasible (Mukaihata et al. 2008; Paul et al. 2010). Ukaji et al. coated thin layers of aminoethyl aminopropyl trimethoxy silane on TiO₂ particles in ethanol, by applying silane during the ball-milling process (Ukaji et al. 2007). Shafi

et al. used ultrasonic irradiation to coat octadecyltri-hydrosilane on TiO₂ surfaces in heptane (Paul et al. 2010). Inert shells, usually composed of silica, were recently coated onto TiO₂ cores to suppress the photocatalytic property of TiO₂ while retaining their UV-protective property (Paul et al. 2010). Toni et al. used a seeded sol–gel method of tetraethyl silicate (TEOS) in ethanol to coat dense SiO₂ shells with TiO₂ particles (El-Toni et al. 2006). The techniques mentioned here could be utilized to effectively create TiO₂–SiO₂ core-shell particles, however, they do have certain limitations. TiO₂ colloids or TiO₂ dispersion must be developed prior to the silica coating procedure. Second, the silica layer is often formed in a non-aqueous environment, requiring a considerable volume of organic solvent. Finally, the core-shell particles manufactured using the techniques described above are relatively large due to the agglomeration of commercial TiO₂ powders. As a result, these particles can not be found in transparent materials (El-Toni et al. 2006; Demirörs et al. 2010).

Zhang et al. used a simple miniemulsion-combined sol–gel approach to make the TiO₂–SiO₂ hybrid. The UV-blocking efficiency of this hybrid was excellent without affecting the transparency (Zhang et al. 2010). Zhang et al. used the sol–gel technique to synthesize TiO₂–SiO₂. Materials modified with TiO₂/SiO₂ had better protection compared to materials modified with silica particles or materials that were not treated. Furthermore, the coated nanoparticles had no impact on the organic materials in terms of photodecomposition. The TiO₂/SiO₂ has potential in UV blocking utilizations during inhibiting photodecomposition upshot on organic substrate, according to the experimental results and the technological approach (Zhang et al. 2011). Figure 13 exhibits SEM of cotton colored with CI reactive red 120 at varying concentrations of TiO₂, as well as specimens colored with commercial CI reactive red. Figures 14 and 15 demonstrate XRD, and SEM images of untreated and treated cotton with TiO₂ NPs based on different urea nitrate (UN) concentrations.

As indicated in Fig. 14, the structural characterization of TiO₂NPs with various concentrations on the cotton surface was studied using XRD with Cu radiation. The peaks at 2theta 14.8°, 16.6°, 22.7°, and 34.4° (Fig. 14) correspond to the diffraction planes of cellulose Ibeta (1-10), (110), (200) and (004), respectively (French 2014). Some reasonably strong

Fig. 13 SEM of colored cotton with colour index (CI) reactive red 120 doped with various amounts of TiO₂ nano-sol and specimens colored with commercial CI reactive red 120. Reproduced with permission (Alebeid and Zhao 2016). Copyright © 2016, Taylor & Francis



reflection peak at 27.56°, 40.44°, 43.33°, 65.88°, and 87.42° correspond to TiO₂NPs (T1). There is a small shift for the stated peak as the concentration of TiO₂ NPs increases (T2 and T3). The produced TiO₂NPs were found to be well correlated to the rutile phase, with significant diffraction peaks corresponding to the (110), (101), (111), (211), and (220) orientations, accordingly.

Figure 15 shows how treated cotton modifies the morphological structure (T1, T2 and T3). As a result, the surface of the cotton turns rough and uneven, suggesting that TiO₂ NPs have been successfully coated on the surface. The EDX spectrum revealed elemental analyses of C, O, and Ti, indicating the existence of a Ti layer coating on the cotton surface.

Graphene as UV protective nanoparticles

Because of its remarkable mechanical, electrical, thermal, and optical properties, graphene and its derivatives have attracted a lot of attention from the semiconductor field (Bonaccorso et al. 2010; Ponraj et al. 2016; Ergoktas et al. 2020; Bhattacharjee et al. 2021). The pad-dry-cure approach was employed by Lijun et al. to functionalize cotton fabric coated with low graphene nanoplate (GNP) (0.05–0.4 wt.%). With only 0.4% weight of GNP, the modified cotton gave

outstanding UV protection, with a 10-fold increase in UPF (from 32.71 to 356.74) (Qu et al. 2014). Pandiyarasan et al. proposed a new way for increasing the UPF value of cotton fabric by using a non-toxic hydrothermal technique to deposit reduced graphene oxide (rGO). Before and after laundering, the UPF values of bare cotton and rGO-deposited cotton fabric were calculated to be 7.83, 442.69, and 442.32, respectively. The manufactured material was established to have outstanding UV protection properties as well as a long lifespan (Pandiyarasan et al. 2017). In order to improve the UPF value of cotton fabric, Tian et al. developed a new electrostatic self-assembly (ESA) technology (Tian et al. 2016).

Graphene oxide (GO) is a negatively charged nanostructure in an aqueous solution that may be simply constructed on a substrate with positively charged polyelectrolyte through the ESA method to form a multilayer network. They used the layer-by-layer ESA technique to create a UV-protective cotton fabric with GO as a polyanion and chitosan (CS) as a polycation. The UPF values increased as the number of GO/CS-deposited layers on the textile increased. In comparison to cotton control fabric with a UPF of 9.37, fabric with a double layer of (GO/CS)₁ had a UPF of 88.93, while fabric with ten double layers of (GO/CS)₁₀ had a UPF of 452. The UPF values of the

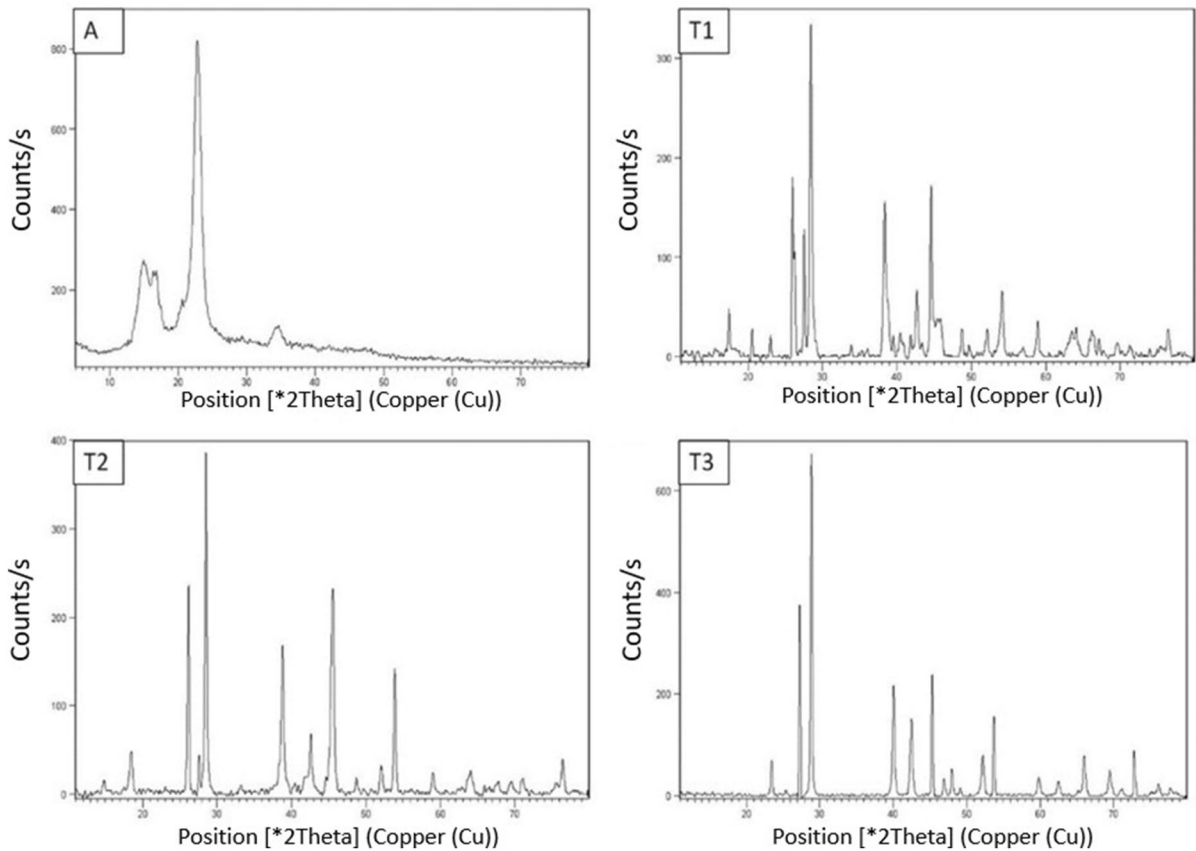


Fig. 14 XRD of untreated and treated cotton fabrics with TiO_2 NPs based on different concentrations of UN, (A) untreated, (T1) treated cotton fabric with 0.2 g, (T2) treated cotton fabric

with 0.4 g, and (T3) treated cotton fabric with 0.6 g of UN. Reproduced with permission (El-Naggar et al. 2016). Copyright © 2016, American Chemical Society

$(\text{GO}/\text{CS})_1$ and $(\text{GO}/\text{CS})_{10}$ specimens decreased from 88.93 to 80.22 and 452 to 431.39, respectively, after 10 times water washings. The UV (UVA and UVB) transmittance increased by less than 1%, showing that GO/CS-deposited textiles delivered excellent UV protection and washing endurance. Figure 16 illustrates a graphical representation of UV protection cotton fabric developed through layer by layer self-assembly of GO and chitosan technique (Tian et al. 2016).

