Eclética Química

Review article

revista.iq.unesp.br

| Vol. 48 | n. 1 | 2023 |

UV-protective compound-containing smart textiles: A brief overview

João Henrique Barcha Lupino[1], Gustavo Pereira Saito[1], Marco Aurélio Cebim[1], Marian Rosaly Davolos[1+]

1. São Paulo State University, Institute of Chemistry, Araraquara, Brazil.

+Corresponding author: Marian Rosaly Davolos, **Phone:** +55 16 33019634, **Email address:** marian.davolos@unesp.br

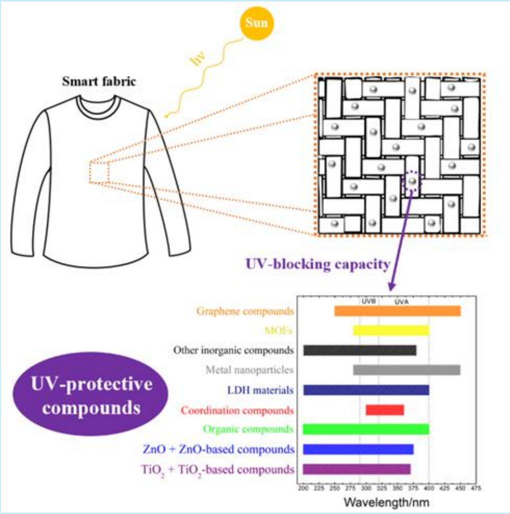
ARTICLE INFO

Article history:
Received: March 29, 2022
Accepted: December 12, 2022
Published: January 01, 2023

Section Editors: Assis Vicente Benedetti

Keywords:
1. smart fabrics
2. textile properties
3. different UV-protective compound classes
4. UV-blocking ability
5. ultraviolet protection factor

ABSTRACT: Excessive exposure to solar ultraviolet (UV) radiation causes human health damages, such as sunburns and skin cancer. Thus, the use of sun-protective clothing is a simple, easy, and practical method for UV protection of the human organism. In this perspective, incorporation, coating, and anchorage of UV-protective compounds in textile fibers have been employed to enhance the UV-blocking ability and/or promote functional finishings to smart fabrics. This review describes recent research efforts on the development of UV-protective compound-containing smart fabrics highlighting the UV-blocking properties and multifunctional activities. Different compound class examples and discussions are presented in order to contribute to new insights into sun-protective clothing and future applications of multifunctional textiles.



CONTENTS

CC BY

1. Introduction

The sun is essential for the Earth's life and its environment (Powers and Murphy, 2019); consequently, solar radiation effects provide human health benefits, such as physical and mental well-being (Flor *et al.*, 2007) and the stimulation of melanin (Serre *et al.*, 2018) and vitamin D biosynthesis (Baker *et al.*, 2017). However, the excessive solar radiation exposure cause sunburns (Sambandan and Ratner, 2011), irregular skin pigmentation, immune system depression, premature aging (Kockler *et al.*, 2012) and skin cancer (Bagde *et al.*, 2018). Among electromagnetic radiations emitted by the sun that reach the Earth's surface, the ultraviolet (UV) radiation is the main responsible for photochemical reactions in the human organism (Baker *et al.*, 2017). UV radiation may be subdivided into following regions: UVC (200–290 nm), UVB (290–320 nm) and UVA (320–400 nm) (Velasco *et al.*, 2008). Stratospheric ozone layer blocks a high percentage of the incident UVC radiation (Baker *et al.*, 2017); therefore, a combination of UVB and UVA radiation reaches the terrestrial surface (Fourtanier *et al.*, 2012). UV radiation penetrates in the upper and deeper layers on the skin causing cellular damages and immune system function modifications (Kockler *et al.*, 2012). Thus, sunscreens and UV-blocking fabrics can be used to minimize the human health risks induced by excessive UVB and UVA radiation exposure. According to the literature, UV blocking (Faure *et al.*, 2013) and UV shielding (Parwaiz *et al.*, 2019) are scientific terms commonly used to express the solar UV protection performance of photoprotective materials. However, UV blocking term is more used than UV shielding to designate the photoprotective capacity of textiles (Mondal, 2022).

The main constituents of photoprotective products are organic and inorganic filters, which are chemical compounds that absorb and/or scatter UV radiation without changes in their physicochemical properties (Saito *et al.*, 2021). Organic filters are organic molecules composed by chromophore groups that commonly exhibit high degree of the π-conjugated system (Saito *et al.*, 2021). The UV absorption capacity of organic filters depends on both the energy differences from electronic transitions between frontier orbitals and molar absorption coefficient (ε). In general, $\pi \rightarrow \pi^*$ and/or $n \rightarrow \pi^*$ transitions give rise the UV absorption mechanism of organic filters (Baker *et al.*, 2017; Flor *et al.*, 2007). Some examples of organic filters are beta-diketones and organic compounds derived from: benzophenone, anthranilate, salicylic acid, cinnamic acid, p-aminobenzoic acid and camphor (Antoniou *et al.*, 2008). Organic filters are widely used in sunscreen applications due to their UVB and/or UVA absorption capacity (Kockler *et al.*, 2012). Furthermore, these organic compounds show solubility in different dispersion mediums, which facilitates the use of them in the manufacturing process of photoprotective products (Forestier, 2008; Morabito *et al.*, 2011).

Organic filter decomposition under high temperature and/or oxidizing environment exposure results in changes and/or loss of the UV shielding ability and induces the free radical's production that could cause DNA, elastin and/or collagen damages (S. Jain and N. Jain, 2010).