Carbon nanotube (CNT) as UV protective nanoparticles

Carbon nanotubes (CNTs) are one of the important components of nanotechnology, with a length-to-diameter ratio of more than 1,000,000. They are used in a variety of sectors in material research because of their anisotropic electrical, mechanical, and thermal

properties. CNT has been created through a variety of ways. They offer great promise for use in a variety of industries, including nanoelectronics, biotechnology, material science, polymer, composite, and textiles. Recent studies on the use of carbon nanotubes in UV protection for cotton fabrics are covered in this study. Fabrics treated with carbon nanotubes produce a wide range of conductive textiles with varying electrical characteristics. The fabric wear properties combined with carbon nanotubes expand the possibility of creating composite materials for both traditional and novel implementations, ranging from traditional apparel and sportswear to protective clothing, heating equipment, automotive textiles, building coverings, geotextiles, biomedical textiles, and so on. Nanotubes are classified into two types: single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs). To develop single-walled nanotubes, a

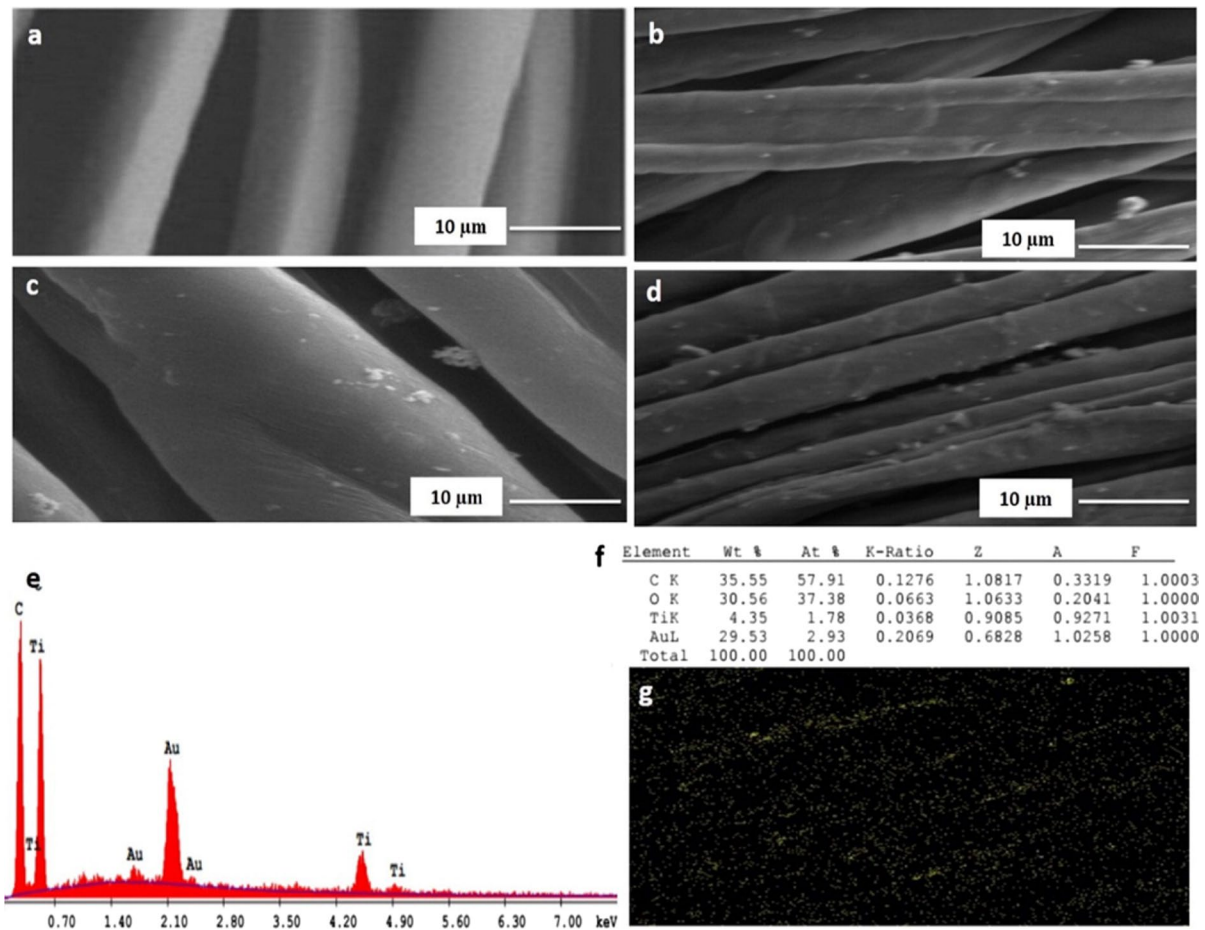


Fig. 15. SEM of (a) pristine cotton, TiO_2 NPs treated cotton employing (b) 0.2 g of UN, (c) 0.4 g of UN, and (d) 0.6 g of UN, (e) EDX, and (f) elemental contents of TiO_2 NPs treated

cotton fabrics. Reproduced with permission (El-Naggar et al. 2016). Copyright © 2016, American Chemical Society

single graphite sheet is precisely coiled into a cylindrical tube (SWNT). The majority of SWNTs are about 1 nanometer in diameter, although they can be much larger. The multi-walled carbon nanotubes (MWCNTs) were made up of tens of graphitic shells, each with a high length-to-diameter ratio (Kuzmany et al. 2004; Grobert 2007; Wu 2009; Bilotti et al. 2013; Cao et al. 2013; Mallakpour and Khadem 2016; Siqueira and Oliveira 2017; Shahidi and Moazzenchi 2018; Devi and Gill 2021).

Chemically, inorganic UV blockers are harmless and chemically stable. UV radiation is efficiently absorbed and scattered by nanoscale semiconductor oxides. Scattering is affected by the size and wavelength of the nanoparticles (Yetisen et al. 2016). The surface coating approach was used to modify the

properties of cotton fibers using CNT. CNT network armor has indeed been constructed on the exterior of cotton fibers, and cotton fabrics with 0.25 percent CNT demonstrate remarkable UV protection (Liu et al. 2008). The UV-blocking characteristics of polymer materials can really be improved by carbon nanotubes. The coloring effect is a limitation of employing CNT in textiles. After the operation, the cotton fabrics will turn black. Combining CNT with additional UV-blocking chemicals is recommended to reduce the coloring influence of CNT on fabrics (Liu et al. 2008). The schematic of the structures of cotton fiber and cotton fiber with CNT network armor is shown in Fig. 17. SEM images of pristine cotton fibers and CNT-coated cotton fibers are presented in Fig. 18.

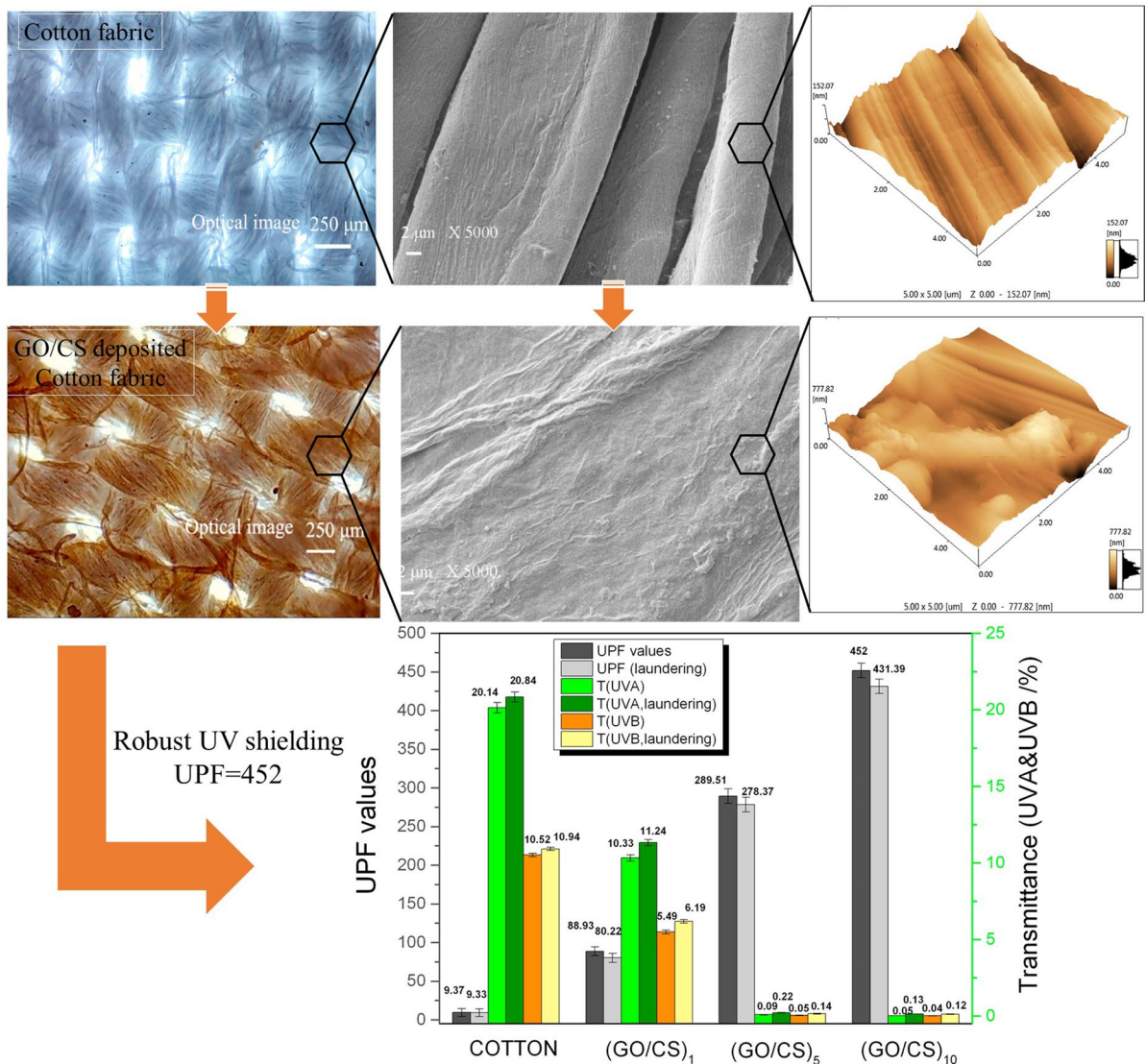


Fig. 16 Schematic illustration of UV protection cotton fabric developed through layer by layer self-assembly of GO and chitosan. Reproduced with permission (Tian et al. 2016). Copyright © 2016, Elsevier