Inorganic filters are inorganic compounds that exhibit UV-visible (UV-VIS) absorption capacity and, depending on the refractive index and/or particle size of them, can scatter UV radiation (Abuçafy *et al.*, 2016; Seixas and Serra, 2014). In general, UV-VIS absorption process in metal oxides (e.g., ZnO and TiO_2) involves electronic transitions between valence band and conduction band (VB→CB). The main advantages of inorganic filters are thermal stability, broad spectrum absorption (Seixas and Serra, 2014) and low toxicity to the human body (S. Wang *et al.*, 2010). For these reasons, inorganic filters are widely incorporated in cosmetic formulations and/or UV-blocking products intended for children and people with skin diseases or sensitive skin (Serpone *et al.*, 2007). However, these inorganic compounds can promote photocatalytic reactions (L. Wang *et al.*, 2018) that decompose cosmetic ingredients affecting on the UV shielding ability of photoprotective products.

The growing concern about deleterious effects of the UV radiation exposure combined with the negative aspects related to the use of commercial inorganic and organic filters has significantly promoted the development of photostable compounds with high UV protection and low toxicity to the human organism and the environment, i.e., UV-protective compounds (Saito *et al.*, 2018). In this perspective, UV-protective compounds have been obtained by the coordination of organic filters with transition metals (Ahmedova *et al.*, 2002; Pettinari *et al.*, 2016), association between inorganic and organic filters (Parisi *et al.*, 2016), encapsulation of organic (Morabito *et al.*, 2011) or inorganic filters (Frizzo *et al.*, 2019), and intercalation of organic filters into inorganic layered matrices (Franco *et al.*, 2020; Saito *et al.*, 2021).

One of the most important manufacturing steps of photoprotective products is the dispersion or incorporation of organic and/or inorganic filters in sunscreens, polymer matrices or textile fibers. Sunscreens are emulsions and/or particle dispersions,

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

whose main purpose is to protect the human skin from UV damages (Saito *et al.*, 2019). However, these cosmetic formulations can cause skin allergies depending on the ingredients present in their composition (Giokas *et al.*, 2007). Thus, the sun-protective clothing is a viable alternative for UV protection due to the lower occurrence of allergic reactions by skin contact and its simple, easy, and practical use. It is important to emphasize that the global smart fabrics market, which includes the promoting and selling of self-cleaning, flame retardant, antibacterial and UV-blocking fabrics, was estimated at US$ 289.5 million in 2012. Before the COVID-19 pandemic, smart fabrics market projections for 2020 was quoted at US$ 361.9 million, keeping similar growth rates and correcting inflation (SEBRAE, 2014).

2. Textile properties and UV protection relationships of the sun-protective clothing

The UV shielding ability of the sun-protective clothing is directly related to the physical and chemical properties of the fabric used in its manufacture. Therefore, the chemical composition, weave pattern and optical properties are the main factors that should be considered when making sun UV-blocking fabrics (Alebeid and Zhao, 2017).

In the last decades, several kinds of textile fibers or fiber blends have been used to fabric manufacturing (Jabbar and Shaker, 2016). Polyethylene terephthalate (PET), commonly named polyester, and cotton fibers are the most employed to produce sun-protective fabrics. Generally, PET (Fig. 1) is obtained by the condensation polymerization process of terephthalic acid and ethylene glycol under specific synthetic conditions (Jaffe *et al.*, 2020). In the first step of the PET polymerization, the bis(hydroxyethyl)terephthalate (BHET) monomer is produced by esterification of terephthalic acid. It is important to highlight that the esterification reaction produces a mixture of PET oligomers and BHET; consequently, water and impurity removal is essential to the ultimate achievement of the PET polymer. The next step of the PET polymerization consists in the ester interchange reaction between two BHET molecules to split off a glycol molecule, building polymer molecular weight. This condensation reaction must be catalyzed, being the antimony trioxide (Sb_2O_3) the catalyzer most used. Moreover, the melt-polymerization temperatures at or above 285°C are used to promote the uniform stirring of the reactional medium. In the last step, PET polymer is pelletized for melt spinning or putted on a spinning machine and transformed to fiber (Jaffe *et al.*, 2020). The main reasons for the using of PET fibers in sun-protective clothing are the low cost, ease of blending with natural fibers and UVB absorption capacity (Curtzwiler *et al.*, 2017). Its UVB absorption ability is directly related to the presence of aromatic rings and carboxyl groups, i.e., chromophores groups in the polymeric structure.

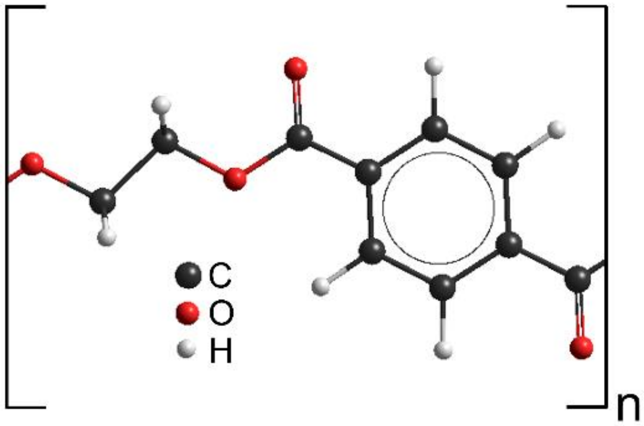


Figure 1. Polyethylene terephthalate (PET) monomer structure.

Cotton is a natural fiber formed by dried cell walls of formerly living cells of Gossypium genus plants (Ioelovich and Leykin, 2008; Liu, 2018). The cotton fiber formation starts in an ovary of the cotton flower and proceeds in a mature seed-containing cotton bowl (or fruit). Thus, fiber development includes initiation, primary cell wall formation for fiber elongation, secondary cell wall biosynthesis for cellulose deposition and cell wall thickening, and maturation. Cotton fibers are composed by cellulose (88.0–96.5%), proteins (1.0–1.9%), waxes (0.4–1.2%), pectins (0.4–1.2%), inorganic compounds (0.7–1.6%), and other substances (0.5–8.0%). It is important to emphasize that the chemical composition of cotton fibers depends on the cotton cultivar, growing environment and degree of fiber maturity (Liu, 2018). Cellulose, major chemical component of cotton fibers, consists in linear β-1,-4-linked chains of D-glucopyranose (Fig. 2) produced by photosynthesis process (Yue *et al.*, 2012). In the cloth manufacturing, cotton fibers are widely used due to their low cost, softness, high air permeability, moisture-absorptive features, high thermal resistance, and hypoallergenic properties (H. Wang and Memon, 2020).

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

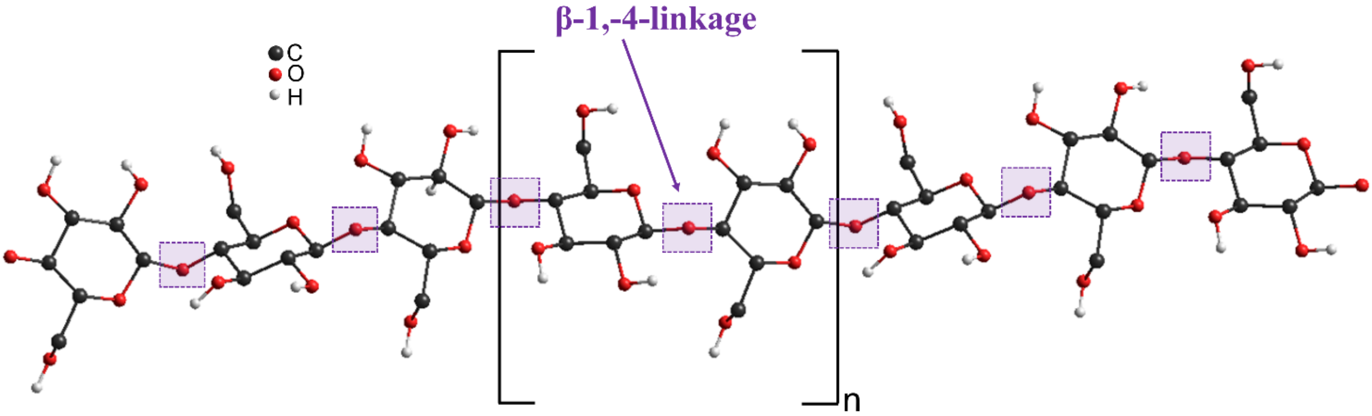


Figure 2. Schematic representation of the simplified cellulose structure.

Different weft types can be used in weaving stage of the sun-protective fabrics. The weft is the arrangement of intertwined threads that gives rise to fabric. This thread arrangement is classified into plain weave fabric and mesh (Pezzolo, 2007). In the plain weave fabric, the thread interweaving turns it more difficult to deform in shear. (Mohammed *et al.*, 2000; Pezzolo, 2007). While the mesh allows the stretching of the fabric because there are no fixed thread loops in its weft (Pezzolo, 2007).

Plain fabric's frames are commonly classified in taffeta, twill or satin. The taffeta has a weft design that looks like a chessboard (Fig. 3a), which provides a higher mechanical resistant due to its homogeneous shape. Twill has a diagonal pattern (Fig. 3b), offering less dirt adhesion and easier cleaning, because its weft pattern provides more empty spaces among the plain weave fabric. Satin weft presents larger heels between the threads than other plain weave designs (Fig. 3c), consequently, this weft design influence on the fabric brightness (Pezzolo, 2007).

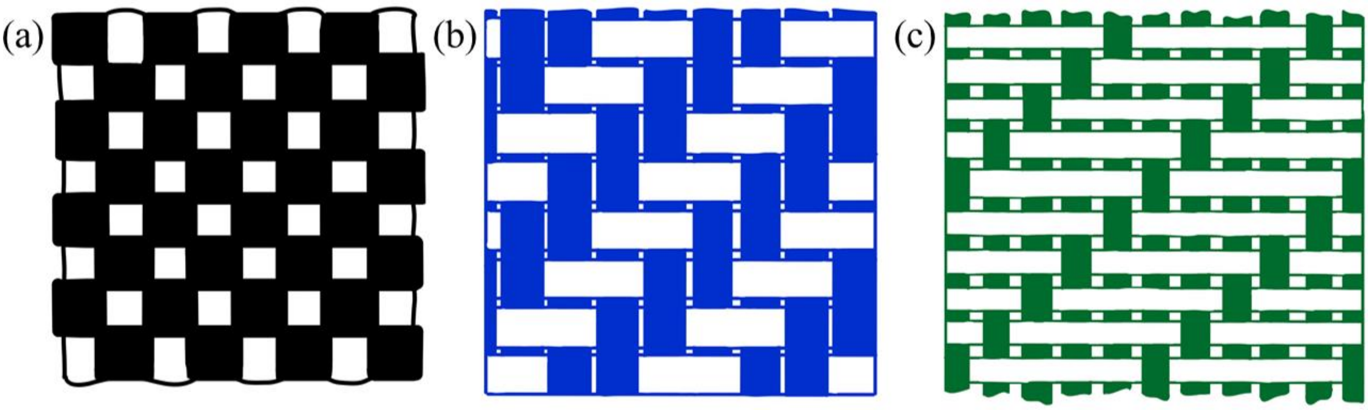


Figure 3. Schematic representations of plain fabric's frames: **(a)** taffeta, **(b)** twill and **(c)** satin.

After the weaving process, fabrics are submitted to the finishing stages (1^{st}, 2^{nd}, and 3^{rd} stage) of the textile processing. The 1^{st} finishing stage is mainly composed by the brushing, shaving, singeing and scouring processes. In the 2^{nd} finishing stage, also known as dyeing and printing, pigments and/or dyes are adsorbed and/or anchored in the surface of textile fibers. Finally, the 3^{rd} finishing stage consists in chemical processes used to generate specific physical-chemical properties in fabrics, e.g., waterproofing ability (Pezzolo, 2007). Among these chemical processes, the incorporation of nanoparticles in textile fibers has been widely used (Chau *et al.*, 2007; Costa, 2012; Ferreira *et al.*, 2014; Sánchez, 2006) in order to create smart fabrics, i.e., fabric with self-cleaning, antibacterial or even flame-retardant properties. It is important to point that the 2^{nd} stage can provide textile benefits similar to 3^{rd} stage depending on the physical and chemical properties of pigments and/or dyes used. Thus, 2^{nd} and 3^{rd} stage can be understood as the same finishing stage of the textile processing.