The UV absorption capabilities of single and multi-wall carbon nanotubes were investigated, and the results obtained were compared to chemical and mineral UV absorbers (Mahmoudifard and Safi 2012). CNTs, particularly SWCNTs, have the same specific absorption value as typical UV absorbers in the UV region of the electromagnetic spectrum. Moreover, the cotton cloth impregnated with the SWCNT had the highest UPF value. UV protection treatment for textiles might include SWCNT and MWCNT (Amini et al. 2014). Cotton fabrics were

treated with MWCNTs using a cross-linking agent. It was found that treating cotton fabrics with MWCNTs boosts UV blocking performance significantly (Karimi et al. 2014). The effectiveness of the cured sample to block UV light is greater than that of the uncured sample. It could be due to nanomaterials' capacity to block UV light. To manufacture conductive cotton yarns, cotton yarns were dipped in SWCNTs solutions and then dried at room temperature—a simple procedure that exhibits uniformity in coating cotton yarns with conductive CNTs. The impact

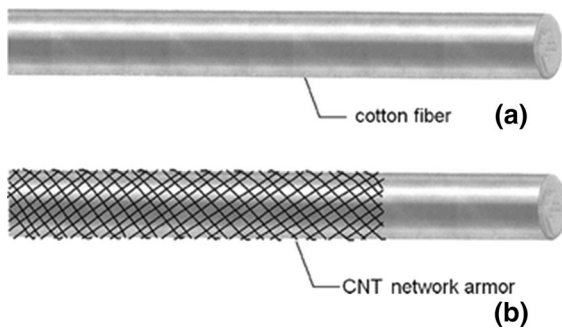


Fig. 17 Schematic showing the structures of: (a) cotton fiber and (b) cotton fiber with CNT network armor. Reproduced with permission (Liu et al. 2008). Copyright © 2008, Royal Society of Chemistry

of manufacturing conditions on the conductivity of SWNT-CY was investigated. According to the results (Zhao et al. 2018), the conductive yarns can transport weak bio-electrical impulses without significant attenuation or distortion. Figure 19 shows a schematic explanation of the manufacturing pathway for SWNT-coated conductive cotton yarns.

Boron and nitrogen co-doped carbon dots (BN-CD) were developed using one-pot hydrothermal carbonization and used as UV-absorbers for cotton textiles. The UV protection and washing resistance of treated cotton fabrics are assessed. According to the findings, as-prepared BN-CD has a substantial fluorescence and down-conversion fluorescence emission. The UV transmittance of cotton fabric finished

Fig. 18 SEM of pristine cotton fibers (a, bar = 10 μm ; b, bar = 1 μm) and CNT coated cotton (c, bar = 10 μm ; d, bar = 1 μm ; e, bar = 1 μm ; f, bar = 1 μm). Reproduced with permission (Liu et al. 2008). Copyright © 2008, Royal Society of Chemistry

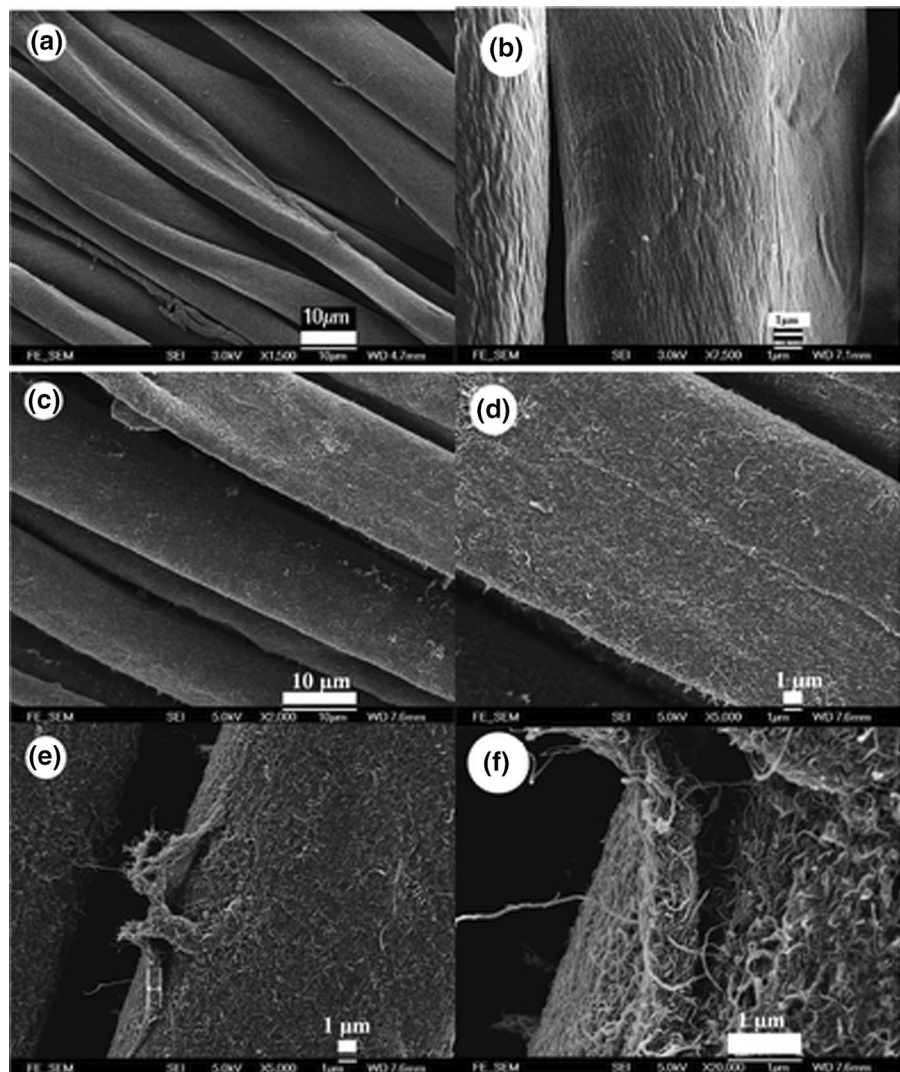
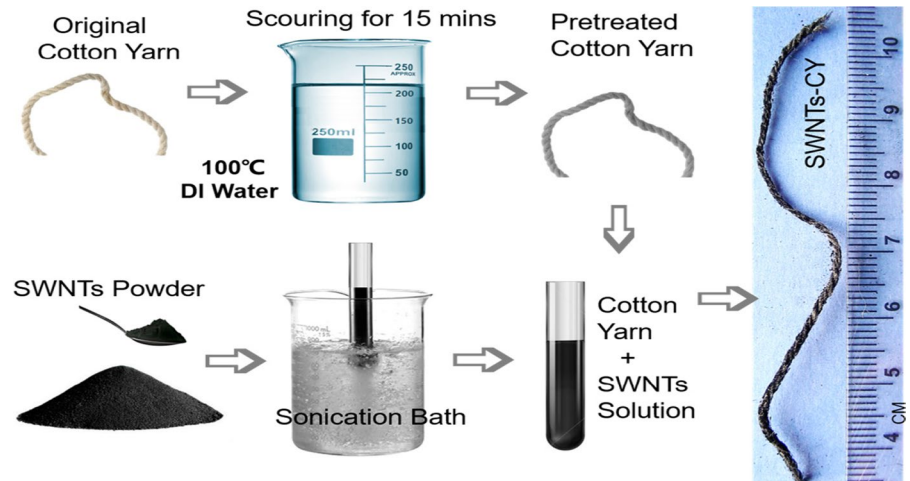


Fig. 19 Graphical presentation of the fabrication process for the conductive SWNT-coated cotton yarns (Zhao et al. 2018). Published under a CC-BY license, MDPI



with BN-CD and poly(vinyl alcohol) in the 280–400 nm range is less than 4%, with a UV protection factor of up to 38.6 and remarkable laundry durability, indicating that BN-CD has a promising potential as UV absorbers for finishing cotton fabrics (Zuo et al. 2019). The possible mechanism of anti-ultraviolet radiation for cotton fabrics by BN-CD is shown in Fig. 20.

Nanoparticles synthesis

Multiple nanoparticle synthesis methods have been applied, since they are appropriate for the synthesis of nanoparticles of diverse formats. Synthesizing is the primary step of preparing the ultimate solution that coats the fabric and acquires a good UV protection ability. Various nanoparticles synthesis for cotton fabric, their UPF and durability are shown in Table 4.

Conclusions and outlook

The UV protection factors of cotton fabric depend on its structural parameters. The type of weave or knit, yarn fineness, weave or knit density, relative fabric tightness, cover factor, open porosity, and thickness are the most key aspects to consider. Treating cotton fabric with conventional ultraviolet absorbers is another way to achieve ultraviolet blocking properties of a fabric. Even so, recent findings have shown that these chemicals have limitations in terms of

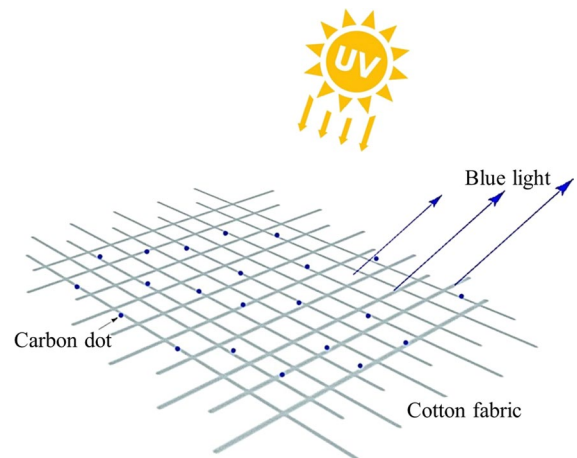


Fig. 20 Potential anti-ultraviolet radiation technique for cotton using BN-CD. Reproduced with permission (Zuo et al. 2019). Copyright © 2019, Springer nature

application because of toxicity, low activity, and poor washability. Due to their effectiveness against UV radiation and multifunctional properties, nanoparticles have attracted much attention from researchers. The effectiveness and durability of ZnO and TiO₂ have been documented in a number of studies and investigations. Because of its exceptional mechanical, electrical, thermal, and optical properties, graphene is also gaining attention as an excellent ultraviolet protective nanoparticle. In recent studies, UV-protective substances derived from natural sources have been disregarded and very few studies are available for discussion. Different nanoparticles are more advanced solutions due to their superior fastness properties.

Table 4 Various nanoparticles synthesis for cotton fabric, their UPF and durability

Nanoparticles	Fabric	Process	UPF	Durability	Reference
Zinc Oxide	Pretreated cotton (woven)	100 ml aqueous solution, 0.005 mol Zn (NO ₃) ₂ ·6H ₂ O, 0.02 mol NH ₄ Cl, 0.01 mol CH ₄ N ₂ O, 5ml NH ₃ , heat (10°C/min) to 90°C for 60 min, pH 10±0.5	105.61	54.67 (5th wash cycles)	(Shateri-Khalilabad and Yazdansheenas 2013)
Zinc Oxide	100% cotton woven fabric (acrylic binder)	Zinc oxide (ZnO), sodium hydroxide (NaOH), soluble starch (0.1%, 0.5%, and 1%), 500 mlL of distilled water, zinc nitrate, 14-874 g (0.1 mol), 0.2 mol of sodium hydroxide, Zn (OH) ₂	75% absorption	–	(Yadav et al. 2006)
Zinc Oxide	100% cotton & 65/35% cotton/polyester (epoxy binder)	2.8 g of (ZnAc ₂ ·H ₂ O), 100 ml 2-propanol, 0.75 g LiOH·H ₂ O, 100 ml C ₃ H ₈ O.	177	179 (5th wash cycles)	(Farouk et al. 2010)
Zinc Oxide	Cotton	3g ZnO, 5g methyl acrylic acid (C ₄ H ₆ O ₂), 3g poly(ethylene-alt-maleic anhydride), 1g 2,2-azobisisobutyronitrile[(CH ₃) ₂ C=N-], 2 g sodium lauryl sulfate, 0.4 g Igepal DM-970, 5 g NaH ₂ PO ₂ ·H ₂ O	329.8	–	(Wang et al. 2005)
Titanium dioxide, Silicon dioxide	Cotton fabrics	4 ml tetraethyl orthosilicate (SiC ₈ H ₂₀ O ₄), 20 ml solution, ethanol/ammonia/deionized water (90/5/5) 1.0 g TiO ₂ , 50 ml ethanol, 2.0 ml deionized water, 1 ml ammonia, 3 ml tetraethyl orthosilicate (SiC ₈ H ₂₀ O ₄).	170.1	~50 (30th wash cycles)	(Zhang et al. 2011)
Graphene	Cotton woven fabric	Graphite powder (<30 μm), H ₂ SO ₄ , NaNO ₃ , KmnO ₄ , temperature 20°C, 35°C water bath, stirred 40 min, 3% H ₂ O ₂ aqueous solution, washed 5% aqueous HCl,	356.74	–	(Qu et al. 2014)
Zinc Oxide	Cotton fabric	50 ml leaf extract of <i>A. Indica</i> , 0.5g of 1 M zinc acetate, stirring 1 hr at 60°C, heat 24 hrs at 80°C	87.8	56.4 (10th wash cycles)	(Karthik et al. 2017; Seth et al. 2021)

Table 4 (continued)

Nanoparticles	Fabric	Process	UPF	Durability	Reference
Gold nanoparticles	Woven cotton	2.5 ml extract leaf of <i>C. sparsiflorus</i> , 2.5 ml 0.001 M chloroauric acid, 1 ml neutral buffer solution, stirring at 240 rpm.	16.0	–	(Boomi et al. 2020)
Silver nanoparticles	Cotton fabric	AgNO ₃ aqueous solution (20 mmol/L), 10 g of <i>black rice</i> extract, shaking at 60 °C for 40 min.	24.0	18.0 (25th wash cycle)	(Yu et al. 2020)
Zinc Oxide	Cotton fabric	30 ml of 0.21 M zinc acetate precursor, 20 ml of <i>C. sativum</i> extract, stirring at 600 rpm.	78.01% absorption	–	(Asmat-campos et al. 2021)
Zinc Oxide	Cotton fabric	12.5 mg of ZnO, aminopropyltriethoxysilane, hexadecyltrimethoxysilane, stirred at 100°C	1650.3	–	(Agrawal et al. 2019)

Different semiconductor nanoparticles like silicon dioxide can be an advanced solution, as they also have self-cleaning properties. Cotton surface modification has been pioneered by textile and polymer scientists, and R&D continues to prioritize the development of functional textiles in a variety of industries, including medical, defence, garments, and sports. Despite the progress made thus far, a few research have been carried out to verify all of the statements mentioned in this review. There is not enough scientific evidence to figure out how bioactive natural colorants work once they have been applied to cotton substrates. As a result, more research on surface changes is needed to better understand how they attach to various textile substrates. The current point of view, according to the authors, will help scientists in developing novel green surface modification technologies for cotton and understanding the dye-fiber bonding mechanism for UV protection.

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Declarations

Conflicts of interest The authors declare no conflict of interest.

Human or animal research Not applicable.

References

- Abd Elhady MM (2012) Preparation and Characterization of Chitosan/Zinc Oxide Nanoparticles for Imparting Antimicrobial and UV Protection to Cotton Fabric. *Int J Carbohydr Chem* 2012:1–6. <https://doi.org/10.1155/2012/840591>
- Abidi N (2018) Chemical Properties of Cotton Fiber and Chemical Modification. In: Fang DD (ed) *Cotton Fiber: Physics, Chemistry and Biology*. Springer, Cham, pp 95–115
- Abidi N, Hequet E, Tarimala S, Dai LL (2007) Cotton fabric surface modification for improved UV radiation protection using sol-gel process. *J Appl Polym Sci* 104:111–117. <https://doi.org/10.1002/app.24572>
- Abidi N, Cabrales L, Hequet E (2009) Functionalization of a cotton fabric surface with titania nanosols: Applications for self-cleaning and UV-protection properties. *ACS Appl Mater Interfaces* 1:2141–2146. <https://doi.org/10.1021/am900315t>
- Advances R (2019) Zinc Oxide for Functional Textile Coatings. *Coatings* 550:17–23
- Agrawal N, Si J, Tan J et al (2019) Green Synthesis of Robust Superhydrophobic Antibacterial and UV-Blocking Cotton Fabrics by a Dual-Stage Silanization Approach. *Adv Mater Interfaces* 6:1–10. <https://doi.org/10.1002/admi.201900032>
- Aguilera J, De-Gálvez MV, Sánchez- Roldán C, Herrera-Ceballos E (2014) New Advances in Protection Against Solar Ultraviolet Radiation in Textiles for Summer Clothing. *Photochem Photobiol* 90:1199–1206. <https://doi.org/10.1111/php.12292>
- Ahmad I, Kan CW, Yao Z (2019) Photoactive cotton fabric for UV protection and self-cleaning. *RSC Adv* 9:18106–18114. <https://doi.org/10.1039/c9ra02023c>
- Akhavan Sadr F, Montazer M (2014) In situ sonosynthesis of nano TiO₂ on cotton fabric. *Ultrason Sonochem* 21:681–691. <https://doi.org/10.1016/j.ulsonch.2013.09.018>
- Alebeid OK, Zhao T (2016) Simultaneous dyeing and functional finishing of cotton fabric using reactive dyes doped with TiO₂ nano-sol. *J Text Inst* 107:625–635. <https://doi.org/10.1080/00405000.2015.1054209>
- Alebeid OK, Zhao T (2017) Review on: developing UV protection for cotton fabric. *J Text Inst* 108:2027–2039. <https://doi.org/10.1080/00405000.2017.1311201>
- Alebeid OK, Tao Z, Seedahmed AI (2015) New approach for dyeing and UV protection properties of cotton fabric using natural dye extracted from henna leaves. *Fibres Text East Eur* 23:60–65. <https://doi.org/10.5604/12303666.1161758>
- Algaba I, Riva A (2002) In vitro measurement of the ultraviolet protection factor of apparel textiles. *Color Technol* 118:52–58. <https://doi.org/10.1111/j.1478-4408.2002.tb00137.x>
- Aloui F, Ahajji A, Irmouli Y et al (2007) Inorganic UV absorbers for the photostabilisation of wood-clearcoating systems: Comparison with organic UV absorbers. *Appl Surf Sci* 253:3737–3745. <https://doi.org/10.1016/j.apsusc.2006.08.029>
- Amini A, Zohoori S, Mirjalili A et al (2014) Improvement in physical properties of paper fabric using multi-wall carbon nanotubes. *J Nanostruct Chem* 4:1–5. <https://doi.org/10.1007/s40097-014-0103-4>
- Andrady AL, Torikai A, Redhwi HH et al (2015) Consequences of stratospheric ozone depletion and climate change on the use of materials. *Photochem Photobiol Sci* 14:170–184. <https://doi.org/10.1039/c4pp90038c>
- Asmat-Campos D, Delf D, Ju L (2021) Textiles Functionalized with ZnO Nanoparticles Obtained by Chemical and Green Synthesis Protocols : Evaluation of the Type of Textile and Resistance to UV Radiation. *Fibers* 9:1–14
- Bae HS, Lee MK, Kim WW, Rhee CK (2003) Dispersion properties of TiO₂ nano-powder synthesized by homogeneous precipitation process at low temperatures. *Colloids Surf A Physicochem Eng Asp* 220:169–177. [https://doi.org/10.1016/S0927-7757\(03\)00077-3](https://doi.org/10.1016/S0927-7757(03)00077-3)
- Bais AF, Lucas RM, Bornman JF et al (2018) Environmental effects of ozone depletion, UV radiation and interactions with climate change: UNEP Environmental Effects Assessment Panel, update 2017. *Photochem Photobiol Sci* 17:127–179. <https://doi.org/10.1039/c7pp90043k>
- Bajaj P, Kothari VK, Ghosh SB (2000) Some innovations in UV protective clothing. *Indian J Fibre Text Res* 25:315–329
- Barani H (2014) Preparation of antibacterial coating based on in situ synthesis of ZnO/SiO₂ hybrid nanocomposite on cotton fabric. *Appl Surf Sci* 320:429–434. <https://doi.org/10.1016/j.apsusc.2014.09.102>
- Barnes PW, Williamson CE, Lucas RM et al (2019) Ozone depletion, ultraviolet radiation, climate change and prospects for a sustainable future. *Nat Sustain* 2:569–579. <https://doi.org/10.1038/s41893-019-0314-2>
- Becheri A, Dürr M, Lo Nostro P, Baglioni P (2008) Synthesis and characterization of zinc oxide nanoparticles: Application to textiles as UV-absorbers. *J Nanopart Res* 10:679–689. <https://doi.org/10.1007/s11051-007-9318-3>
- Behcet B, Halil Rifat A (2010) Ultraviolet (Uv) Protection of Textiles : a Review. *Int Sci Conf Gabrovo* 2010:301–311
- Bhattacharjee S, Joshi R, Yasir M et al (2021) Graphene- And Nanoparticle-Embedded Antimicrobial and Biocompatible Cotton/Silk Fabrics for Protective Clothing. *ACS Appl Bio Mater* 4:6175–6185. <https://doi.org/10.1021/acsabm.1c00508>
- Bilotti E, Zhang H, Deng H et al (2013) Controlling the dynamic percolation of carbon nanotube based conductive polymer composites by addition of secondary nanofillers: The effect on electrical conductivity and tuneable sensing behaviour. *Compos Sci Technol* 74:85–90. <https://doi.org/10.1016/j.compscitech.2012.10.008>
- Bonaccorso F, Sun Z, Hasan T, Ferrari AC (2010) Graphene photonics and optoelectronics. *Nat Photonics* 4:611–622. <https://doi.org/10.1038/nphoton.2010.186>
- Bonet-Aracil MÁ, Díaz-García P, Bou-Belda E et al (2016) UV protection from cotton fabrics dyed with different tea extracts. *Dyes Pigments* 134:448–452. <https://doi.org/10.1016/j.dyepig.2016.07.045>
- Boomi P, Poorani GP, Selvam S et al (2020) Green biosynthesis of gold nanoparticles using *Croton sparsiflorus* leaves extract and evaluation of UV protection, antibacterial and