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

UV protection on fabrics depends on the fiber type, weft design, fabric thickness, yarn linear density, and the optical properties of pigments or dyes. For example, the solar transmittance decreases, and the diffuse reflectance increases when yarn linear density, i.e., the number of weft yarns per unit length increases (Yildirim *et al.*, 2018). Besides textile properties, UV shielding capacity can be enhanced by incorporation, coating, or anchorage of UV-protective compounds in the textile fiber surface (Table 1a–d). Thus, the purpose of this review is to report scientific results about UV-protective compound-containing smart fabrics in the period from 2010 to 2021.

It is known that the incorporation, coating and/or anchorage of UV-protective compounds in smart fabrics protects human skin against excessive UV radiation exposure and reduces the photodecomposition percentage of textile fibers. Nevertheless, this brief review focused in showing the main scientific results and potential applications of UV-blocking fabrics used to minimize the human health hazards.

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

Table 1a. Examples of UV-protective compound-containing textile fibers described in scientific literature between 2010 and 2012.

Textile fiber composition	UV-protective compound	Assessment method of the UV shielding performance	Additional fabric properties	Reference
PET and PET/wool (70:30) blend, PET/cotton (70:30) blend and PET/viscose (70:30) blend	Monochlorotriazinyl β-cyclodextrin, chitosan, ethylenediamine or Dyes (*Disperse Red FB 60, Disperse Blue 2BL 56 or Disperse Orange 25*)	UPF	-	Ibrahim *et al.* (2010a)
Cotton	Europium(III) complex	UPF	-	Z. Chen and Yin (2010)
Linen	Metal salts ($M(CH_3COO)_2$, *where* $M = Cu^{2+}$, Zn^{2+} *and* Ca^{2+}), ZrOCl, Ag, ZrO, TiO_2 or Dyes (*C.I Basic Red 24 or C.I Reactive Violet 5*)	UPF	Antibacterial	Ibrahim *et al.* (2010b)
Polyethersulfone	TiO_2	UPF	Antibacterial and self-cleaning	Mihailović *et al.* (2010)
PET	Ag/TiO_2 nanocomposite	Diffuse reflectance spectra	Antibacterial, self-cleaning, and anti-staining	Dastjerdia *et al.* (2010)
Wool	TiO_2	Diffuse reflectance spectra	-	Montazer and Pakdel (2010)
PET/wool (45:55) blend	TiO_2	Diffuse reflectance spectra	Antibacterial and self-cleaning	Montazer and Seifollahzadeh (2011)
Cotton	ZnO	Diffuse reflectance spectra	-	Y. Li *et al.* (2011)
Cotton or viscose	Monochlorotriazine-β-cyclodextrin, Neem seed oil and Dyes (*Reactive Red 120, Reactive Red 141, Reactive Blue 160, Reactive Red 195 or Reactive Red 198*)	UPF	Antibacterial	Ibrahim *et al.* (2011)
Nylon	TiO_2	Diffuse reflectance spectra	Antibacterial	Pant *et al.* (2011)
Polyethersulfone	TiO_2	UPF	Antibacterial and self-cleaning	Mihailović *et al.* (2011)
PET	SiO_2-coated ZnO	Transmittance spectra	Waterproofing	Xue *et al.* (2011)
Cotton	Al	UPF	Waterproofing	Pan *et al.* (2012)
Cotton	ZnO	Transmittance spectra	Waterproofing and self-cleaning	Ates and Unalan (2012)
Cotton	SiO_2-coated TiO_2 and Dye (*Bezaktiv Red S-3B 150*)	UPF	-	Fakin *et al.* (2012)
Cotton	ZnO	UPF	Antibacterial and self-cleaning	Çakir *et al.* (2012)
Cotton	Ag	UPF	Antibacterial and waterproofing	Shateri-Khalilabad and Yazdanshenas (2013a)
Cotton	ZnO	Transmittance spectra	-	Y. Li *et al.* (2012)

PET: Polyethylene terephthalate.

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

Table 1b. Examples of UV-protective compound-containing textile fibers described in scientific literature between 2013-2016.

Textile fiber composition	UV-protective compound	Assessment method of the UV shielding performance	Additional fabric properties	Reference
Cotton	Mg_2Al-LDH intercalated with 2-hydroxy-4-methoxybenzophenone-5-sulfonate anions	UPF	Waterproofing	Zhao *et al.* (2013)
PET	SiO_2-coated ZnO	Transmittance spectra	Waterproofing	Xue *et al.* (2013)
Cotton	ZnO	UPF	Bacterial inhibition	Shateri-Khalilabad and Yazdanshenas (2013b)
Cotton	ZnO	UPF	Antibacterial	Zhang *et al.* (2013)
PET	TiO_2	Transmittance spectra	-	Nazari *et al.* (2013)
Cotton	TiO_2	Diffuse reflectance spectra	Self-cleaning	Sadr and Montazer (2014)
Cotton	TiO_2, ZnO or CuO	UPF	-	Emam and Bechtold (2015)
Cotton	Graphene/polyurethane composite	UPF	Electrical conductivity and far-infrared emission	Hu *et al.* (2015)
Cotton	Ag	UPF	Antibacterial and waterproofing	Nateghi and Shateri-Khalilabad (2015)
PET	TiO_2/carbon nanotubes or TiO_2/nanocarbon black nanocomposites	Diffuse reflectance spectra	Electrical conductivity	Chimeh and Montazer (2016)
Cotton	Graphene oxide/Fe_3O_4 nanocomposite	UPF	Antibacterial, electrical conductivity and magnetic properties	Mirjalili (2016)
Cotton	Graphene oxide/Chitosan composite	UPF	-	Tian *et al.* (2016)
Cotton	Ag/AgBr-TiO_2 nanocomposite	UPF	Antibacterial	Rana *et al.* (2016)
PET	Graphene oxide/SnO_2 nanocomposite	UPF	Electrical conductivity	Babaahmadi and Montazer (2016)
Cotton	ZnO/Chitosan nanocomposite	UVA and UVB blocking percentages	Antibacterial	Raza *et al.* (2016)

PET: Polyethylene terephthalate.