- anticancer applications. *Appl Organomet Chem* 34:1–13. <https://doi.org/10.1002/aoc.5574>
- Çakir BA, Budama L, Topel Ö, Hoda N (2012) Synthesis of ZnO nanoparticles using PS-b-PAA reverse micelle cores for UV protective, self-cleaning and antibacterial textile applications. *Colloids Surf A Physicochem Eng Asp* 414:132–139. <https://doi.org/10.1016/j.colsurfa.2012.08.015>
- Cao Q, Yu Q, Connell DW, Yu G (2013) Titania/carbon nanotube composite (TiO₂/CNT) and its application for removal of organic pollutants. *Clean Techn Environ Policy* 15:871–880. <https://doi.org/10.1007/s10098-013-0581-y>
- Chakraborty JN (ed) (2014) *Fundamentals and Practices in Colouration of Textiles*, 2nd edn. Woodhead Publishing India, New Delhi
- Chakraborty JN, Sharma V, Gautam P (2014) Enhancing UV protection of cotton through application of novel UV absorbers. *J Text Apparel, Technol Manag* 9:1–17 <https://ojs.cnr.ncsu.edu/index.php/JTATM/article/view/5620/3279>
- Chattopadhyay SN, Pan NC, Roy AK et al (2013) Development of natural dyed jute fabric with improved colour yield and UV protection characteristics. *J Text Inst* 104:808–818. <https://doi.org/10.1080/00405000.2012.758352>
- Çil MG, Nergis UB, Candan C (2009) An Experimental Study of Some Comfort-related Properties of Cotton—Acrylic Knitted Fabrics. *Text Res J* 79:917–923. <https://doi.org/10.1177/0040517508099919>
- Daoud WA, Kong YY (2004) A New Approach to UV-Blocking Treatment for Cotton Fabrics. *Text Res J* 74:97–100. <https://doi.org/10.1177/004051750407400202>
- Daoud WA, Xin JH, Zhang YH (2005) Surface functionalization of cellulose fibers with titanium dioxide nanoparticles and their combined bactericidal activities. *Surf Sci* 599:69–75. <https://doi.org/10.1016/j.susc.2005.09.038>
- Das BR, Ishtiaque SM, Rengasamy RS et al (2010) Ultraviolet Absorbers for Textiles. *Res J Text Appar* 14:42–52. <https://doi.org/10.1108/RJTA-14-01-2010-B005>
- Dastjerdi R, Mojtahedi MRM, Shoshtari AM, Khosroshahi A (2010) Investigating the production and properties of Ag/TiO₂/PP antibacterial nanocomposite filament yarns. *J Text Inst* 101:204–213. <https://doi.org/10.1080/00405000802346388>
- Demirörs AF, Van Blaaderen A, Imhof A (2010) A general method to coat colloidal particles with titania. *Langmuir* 26:9297–9303. <https://doi.org/10.1021/la100188w>
- Devi R, Gill SS (2021) A squared bossed diaphragm piezoresistive pressure sensor based on CNTs for low pressure range with enhanced sensitivity. *Microsyst Technol* 27:3225–3233. <https://doi.org/10.1007/s00542-020-05208-7>
- Dimitrovski K, Sluga F, Urbas R (2010) Evaluation of the Structure of Monofilament PET Woven Fabrics and their UV Protection Properties. *Text Res J* 80:1027–1037. <https://doi.org/10.1177/0040517509352527>
- Downs NJ, Harrison SL (2018) A comprehensive approach to evaluating and classifying sun-protective clothing. *Br J Dermatol* 178:958–964. <https://doi.org/10.1111/bjd.15938>
- Duan W, Xie A, Shen Y et al (2011) Fabrication of superhydrophobic cotton fabrics with UV protection based on CeO₂ particles. *Ind Eng Chem Res* 50:4441–4445. <https://doi.org/10.1021/ie101924v>
- Dubrovski PD, Brezocnik M (2009) Prediction of the ultraviolet protection of cotton woven fabrics dyed with reactive dyes. *Fibres Text East Eur* 72:55–59
- Dubrovski PD, Golob D (2009) Effects of Woven Fabric Construction and Color on Ultraviolet Protection. *Text Res J* 79:351–359. <https://doi.org/10.1177/0040517508090490>
- El Shafei A, Abou-Okeil A (2011) ZnO/carboxymethyl chitosan bionano-composite to impart antibacterial and UV protection for cotton fabric. *Carbohydr Polym* 83:920–925. <https://doi.org/10.1016/j.carbpol.2010.08.083>
- El Tahlawy K, El Nagar K, Elhendawy AG (2007) Cyclodextrin-4 Hydroxy benzophenone inclusion complex for UV protective cotton fabric Cyclodextrin-4 Hydroxy benzophenone inclusion complex for UV protective cotton fabric. *J Text Inst* 98:453–462. <https://doi.org/10.1080/00405000701556327>
- El-Naggar ME, Shaheen TI, Zaghloul S et al (2016) Antibacterial Activities and UV Protection of the in Situ Synthesized Titanium Oxide Nanoparticles on Cotton Fabrics. *Ind Eng Chem Res* 55:2661–2668. <https://doi.org/10.1021/acs.iecr.5b04315>
- El-Toni AM, Yin S, Sato T (2006) Control of silica shell thickness and microporosity of titania-silica core-shell type nanoparticles to depress the photocatalytic activity of titania. *J Colloid Interface Sci* 300:123–130. <https://doi.org/10.1016/j.jcis.2006.03.073>
- Emam HE, Bechtold T (2015) Cotton fabrics with UV blocking properties through metal salts deposition. *Appl Surf Sci* 357:1878–1889. <https://doi.org/10.1016/j.apsusc.2015.09.095>
- Ergoktas MS, Bakan G, Steiner P et al (2020) Graphene-Enabled Adaptive Infrared Textiles. *Nano Lett* 20:5346–5352. <https://doi.org/10.1021/acs.nanolett.0c01694>
- Farouk A, Textor T, Schollmeyer E et al (2010) Sol-gel-derived inorganic-organic hybrid polymers filled with zno nanoparticles as an ultraviolet protection finish for textiles. *Autex Res J* 10:58–63
- Feng XX, Zhang LL, Chen JY, Zhang JC (2007) New insights into solar UV-protective properties of natural dye. *J Clean Prod* 15:366–372. <https://doi.org/10.1016/j.jclepro.2005.11.003>
- Fioletov V, Kerr JB, Fergusson A (2010) The UV index: Definition, distribution and factors affecting it. *Can J Public Health* 101:15–19. <https://doi.org/10.1007/bf03405303>
- Frederick JE (2015) *Ozone Depletion and Related Topics: Ozone as a UV Filter*, 2nd edn. Elsevier, Amsterdam
- French AD (2014) Idealized powder diffraction patterns for cellulose polymorphs. *Cellulose* 21:885–896. <https://doi.org/10.1007/s10570-013-0030-4>
- Fu G, Vary PS, Lin CT (2005) Anatase TiO₂ nanocomposites for antimicrobial coatings. *J Phys Chem B* 109:8889–8898. <https://doi.org/10.1021/jp0502196>
- Gabrijelčič H, Urbas R, Sluga F, Dimitrovski K (2009) Influence of fabric constructional parameters and thread colour on UV radiation protection. *Fibres Text East Eur* 72:46–54