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

Table 1c. Examples of UV-protective compound-containing textile fibers described in scientific literature between 2017 and 2018.

Textile fiber composition	UV-protective compound	Assessment method of the UV shielding performance	Additional fabric properties	Reference
Cotton	ZnO	UPF	Self-cleaning	Thi and Lee (2017)
Cotton or Silk	MIL-MOFs* (*MIL-68(In)-NH_2 or MIL-125(Ti)-NH_2*)	UPF	-	Emam and Abdelhameed (2017)
Polyamine 6	TiO_2	UPF	Antibacterial, self-cleaning, and waterproofing	Zhou *et al.* (2017)
Cotton	TiO_2 and Ag	UPF	Antibacterial	S. Li *et al.* (2017)
Cotton	*Aloe vera*#/Chitosan nanocomposite	UPF	Antibacterial and waterproofing	Subramani *et al.* (2017)
Cotton	Au	UPF	Antibacterial	Tang *et al.* (2017)
PET	CuO	UV protection enhancement	Antibacterial and self-cleaning	Rezaie *et al.* (2017a)
Wool	CuO	UV protection enhancement	Antibacterial	Rezaie *et al.* (2017b)
PET	CuO	UV protection enhancement	Antibacterial and ammonia sensing	Rezaie *et al.* (2017c)
Cotton/nylon (50:50) blend	Graphene oxide	Diffuse reflectance spectra	Antibacterial, antifungal, and electrical conductivity	Hasani and Montazer (2017a)
Cotton/nylon (50:50) blend	Graphene oxide	Diffuse reflectance spectra	Antibacterial and electrical conductivity	Hasani and Montazer (2017b)
Cotton	TiO_2/SiO_2 nanocomposite	UPF	Waterproofing	Xu *et al.* (2018)
Cotton	ZnO	UPF	Gas sensor	Subbiah *et al.* (2018)
Cotton	ZnO	UPF	Antibacterial	El-Naggar *et al.* (2018)
Cotton	Polyvinylsilsesquioxane/ZnO composite	UPF	Antibacterial and waterproofing	Mai *et al.* (2018)
PET	SiO_2, ZnO, TiO_2 or ZrO	UPF	Antibacterial and self-cleaning	Ibrahim *et al.* (2018)
Cotton	Polyoxotitanate ($Ti_{18}Mn_4O_{30}(OEt)_{20}Phen_3$)	Diffuse reflectance spectra	Antibacterial and waterproofing	N. Li *et al.* (2018)
Cotton	TiO_2	UPF	Waterproofing	D. Chen *et al.* (2018)
Wool	*Cinnamomum camphora* extracts	UPF	Antibacterial	Khan *et al.* (2018)
Cotton	TiO_2	UPF	-	Morshed *et al.* (2018)
PET	3,4-ethylene dioxythiophene polymer (PEDOT)/Fe_3O_4 composite	Transmittance spectra	Antibacterial, electrical conductivity, microwave attenuation, and magnetic properties	Sedighi *et al.* (2018)
Wool	Marigold (*Tagetes erecta*) flower extract	UPF	Antioxidant	Shabbir *et al.* (2018)

PET: Polyethylene terephthalate. * MIL: Materials Institute Lavoisier. MOF: metal-organic framework. # Natural herbal nanoparticles prepared from shade-dried *Aloe vera* plant.

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

Table 1d. Examples of UV-protective compound-containing textile fibers described in scientific literature between 2019 and 2021.

Textile fiber composition	UV-protective compound	Assessment method of the UV shielding performance	Additional fabric properties	Reference
Cotton	$BiPO_4$	UPF	Self-cleaning	Jin *et al.* (2019)
Silk	ZnO	UPF	Waterproofing	Huang *et al.* (2019)
Cotton	ZnO	UPF	-	X. Wang *et al.* (2019)
Cotton, Aramid or PET	MOF (*InOF-1*)	UPF	-	G.-P. Li *et al.* (2020)
Cotton	MOFs (*Cu−BTC, ZIF-8 or ZIF-67*)	UPF	Noise reduction	Zhang *et al.* (2020)
PET	MO_x/polyvinylidene fluoride/Chitosan composite (MO_x = ZnO, TiO_2 or SiO_2)	UPF	-	Bouazizi *et al.* (2020)
Cotton	MOFs (*ZIF(Ni), ZIF-8(Zn) or ZIF-67(Co)*)	UPF	Antibacterial	Emam *et al.* (2020)
Cotton	ZnO	UPF	Waterproofing	Khan *et al.* (2020)
Silk	Graphene oxide	UPF	Antibacterial	S.-D. Wang *et al.* (2020)
Cotton	ZnO	UPF	Antibacterial	Noorian *et al.* (2020)
Cotton	TiO_2 and hollow glass microspheres	UPF	Thermal insulation, flame retardancy and noise reduction	Pakdel *et al.* (2020)
Cotton	TiO_2	Transmittance spectra	Waterproofing and self-cleaning	Suryaprabha and Sethuraman, (2021)
Wool	TiO_2/Ce or ZnO/Ce nanocomposite	Transmittance spectra	Antibacterial and self-cleaning	Zohoori *et al.* (2021)
Cotton	TiO_2	UPF	-	Riaz *et al.* (2021)
Wool	Se	UV protection enhancement	Antibacterial and antifungal	Razmkhah *et al.* (2021)
Cotton	Ag	UPF	Antibacterial	Čuk *et al.* (2021)

PET: Polyethylene terephthalate. MOF: metal-organic framework.

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

3. UV-protective compound-containing smart fabrics

The growing request for UV-protective textiles, especially for clothes manufacturing, has driven scientific studies about textile fibers with UV shielding properties. Therefore, incorporation, coating and/or anchorage of metal oxides, dyes, organic filters, graphene compounds, metal-organic frameworks (MOFs), coordination compounds, metal nanoparticles or composites in the fiber surface are widely related in the recent literature (Table 1a–d). Several different synthetic methods have been used to produce these textile fibers, including pad-dry-cure (Z. Chen and Yin, 2010), electrospinning (Pant *et al.* 2011), hydrothermal (Y. Li *et al.*, 2011), microwave (Y. Li *et al.*, 2012; Thi and Lee, 2017), microwave assisted hydrothermal (Ates and Unalan, 2012), simple spray coating (Rana *et al.*, 2016), electrostatic layer-by-layer self-assembly approach (Zhao *et al.*, 2013), solid-phase hot-pressing procedure (G.-P. Li *et al.*, 2020) and dip-pad-cure (Ibrahim *et al.*, 2010b). Among them, the pad-dry-cure method is the most used due to the easier synthetic procedures and high-efficiency fiber coating. In the pad-dry-cure process, fabrics are soaked in UV-protective compound solution or suspension under specific conditions, e.g., liquor to fabric ratio. Then, fabric specimens are padded through two dips and two nips using a padding machine. After padding step, fabrics are dried and cured at specific temperatures and times, which are based on fabric properties. Regardless of experimental method and/or fiber type used, UV-protective compounds incorporated, coated and/or anchored improve UV-blocking properties of textile fabrics (Fig. 4) as proven by UV-VIS spectroscopic measurements, e.g., *in vitro* UV protection factor (UPF) assessment. Moreover, these UV-protective compounds can promote other beneficial functions to textile fibers such as antibacterial and self-cleaning properties (Table 1a–d). In so many cases, a superhydrophobic coating in the textile fibers is also made to provides waterproofing (Table 1a–d). It is important to highlight that multifunctional textile fibers give rise smart fabrics, which offer new insights to clothing manufacturing.

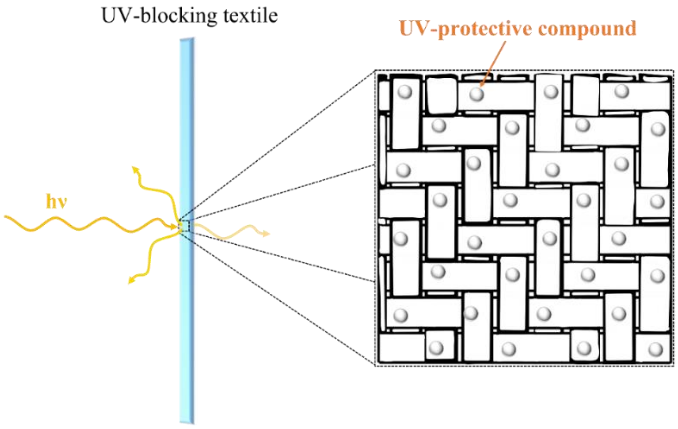


Figure 4. Schematic representation of a UV-protective compound-containing smart fabric.

3.1 TiO_2

Titanium oxide is a commercial inorganic filter commonly used in skin care products due to its UV absorption capacity (Abuçafy *et al.*, 2016; Seixas and Serra, 2014) and low skin toxicity (Abuçafy *et al.*, 2016). Besides UV shielding ability, TiO_2 exhibits photocatalytic activity that enable its use in self-cleaning systems (Banerjee *et al.*, 2015). According to the literature (Yadav *et al.*, 2016), this metal oxide also has antibacterial properties. For these reasons, TiO_2-containing textile fibers have attracted considerable interest in the field of smart fabrics.

Mihailović *et al.* (2010; 2011), in two different scientific research publications, investigated the multifunctional properties of polyethersulfone (PES) fabrics loaded with TiO_2 prepared by oxygen, argon or air RF plasma or corona discharge pretreatment and subsequent dip-pad-cure process with titanium oxide. On both studies, oxygen, argon or air RF plasma and corona discharge pretreatments of PES fibers induced the enhanced deposition of TiO_2 nanoparticles ensuring excellent self-cleaning properties, UV protection and antibacterial activity. Considering UV blocking efficiency of PES fabrics obtained, high UPF values (UPF > 66) were reached and retained after five laundering cycles. The washing procedure used in the laundering durability test can be summarized as follows: the PES fabrics were washed in the bath containing 0.5% Felosan RG-N (Bezema) at liquor-to-fabric ratio of 40:1. After 30 min of washing at 40 °C, fabrics were rinsed once with warm water (40 °C) for 3 min and three times (3 min) with cold water. Subsequently, fabrics were dried at 70 °C.

Montazer and Pakdel (2010) reported the UV-blocking ability of TiO_2-containing wool textiles obtained by ultrasonic bath method. The TiO_2-protective

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

layer on fabric surface provided higher UV absorption in the 300-350 nm region. Moreover, the increase of the amount of TiO_2 on wool surface enhanced the UVB blocking capacity and decreased the UV photodegradation of wool fibers, i.e., photoyellowing of wool textile. In other scientific publication, Montazer and Seifollahzadeh (2011) prepared multifunctional textiles through enzymatic pretreatment of polyester/wool blend followed by the fiber coating with TiO_2 nanoparticles. These textile materials also exhibited higher UVB blocking ability and showed self-cleaning and antibacterial properties.

Pant *et al.* (2011) successfully prepared an electrospun nylon-6 spider-net like nanofiber mats containing TiO_2 nanoparticles. The addition of a small amount of TiO_2 NPs improved the hydrophilicity and mechanical strength of nylon-6 nanofiber mats and gave rise to antibacterial and UV blocking properties.

Nazari *et al.* (2013) developed UV-blocking polyester fabrics using TiO_2 as inorganic filter and polysiloxane as cross-linkable agent. The polysiloxane agent promoted the enhance of TiO_2 nanoparticles absorption and stabilized them on the polyester fiber surface. Consequently, the nano-TiO_2/polysiloxane coating improved the UV-blocking features of polyester fabrics as seen in UV-VIS transmission spectra.