- Gambichler T, Rotterdam S, Altmeyer P, Hoffmann K (2001) Protection against ultraviolet radiation by commercial summer clothing: Need for standardised testing and labelling. *BMC Dermatol* 1:1–4. <https://doi.org/10.1186/1471-5945-1-6>
- Gambichler T, Hatch KL, Avermaete A et al (2002) Ultraviolet protection factor of fabrics: Comparison of laboratory and field-based measurements. *Photodermatol Photoimmunol Photomed* 18:135–140. <https://doi.org/10.1034/j.1600-0781.2001.00739.x>
- Gambichler T, Laperre J, Hoffmann K (2006) The European standard for sun-protective clothing: EN 13758. *J Eur Acad Dermatol Venereol* 20:125–130. <https://doi.org/10.1111/j.1468-3083.2006.01401.x>
- Gies PH, Roy CR, Toomey S, McLennan A (1998) Protection against solar ultraviolet radiation. *Mutat Res* 422:15–22. [https://doi.org/10.1016/S0027-5107\(98\)00181-X](https://doi.org/10.1016/S0027-5107(98)00181-X)
- Gies P, Van Deventer E, Green AC et al (2018) Review of the Global Solar UV Index 2015 Workshop Report. *Health Phys* 114:84–90. <https://doi.org/10.1097/HP.00000000000000742>
- Gnanasekaran L, Hemamalini R, Ravichandran K (2015) Synthesis and characterization of TiO₂ quantum dots for photocatalytic application. *J Saudi Chem Soc* 19:589–594. <https://doi.org/10.1016/j.jscs.2015.05.002>
- Golob V, Ojstršek A (2005) Removal of vat and disperse dyes from residual pad liquors. *Dyes Pigments* 64:57–61. <https://doi.org/10.1016/j.dyepig.2004.04.006>
- Gorenšek M, Recelj P (2007) Nanosilver Functionalized Cotton Fabric. *Text Res J* 77:138–141. <https://doi.org/10.1177/0040517507076329>
- Gorenšek M, Sluga F (2004) Modifying the UV blocking effect of polyester fabric. *Text Res J* 74:469–474. <https://doi.org/10.1177/004051750407400601>
- Gorjanc M, Jazbec K, Mozetič M, Kert M (2014) UV protective properties of cotton fabric treated with plasma, UV absorber, and reactive dye. *Fibers Polym* 15:2095–2104. <https://doi.org/10.1007/s12221-014-2095-6>
- Grifoni D, Bacci L, Zipoli G et al (2009) Laboratory and outdoor assessment of UV protection offered by flax and hemp fabrics dyed with natural dyes. *Photochem Photobiol* 85:313–320. <https://doi.org/10.1111/j.1751-1097.2008.00439.x>
- Grifoni D, Bacci L, Zipoli G et al (2011) The role of natural dyes in the UV protection of fabrics made of vegetable fibres. *Dyes Pigments* 91:279–285. <https://doi.org/10.1016/j.dyepig.2011.04.006>
- Grishanov S (2011) Structure and properties of textile materials. Woodhead Publishing Limited, Sawston
- Grobert N (2007) Carbon nanotubes - becoming clean. *Mater Today* 10:28–35. [https://doi.org/10.1016/S1369-7021\(06\)71789-8](https://doi.org/10.1016/S1369-7021(06)71789-8)
- Gupta D, Jain A, Panwar S (2005) Anti-UV and anti-microbial properties of some natural dyes on cotton. *Indian J Fibre Text Res* 30:190–195
- Han K, Yu M (2006) Study of the preparation and properties of UV-blocking fabrics of a PET/TiO₂ nanocomposite prepared by in situ polycondensation. *J Appl Polym Sci* 100:1588–1593. <https://doi.org/10.1002/app.23312>
- Harrison SL, Downs N (2015) Development of a Reproducible Rating System for Sun Protective Clothing That Incorporates Body Surface Coverage. *World J Eng Technol* 03:208–214. <https://doi.org/10.4236/wjet.2015.33c031>
- Hearle JWS, Morton WE (2008) Physical Properties of Textile Fibres, 4th edn. Woodhead Publishing Limited, Cambridge
- Hussain M, Shamey R, Hinks D et al (2012) Synthesis of novel stilbene-alkoxysilane fluorescent brighteners, and their performance on cotton fiber as fluorescent brightening and ultraviolet absorbing agents. *Dyes Pigments* 92:1231–1240. <https://doi.org/10.1016/j.dyepig.2011.06.034>
- Hustvedt G, Crews PC (2005) The ultraviolet protection factor of naturally-pigmented cotton. *J Cotton Sci* 9:47–55
- Ibănescu M, Mușat V, Textor T et al (2014) Photocatalytic and antimicrobial Ag/ZnO nanocomposites for functionalization of textile fabrics. *J Alloys Compd* 610:244–249. <https://doi.org/10.1016/j.jallcom.2014.04.138>
- Ibrahim NA, Gouda M, Hussefny SM et al (2009) UV-protectleg and antibacterial finishing of cotton knits. *J Appl Polym Sci* 112:3589–3596. <https://doi.org/10.1002/app.29669>
- Ibrahim NA, Eid BM, Abdel-aziz MS (2016) Applied Surface Science Green synthesis of AuNPs for eco-friendly functionalization of cellulosic substrates. *Appl Surf Sci* 389:118–125. <https://doi.org/10.1016/j.apsusc.2016.07.077>
- Islam MT, Liman MLR, Roy MN et al (2021a) Cotton dyeing performance enhancing mechanism of mangiferin enriched bio-waste by transition metals chelation. *J Text Inst* 0:1–13. <https://doi.org/10.1080/00405000.2021.1892337>
- Islam MT, Repon MR, Liman MLR et al (2021b) Functional modification of cellulose by chitosan and gamma radiation for higher grafting of UV protective natural chromophores. *Radiat Phys Chem* 183:109426. <https://doi.org/10.1016/j.radphyschem.2021.109426>
- Islam MT, Repon MR, Liman MLR et al (2021c) Plant tannin and chitosan-templated cellulose for improved absorption of UV protective natural chromophores. *Sustain Chem Pharm* 21:100452. <https://doi.org/10.1016/j.scp.2021.100452>
- Jansen R, Wang SQ, Burnett M et al (2013) Photoprotection: Part I. Photoprotection by naturally occurring, physical, and systemic agents. *J Am Acad Dermatol* 69:853.e1–853.e12. <https://doi.org/10.1016/j.jaad.2013.08.021>
- Kamel MM, El-Shishtawy RM, Youssef BM, Mashaly H (2007) Ultrasonic assisted dyeing. IV. Dyeing of cationised cotton with lac natural dye. *Dyes Pigments* 73:279–284. <https://doi.org/10.1016/j.dyepig.2005.12.010>
- Kan CW (2014) A study on ultraviolet protection of 100% cotton knitted. *Sci World J* 2014:1–10
- Kang SM, Polvani LM, Fyfe JC, Sigmund M (2011) Impact of polar ozone depletion on subtropical precipitation. *Science* (80) 332:951–954. <https://doi.org/10.1126/science.1202131>
- Karimi L, Zohoori S, Amini A (2014) Multi-wall carbon nanotubes and nano titanium dioxide coated on cotton fabric for superior self-cleaning and UV blocking. *New Carbon*

- Mater 29:380–385. [https://doi.org/10.1016/S1872-5805\(14\)60144-X](https://doi.org/10.1016/S1872-5805(14)60144-X)
- Karthik S, Siva P, Shanmugam K, Suriyaprabha R (2017) Acalypha indica – mediated green synthesis of ZnO nanostructures under differential thermal treatment : Effect on textile coating , hydrophobicity , UV resistance , and antibacterial activity. *Adv Powder Technol* 28:3184–3194. <https://doi.org/10.1016/j.apt.2017.09.033>
- Kathirvelu S, D'Souza L, Dhurai B (2009) UV protection finishing of textiles using ZnO nanoparticles. *Indian J Fibre Text Res* 34:267–273
- Kerr JB, Fioletov VE (2008) Surface ultraviolet radiation. *Atmosphere-Ocean* 46:159–184. <https://doi.org/10.3137/ao.460108>
- Keshmiri M, Mohseni M, Troczynski T (2004) Development of novel TiO₂ sol-gel-derived composite and its photocatalytic activities for trichloroethylene oxidation. *Appl Catal B Environ* 53:209–219. <https://doi.org/10.1016/j.apcatb.2004.05.016>
- Khan ZA, Iqbal A, Shahzad SA (2017) Synthetic approaches toward stilbenes and their related structures. *Mol Divers* 21:483–509. <https://doi.org/10.1007/s11030-017-9736-9>
- Khan A, Nazir A, Rehman A et al (2020) A review of UV radiation protection on humans by textiles and clothing. *Int J Cloth Sci Technol* 32:869–890. <https://doi.org/10.1108/IJCST-10-2019-0153>
- Kim S (2006) Dyeing characteristics and UV protection property of green tea dyed cotton fabrics. *Fibers Polym* 7:255–261. <https://doi.org/10.1007/bf02875682>
- Knollmann-Ritschel BEC, Markowitz M (2017) Educational Case: Lead Poisoning. *Acad Pathol* 4:1–3. <https://doi.org/10.1177/2374289517700160>
- Kocić A, Bizjak M, Popović D et al (2019) UV protection afforded by textile fabrics made of natural and regenerated cellulose fibres. *J Clean Prod* 228:1229–1237. <https://doi.org/10.1016/j.jclepro.2019.04.355>
- Krizek DT, Gao W (2004) Ultraviolet Radiation and Terrestrial Ecosystems. *Photochem Photobiol* 79:379. [https://doi.org/10.1562/0031-8655\(2004\)79<379:urate>2.0.co;2](https://doi.org/10.1562/0031-8655(2004)79<379:urate>2.0.co;2)
- Kuzmany H, Kukovec A, Simon F et al (2004) Functionalization of carbon nanotubes. *Synth Met* 141:113–122. <https://doi.org/10.1016/j.synthmet.2003.08.018>
- Laperre J, Gambichler T (2003) Sun protection offered by fabrics: on the relation between effective doses based on Different Action Spectra. *Photodermatol Photoimmunol Photomed* 19:11–17
- Laperre J, Gambichler T, Driscoll C et al (2001) Determination of the ultraviolet protection factor of textile materials: Measurement precision. *Photodermatol Photoimmunol Photomed* 17:223–229. <https://doi.org/10.1034/j.1600-0781.2001.170504.x>
- Ledwith D, Pillai SC, Watson GW, Kelly JM (2004) Microwave induced preparation of a-axis oriented double-ended needle-shaped ZnO microparticles. *Chem Commun*:2294–2295. <https://doi.org/10.1039/b407768g>
- Lee S (2009) Developing UV-protective textiles based on electrospun zinc oxide nanocomposite fibers. *Fibers Polym* 10:295–301. <https://doi.org/10.1007/s12221-009-0295-2>
- Li Y, Zou Y, Hou Y (2011) Fabrication and UV-blocking property of nano-ZnO assembled cotton fibers via a two-step hydrothermal method. *Cellulose* 18:1643–1649. <https://doi.org/10.1007/s10570-011-9600-5>
- Liman MLR, Islam MT, Hossain MM et al (2021) Environmentally benign dyeing mechanism of knitted cotton fabric with condensed and hydrolyzable tannin derivatives enriched bio-waste extracts. *Environ Technol Innov* 23:101621. <https://doi.org/10.1016/j.eti.2021.101621>
- Liu Y, Wang X, Qi K, Xin JH (2008) Functionalization of cotton with carbon nanotubes. *J Mater Chem* 18:3454–3460. <https://doi.org/10.1039/b801849a>
- Louris E, Sfiroera E, Priniotakis G et al (2018) Evaluating the ultraviolet protection factor (UPF) of various knit fabric structures. *IOP Conf Ser Mater Sci Eng* 459:012051. <https://doi.org/10.1088/1757-899X/459/1/012051>
- Lu HF, Fei B, Xin JH et al (2006) Fabrication of UV-blocking nanohybrid coating via miniemulsion polymerization. *J Colloid Interface Sci* 300:111–116. <https://doi.org/10.1016/j.jcis.2006.03.059>
- Mahbulul Bashar M, Khan MA (2013) An Overview on Surface Modification of Cotton Fiber for Apparel Use. *J Polym Environ* 21:181–190. <https://doi.org/10.1007/s10924-012-0476-8>
- Mahltig B, Textor T (2006) Combination of silica sol and dyes on textiles. *J Sol-Gel Sci Technol* 39:111–118. <https://doi.org/10.1007/s10971-006-7744-9>
- Mahmoodi NM, Arami M, Limaee NY, Tabrizi NS (2006) Kinetics of heterogeneous photocatalytic degradation of reactive dyes in an immobilized TiO₂ photocatalytic reactor. *J Colloid Interface Sci* 295:159–164. <https://doi.org/10.1016/j.jcis.2005.08.007>
- Mahmoudifard M, Safi M (2012) Novel study of carbon nanotubes as UV absorbers for the modification of cotton fabric. *J Text Inst* 103:893–899. <https://doi.org/10.1080/00405000.2011.622461>
- Majumdar A, Kothari VK, Mondal AK (2010) Engineering of cotton fabrics for maximizing in vitro ultraviolet radiation protection. *Photodermatol Photoimmunol Photomed* 26:290–296. <https://doi.org/10.1111/j.1600-0781.2010.00545.x>
- Majumdar A, Kothari VK, Mondal AK, Hatua P (2012) Effect of weave, structural parameters and ultraviolet absorbers on in vitro protection factor of bleached cotton woven fabrics. *Photodermatol Photoimmunol Photomed* 28:58–67. <https://doi.org/10.1111/j.1600-0781.2011.00638.x>
- Mallakpour S, Khadem E (2016) Carbon nanotube–metal oxide nanocomposites: Fabrication, properties and applications. *Chem Eng J* 302:344–367. <https://doi.org/10.1016/j.cej.2016.05.038>
- Manaia EB, Kaminski RCK, Corrêa MA, Chiavacci LA (2013) Inorganic UV filters. *Braz J Pharm Sci* 49:201–209. <https://doi.org/10.1590/S1984-82502013000200002>
- Mao Z, Shi Q, Zhang L, Cao H (2009) The formation and UV-blocking property of needle-shaped ZnO nanorod on cotton fabric. *Thin Solid Films* 517:2681–2686. <https://doi.org/10.1016/j.tsf.2008.12.007>
- Marionnet C, Pierrard C, Golebiewski C, Bernerd F (2014) Diversity of biological effects induced by longwave UVA rays (UVA1) in reconstructed skin. *PLoS One* 9:e105263. <https://doi.org/10.1371/journal.pone.0105263>
- McKenzie RL, Lucas RM (2018) Reassessing Impacts of Extended Daily Exposure to Low Level Solar UV