Zhou *et al.* (2017) reported a facile and eco-friendly way to prepare a novel hybrid polyamine/nano TiO_2 fabric by a combination of UV irradiation and ultrasonic bath method. The research results indicated that TiO_2 were fixed on the fiber surface providing photocatalytic, antibacterial, UV blocking and superhydrophobic properties to polyamine fabrics. UPF values equal to 56 and 1123 were obtained.

Sadr and Montazer (2014), Emam and Bechtold (2015), D. Chen *et al.* (2018), Morshed *et al.* (2018), Suryaprabha and Sethuraman (2021) and Riaz *et al.* (2021) investigated the UV blocking properties of TiO_2-containing cotton fabrics. Sadr and Montazer (2014) reported the multifunctional features of TiO_2 nanoparticles coated cotton fabrics obtained by *in situ* sonosynthesis method. The sonochemical method had no negative influence on cotton fabric fibers and provided the formation of the nano-TiO_2 coating on the textile surface that led to UV-blocking and self-cleaning properties. Moreover, UV-protection rating of these cotton fabrics maintained even after 25 home launderings indicating an excellent washing durability. Emam and Bechtold (2015) immobilized TiO_2, ZnO or CuO particles into cotton and oxidized cotton fabrics by using pad-dry-cure method. The surface interactions between carboxylate groups of cotton fibers and metal oxides, mainly TiO_2, provided the enhancement of the UV shielding capacity of cotton fabrics as seen in UV-VIS transmittance spectra and *in vitro* UPF values. D. Chen *et al.* (2018) developed UV-blocking, superhydrophobic and robust cotton fabrics by combination of polyvinylsilsesquioxane (PVS) and nano-TiO_2. Based on structural, thermal, mechanical, and spectroscopic results, the improvement on the UV protection, water repellency and rigidity of the fabrics were attributed to the synergism between the PVS polymer and nano-TiO_2. Morshed *et al.* (2018) reported to sonochemical synthesis of TiO_2 nanoparticles in cotton fibers via low temperature sol-gel technique. Ultrasonication time, ultrasonic power, and concentration of tetrabutyl titanate affected on UPF values of cotton fabrics. Suryaprabha and Sethuraman (2021) prepared multifunctional cotton fabrics based on the deposition of TiO_2 sol followed by surface modification using stearic acid (STA). STA-TiO_2 cotton fabrics exhibited UV-blocking ability and self-cleaning properties. Moreover, these superhydrophobic fabrics showed chemical durability and mechanical stability. Finally, Riaz *et al.* (2021) reported to the fabrication of cotton fabrics with TiO_2 nanoparticles modified with two different silane coupling agents using pad-dry-cure method. The presence of modified nanoparticles in the fiber surface improved the UV-blocking performance causing minimum effect on inherent properties of cotton textiles, e.g., sensorial comfort.

Fakin *et al.* (2012) investigated the SiO_2 coated TiO_2 particles performance in reactive dyeing of cotton fabrics. The incorporation of synthesized particles into the dyeing with reactive dyes brought about an outstanding UV blocking ability of the dyed fabrics even after 15 laundering cycles without considerable negative impact on color and comfortable properties. Washing process was performed according to the BS EN ISO 105-C06:2010 (2010) standard. UV protection, comfort, and dyeing properties of cotton fabrics were directly associated to dyeing temperature and amount of dye and SiO_2 coated TiO_2 particles.

S. Li *et al.* (2017) reported to the development of multifunctional cotton fabrics obtained by hydrothermal deposition of TiO_2 particles onto fiber surface followed by *in situ* deposition of Ag nanoparticles via reduction method. These fabrics exhibited high antibacterial activity with an inhibition rate higher than 99% against *Staphylococcus aureus* and *Escherichia coli* bacteria. Moreover, UPF values between 35 and 57 confirmed the UV-blocking capacity of them. Using a different two-step coating approach, Pakdel *et al.* (2020) prepared cotton fabrics coated with TiO_2 and hollow glass microspheres (HGMs). The presence of TiO_2 layer on cotton fibers gave rise to an excellent UV-blocking

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

activity as proved by UPF values higher than 190. In addition, HGMs coating reduced the inflammability of cotton fabrics and improved their thermal resistance and sound absorption capacity. Therefore, these TiO_2 + HGMs coated cotton fabrics exhibited multifunctional properties, i.e., UV-blocking ability, thermal insulation, flame retardancy and acoustic performance. It is important to highlighting that noise is considered a health hazard (Münzel *et al.*, 2020) and it is required to be eliminated for a better performance of humans in different areas (Pakdel *et al.*, 2020).

In different scientific publications, Dastjerdia *et al.* (2010), Rana *et al.* (2016), Chimeh and Montazer (2016), Xu *et al.* (2018), Bouazizi *et al.* (2020) and Zohoori *et al.* (2021) reported the development of UV-protective fabrics with different nanocomposites based on TiO_2. Dastjerdia *et al.* (2010) investigated the multifunctional properties of Ag/TiO_2 nanocomposite coated polyester fabrics prepared by pad-dry-cure method. The results revealed that the nanocomposite coating gives a considerable antibacterial, self-cleaning, anti-staining and UV-blocking capacity to polyester textiles. In this scientific paper, authors focused on showing the main results of characterization techniques without in-depth discussions about physic-chemical phenomena involved. In similar scientific research, Rana *et al.* (2016) reported the preparation of multifunctional cotton fabrics with Ag/AgBr-TiO_2 nanocomposite coating by simple spray coating process. The results showed that the nanocomposite coating onto cotton fabrics improved textile mechanical properties and gave rise to antibacterial and UV-blocking abilities.