- Radiation. *Sci Rep* 8:1–5. <https://doi.org/10.1038/s41598-018-32056-3>
- Mishra R, Militky J, Baheti V et al (2014) The production, characterization and applications of nanoparticles in the textile industry. *Text Prog* 46:133–226. <https://doi.org/10.1080/00405167.2014.964474>
- Mukaihata N, Matsui H, Kawahara T et al (2008) SiO_x ultrathin layer coverage effect on the (photo)catalytic activities of rutile TiO₂. *J Phys Chem C* 112:8702–8707. <https://doi.org/10.1021/jp801022m>
- Noorian SA, Hemmatinejad N, Bashari A (2015) One-pot synthesis of Cu₂O/ZnO nanoparticles at present of folic acid to improve UV-protective effect of cotton fabrics. *Photochem Photobiol* 91:510–517. <https://doi.org/10.1111/php.12420>
- Oda H (2011) Development of UV absorbers for sun protective fabrics. *Text Res J* 81:2139–2148. <https://doi.org/10.1177/0040517511416277>
- Osterwalder U, Schlenker W, Rohwer H et al (2000) Facts and fiction on ultraviolet protection by clothing. *Radiat Prot Dosim* 91:255–260. <https://doi.org/10.1093/oxfordjournals.rpd.a033213>
- Pal P (2017) Industry-Specific Water Treatment. In: *Industrial Water Treatment Process Technology*, 1st edn. Elsevier Inc., Amsterdam, pp 243–511
- Pan N, Sun G (2011) *Functional textiles for improved performance, protection and health*, Latest edn. Woodhead Publishing, Sawston
- Pandiyarasan V, Archana J, Pavithra A et al (2017) Hydrothermal growth of reduced graphene oxide on cotton fabric for enhanced ultraviolet protection applications. *Mater Lett* 188:123–126. <https://doi.org/10.1016/j.matlet.2016.11.047>
- Parisi AV, Wilson CA (2005) Pre-vitamin D₃ effective ultraviolet transmission through clothing during simulated wear. *Photodermatol Photoimmunol Photomed* 21:303–310. <https://doi.org/10.1111/j.1600-0781.2005.00180.x>
- Parisi AV, Kimlin MG, Mulheran L et al (2000) Field-based measurements of personal erythral ultraviolet exposure through a common summer garment. *Photodermatol Photoimmunol Photomed* 16:134–138. <https://doi.org/10.1111/j.1600-0781.2000.160307.x>
- Park YR, Kim KJ (2005) Structural and optical properties of rutile and anatase TiO₂ thin films: Effects of Co doping. *Thin Solid Films* 484:34–38. <https://doi.org/10.1016/j.tsf.2005.01.039>
- Paul R, Bautista L, de la Varga M et al (2010) Nano-cotton Fabrics with High Ultraviolet Protection. *Text Res J* 80:454–462. <https://doi.org/10.1177/0040517509342316>
- Ponraj JS, Xu ZQ, Dhanabalan SC et al (2016) Photonics and optoelectronics of two-dimensional materials beyond graphene. *Nanotechnology* 27:462001. <https://doi.org/10.1088/0957-4484/27/46/462001>
- Qu L, Tian M, Hu X et al (2014) Functionalization of cotton fabric at low graphene nanoplate content for ultrastrong ultraviolet blocking. *Carbon N Y* 80:565–574. <https://doi.org/10.1016/j.carbon.2014.08.097>
- Rahman Liman ML, Islam MT, Repon MR et al (2021) Comparative dyeing behavior and UV protective characteristics of cotton fabric treated with polyphenols enriched banana and watermelon biowaste. *Sustain Chem Pharm* 21:100417. <https://doi.org/10.1016/j.scp.2021.100417>
- Reidy DJ, Holmes JD, Morris MA (2006) Preparation of a highly thermally stable titania anatase phase by addition of mixed zirconia and silica dopants. *Ceram Int* 32:235–239. <https://doi.org/10.1016/j.ceramint.2005.02.009>
- Riva A, Algaba I (2006) Ultraviolet protection provided by woven fabrics made with cellulose fibres: Study of the influence of fibre type and structural characteristics of the fabric. *J Text Inst* 97:349–358. <https://doi.org/10.1533/joti.2005.0162>
- Riva A, Algaba I, Pepió M, Prieto R (2009) Modeling the effects of color on the UV protection provided by cotton woven fabrics dyed with azo dyestuffs. *Ind Eng Chem Res* 48:9817–9822. <https://doi.org/10.1021/ie9006694>
- Roe B, Zhang X (2009) Durable Hydrophobic Textile Fabric Finishing Using Silica Nanoparticles and Mixed Silanes. *Text Res J* 79:1115–1122. <https://doi.org/10.1177/0040517508100184>
- Roessler S, Zimmermann R, Scharnweber D et al (2002) Characterization of oxide layers on Ti6Al4V and titanium by streaming potential and streaming current measurements. *Colloids Surf B: Biointerfaces* 26:387–395. [https://doi.org/10.1016/S0927-7765\(02\)00025-5](https://doi.org/10.1016/S0927-7765(02)00025-5)
- Rupp JAB (2001) UV textile protection. *Int Text Bull Ed* 47:8–22
- Salah SM (2013) Antibacterial activity and ultraviolet (UV) protection property of some Egyptian cotton fabrics treated with aqueous extract from banana peel. *Afr J Agric Res* 8:3994–4000. <https://doi.org/10.5897/AJAR10.845>
- Samant L, Jose S, Rose NM, Shakyawar DB (2020) Antimicrobial and UV Protection Properties of Cotton Fabric Using Enzymatic Pretreatment and Dyeing with Acacia Catechu. *J Nat Fibers* 00:1–11. <https://doi.org/10.1080/15440478.2020.1807443>
- Saravanan D (2007) UV protection textile materials. *Autex Res J* 7:53–62
- Sarkar AK (2004) An evaluation of UV protection imparted by cotton fabrics dyed with natural colorants. *BMC Dermatol* 4:1–8. <https://doi.org/10.1186/1471-5945-4-15>
- Sarkar AK (2007) On the relationship between fabric processing and ultraviolet radiation transmission. *Photodermatol Photoimmunol Photomed* 23:191–196. <https://doi.org/10.1111/j.1600-0781.2007.00306.x>
- Sayed U, Tiwari R, Dabhi P (2015) UV Protection Finishes on Textile Fabrics. *Int J Adv Sci Eng* 1:56–63
- Scalia S, Tursilli R, Bianchi A et al (2006a) Incorporation of the sunscreen agent, octyl methoxycinnamate in a cellulosic fabric grafted with NL-cyclodextrin. *Int J Pharm* 308:155–159. <https://doi.org/10.1016/j.ijpharm.2005.11.007>
- Scalia S, Tursilli R, Sala N, Iannuccelli V (2006b) Encapsulation in lipospheres of the complex between butyl methoxydibenzoylmethane and hydroxypropyl NL-cyclodextrin. *Int J Pharm* 320:79–85. <https://doi.org/10.1016/j.ijpharm.2006.04.008>
- Sekar N (2000) UV absorbers in textiles. *Colourage* 47:27–30
- Seth M, Khan H, Bhowmik R et al (2020) Facile fabrication of fluoride free zirconium zinc stearate based superhydrophobic and superoleophilic coating on cotton

- fabric with superior antibacterial property. *J Sol-Gel Sci Technol* 94:127–140. <https://doi.org/10.1007/s10971-019-05079-z>
- Seth M, Khan H, Bera S et al (2021) Green Synthesis of Hierarchically Structured Metal and Metal Oxide Nanomaterials. In: Inamuddin, Boddula R, Ahamed MI, Khan A (eds) *Advances in Green Synthesis*, 1st edn. Springer, Cham, pp 91–113
- Shahidi S, Moazzenchi B (2018) Carbon nanotube and its applications in textile industry—A review. *J Text Inst* 109:1653–1666. <https://doi.org/10.1080/00405000.2018.1437114>
- Shateri-Khalilabad M, Yazdanshenas ME (2013) Bifunctionalization of cotton textiles by ZnO nanostructures: Antimicrobial activity and ultraviolet protection. *Text Res J* 83:993–1004. <https://doi.org/10.1177/0040517512468812>
- Shen Y, Zhen L, Huang D, Xue J (2014) Improving anti-UV performances of cotton fabrics via graft modification using a reactive UV-absorber. *Cellulose* 21:3745–3754. <https://doi.org/10.1007/s10570-014-0367-3>
- Shim MH, Park CH, Shim HS (2009) Effect of Ceramics on the Physical and Thermo-physiological Performance of Warm-up Suit. *Text Res J* 79:1557–1564. <https://doi.org/10.1177/0040517508095605>
- Singh MK, Singh A (2013) Ultraviolet Protection by Fabric Engineering. *J Text* 2013:1–6. <https://doi.org/10.1155/2013/579129>
- Siqueira JR, Oliveira ON (2017) Carbon-Based. *Nanomaterials*:233–249. <https://doi.org/10.1016/B978-0-323-49782-4/00009-7>
- Sivakumar A, Murugan R, Sundaresan K, Periyasamy S (2013) UV protection and self-cleaning finish for cotton fabric using metal oxide nanoparticles. *Indian J Fibre Text Res* 38:285–292
- Smith RE (2000) Stilbene Dyes. *Kirk-Othmer Encycl Chem Technol* 11. <https://doi.org/10.1002/0471238961.1920091219130920.a01>
- Smith GJ, Miller IJ, Clare JF, Diffey BL (2002) The Effect of UV Absorbing Sunscreens on the Reflectance and the Consequent Protection of Skin. *Photochem Photobiol* 75:122. [https://doi.org/10.1562/0031-8655\(2002\)075<0122:teouas>2.0.co;2](https://doi.org/10.1562/0031-8655(2002)075<0122:teouas>2.0.co;2)
- Stankovic SB, Popovic D, Poparic GB, Bizjak M (2009) Ultraviolet Protection Factor of Gray-state Plain Cotton Knitted Fabrics. *Text Res J* 79:1034–1042. <https://doi.org/10.1177/0040517508102016>
- Stott ANB (2010) UV Radiation Protective Clothing. *Open Text J* 3:14–21. <https://doi.org/10.2174/1876520301003010014>
- Subramaniyan G, Sundaramoorthy S, Andiappan M (2013) Ultraviolet protection property of mulberry fruit extract on cotton fabrics. *Indian J Fibre Text Res* 38:420–423
- Tian M, Hu X, Qu L et al (2016) Ultraviolet protection cotton fabric achieved via layer-by-layer self-assembly of graphene oxide and chitosan. *Appl Surf Sci* 377:141–148. <https://doi.org/10.1016/j.apsusc.2016.03.183>
- Tsuzuki T, Wang X (2010) Nanoparticle Coatings for UV Protective Textiles. *Res J Text Appar* 14:9–20. <https://doi.org/10.1108/RJTA-14-02-2010-B002>
- Ukaji E, Furusawa T, Sato M, Suzuki N (2007) The effect of surface modification with silane coupling agent on suppressing the photo-catalytic activity of fine TiO₂ particles as inorganic UV filter. *Appl Surf Sci* 254:563–569. <https://doi.org/10.1016/j.apsusc.2007.06.061>
- Vigneshwaran N, Kumar S, Kathe AA et al (2006) Functional finishing of cotton fabrics using zinc oxide-soluble starch nanocomposites. *Nanotechnology* 17:5087–5095. <https://doi.org/10.1088/0957-4484/17/20/008>
- Walger E, Marlin N, Molton F, Mortha G (2018) Study of the direct red 81 dye/copper(II)-phenanthroline system. *Molecules* 23:1–23. <https://doi.org/10.3390/molecules23020242>
- Wang RH, Xin JH, Tao XM (2005) UV-blocking property of dumbbell-shaped ZnO crystallites on cotton fabrics. *Inorg Chem* 44:3926–3930. <https://doi.org/10.1021/ic0503176>
- Wang SQ, Balagula Y, Osterwalder U (2010) Photoprotection: A review of the current and future technologies. *Dermatol Ther* 23:31–47. <https://doi.org/10.1111/j.1529-8019.2009.01289.x>
- Webb AR, Slaper H, Koepke P, Schmalwieser AW (2011) Know your standard: Clarifying the CIE erythema action spectrum. *Photochem Photobiol* 87:483–486. <https://doi.org/10.1111/j.1751-1097.2010.00871.x>
- Wilson CA, Parisi AV (2006) Protection from Solar Erythema Ultraviolet Radiation – Simulated Wear and Laboratory Testing. *Text Res J* 76:216–225. <https://doi.org/10.1177/0040517506060907>
- Wilson CA, Bevin NK, Laing RM, Niven BE (2008) Solar Protection — Effect of Selected Fabric and Use Characteristics on Ultraviolet Transmission. *Text Res J* 78:95–104. <https://doi.org/10.1177/0040517508089660>
- Wong WY, Lam JKC, Kan CW, Postle R (2013) Influence of knitted fabric construction on the ultraviolet protection factor of greige and bleached cotton fabrics. *Text Res J* 83:683–699. <https://doi.org/10.1177/0040517512467078>
- Wong YWH, Yuen CWM, Leung MYS et al (2006) Selected applications of nanotechnology in textiles. *Autex Res J* 6:1–8
- Wong WY, Lam JKC, Kan CW, Postle R (2013) Influence of knitted fabric construction on the ultraviolet protection factor of greige and bleached cotton fabrics. *Text Res J* 83:683–699. <https://doi.org/10.1177/0040517512467078>
- Wong WY, Lam JKC, Kan CW, Postle R (2016a) Influence of reactive dyes on ultraviolet protection of cotton knitted fabrics with different fabric constructions. *Text Res J* 86:512–532. <https://doi.org/10.1177/0040517515591776>
- Wong WY, Lam JKC, Kan CW, Postle R (2016b) Ultraviolet protection of weft-knitted fabrics. *Text Prog* 48:1–54. <https://doi.org/10.1080/00405167.2015.1126952>
- Wu CS (2009) Antibacterial and static dissipating composites of poly(butylene adipate-co-terephthalate) and multi-walled carbon nanotubes. *Carbon N Y* 47:3091–3098. <https://doi.org/10.1016/j.carbon.2009.07.023>
- Xin JH, Daoud WA, Kong YY (2004) A New Approach to UV-Blocking Treatment for Cotton Fabrics. *Text Res J* 74:97–100
- Xu Y, Fisher GJ (2005) Ultraviolet (UV) light irradiation induced signal transduction in skin photoaging. *J*

- Dermatol Sci Suppl 1(2 SUPPL):S1–S8. <https://doi.org/10.1016/j.descs.2006.08.001>
- Yadav A, Prasad V, Kathe AA et al (2006) Functional finishing in cotton fabrics using zinc oxide nanoparticles. *Bull Mater Sci* 29:641–645. <https://doi.org/10.1007/s12034-006-0017-y>
- Yang H, Zhu S, Pan N (2004) Studying the mechanisms of titanium dioxide as ultraviolet-blocking additive for films and fabrics by an improved scheme. *J Appl Polym Sci* 92:3201–3210. <https://doi.org/10.1002/app.20327>
- Yetisen AK, Qu H, Manbachi A et al (2016) Nanotechnology in Textiles. *ACS Nano* 10:3042–3068. <https://doi.org/10.1021/acsnano.5b08176>
- Yu Y, Hurren C, Millington K et al (2015) UV protection performance of textiles affected by fiber cross-sectional shape. *Text Res J* 85:1946–1960. <https://doi.org/10.1177/0040517515578335>
- Yu Y, Hurren C, Millington KR et al (2017) Research on the influence of yarn parameters on the ultraviolet protection of yarns. *J Text Inst* 108:178–188. <https://doi.org/10.1080/00405000.2016.1160765>
- Yu Z, He H, Liu J et al (2020) Simultaneous dyeing and deposition of silver nanoparticles on cotton fabric through in situ green synthesis with black rice extract. *Cellulose* 27:1829–1843. <https://doi.org/10.1007/s10570-019-02910-2>
- Zaratti F, Piacentini RD, Guillén HA et al (2014) Proposal for a modification of the UVI risk scale. *Photochem Photobiol Sci* 13:980–985. <https://doi.org/10.1039/c4pp00006d>
- Zhang Y, Wu Y, Chen M, Wu L (2010) Fabrication method of TiO₂-SiO₂ hybrid capsules and their UV-protective property. *Colloids Surf A Physicochem Eng Asp* 353:216–225. <https://doi.org/10.1016/j.colsurfa.2009.11.016>
- Zhang Y, Yu L, Ke S et al (2011) TiO₂/SiO₂ hybrid nanomaterials: Synthesis and variable UV-blocking properties. *J Sol-Gel Sci Technol* 58:326–329. <https://doi.org/10.1007/s10971-010-2395-2>
- Zhao Y, Cao Y, Liu J et al (2018) Single-Wall carbon nanotube-coated cotton yarn for electrocardiography transmission. *Micromachines* 9:1–10. <https://doi.org/10.3390/mi9030132>
- Zheng C, Chen G, Qi Z (2011) Ultraviolet resistant/antiwrinkle finishing of cotton fabrics by sol-gel method. *J Appl Polym Sci* 122:2090–2098. <https://doi.org/10.1002/app.34289>
- Zimniewska M, Batog J (2012) Ultraviolet-blocking properties of natural fibres. Woodhead Publishing Limited, Sawston
- Zuo D, Liang N, Xu J et al (2019) UV protection from cotton fabrics finished with boron and nitrogen co-doped carbon dots. *Cellulose* 26:4205–4212. <https://doi.org/10.1007/s10570-019-02365-5>

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