Chimeh and Montazer (2016) prepared polyester fabrics with nano-TiO_2/carbon nanotubes or nano-TiO_2/nanocarbon black composites through exhaustion method and post-curing. The composite coating increased the UV blocking capacity of PET textiles as seen in UV-VIS reflectance spectra. Furthermore, nano-TiO_2/carbon composites imparted photocatalytic activity and electrical conductivity to fabrics. Also, Xu *et al.* (2018) successfully prepared superhydrophobic and UV-protective cotton fabrics by the incorporation of TiO_2/SiO_2 composite nanoparticles followed by hydrophilization with hexadecyltrimethoxysilane. TiO_2/SiO_2 composite nanostructures onto fibers made the textiles rougher, which contributed to the formation of superhydrophobic surfaces, and decreased the UV transmittance of cotton fabrics promoting UPF values higher than 80.

Bouazizi *et al.* (2020) reported the design and functionalization of new composite-based PET fibers with UV protection. The fixation of MO_x/polyvinylidene fluoride/Chitosan composite (MO_x = TiO_2, ZnO or SiO_2) into PET fibers improved both the thermal stability and UV protection of textiles. High UPF values (80.5 – 113.4) of textiles indicated their excellent UV-blocking capacity.

Zohoori *et al.* (2021) prepared wool fabrics coated with TiO_2/Ce or ZnO/Ce nanocomposite coated wool fabrics by ultrasonic method. XRD, EDX and SEM results showed the formation of nanocomposites and indicated a good distribution of them on the wool surface. The wool fabrics coated with TiO_2/Ce or ZnO/Ce nanocomposites showed lower UV transmission percentage than raw wool fabric indicating an improvement on the UV protection. Also, these fabrics exhibited antibacterial and self-cleaning activity.

3.2 ZnO

Zinc oxide is also a commercial inorganic filter widely used in cosmetic formulations and/or self-cleaning systems. Like TiO_2, zinc oxide has UVB absorption capacity (Flor *et al.*, 2007; Seixas and Serra, 2014), low skin toxicity (Abuçafy *et al.*, 2016), photocatalytic and antibacterial ability (Qi *et al.*, 2017). Consequently, fabric fibers with zinc oxide or nanocomposite based on ZnO have been investigated to provide new insights in UV-protective textile manufacturing.

Y. Li *et al.* (2011) reported the preparation of cotton fabric with ZnO, in which ZnO particles were *in situ* synthesized inside of textile fibers, via two-step hydrothermal method. The results showed that zinc oxide particles were successfully assembled into the lumen and the mesoporous cotton fibers. Therefore, UV-blocking ability of the cotton fabric was significantly improved by assembling ZnO inside the fibers.

Ates and Unalan (2012) investigated to self-cleaning, superhydrophobic and UV-blocking properties of zinc oxide nanowire-containing cotton fabric prepared by microwave assisted hydrothermal method and subsequently functionalized with stearic acid. The results showed the superhydrophobic nature of textile fibers, the decrease of the transmission intensity in UV spectral region and considerable degradation of methylene blue under UV light irradiation, one of the main photodegradation methods to investigate self-cleaning properties.

Çakir *et al.* (2012) successfully prepared ZnO coated cotton fabrics that exhibit UV-blocking, self-cleaning and antibacterial properties. It is important to emphasize that ZnO nanoparticles were synthesized in reverse micelle cores of PS(10912)-b-PAA(3638) copolymer obtained by atom transfer radical polymerization. The ZnO nanoparticles coating onto textile fibers provided

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

photocatalytic activity on degradation of methylene blue and antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* bacteria. Moreover, ZnO coated cotton fabrics exhibited UPF values greater than 60.

Y. Li *et al.* (2012) investigated UV blocking property and water-wash durability of nano-ZnO assembled cotton fibers obtained by microwave assisted precipitation and crystallization process synchronously *in situ* for the first time. UV-VIS transmission spectra showed an excellent UV-blocking activity in the 225–380 nm region. The water-washing process of nano-ZnO assembled cotton fibers did not change their UV absorption capacity as seen in UV transmission measurements. The water-washing durability test was carried out in a domestic washer (XQB45-846B National, Panasonic), where nano-ZnO assembled cotton textiles were washed with water (v = 33 L) for 20, 40 and, 60 min.

Shateri-Khalilabad and Yazdanshenas (2013b) and Zhang *et al.* (2013) successfully prepared smart fabrics via *in situ* synthesis of ZnO on the cotton fiber surface. In both publications, ZnO coated cotton fabric exhibited high UV-blocking ability as proven in UPF values (105.61 [Shateri-Khalilabad and Yazdanshenas, 2013b] and 136 [Zhang *et al.*, 2013]). Moreover, it showed bacterial inhibition (Shateri-Khalilabad and Yazdanshenas, 2013b) or antibacterial (Zhang *et al.*, 2013) activity.

The pad-dry-cure method was used by Raza *et al.* (2016) and El-Naggar *et al.* (2018) in the preparation of cotton fabrics coated with chitosan/ZnO nanocomposites and ZnO nanoparticles, respectively. Nanocomposite (Raza *et al.* 2016) and ZnO (El-Naggar *et al.*, 2018) coated cotton fabrics exhibited antibacterial activity and UV-blocking capacity.

Thi and Lee (2017) reported the development of self-cleaning and UV-blocking cotton fabric with modification of photoactive ZnO coating via microwave method. ZnO coated cotton fabrics synthesized at pH range equal 6–7, 8–9 and 10–11 showed UPF values of 222.52, 162.68 and 202.57, respectively. In addition, these cotton fabrics exhibited excellent self-cleaning ability proved by high removal degree of the coffee stains under UV irradiation at different air humidity levels.

Subbiah *et al.* (2018) successfully prepared nanostructured ZnO modified cotton fabrics via sol-gel and sputter seed layer-coated sol-gel techniques. All modified cotton fabrics exhibited greater UPF values than raw fabric, but the seed layer-initiated sol-gel modified cotton fabric showed the highest UPF value (378). Moreover, these modified cotton fabrics showed room temperature gas sensing response towards volatile organic compounds enabling their use as gas sensor.

Mai *et al.* (2018) reported the development of multifunctional polyvinylsilsesquioxane/ZnO coated cotton fabrics. Composite coatings improved UV-blocking, superhydrophobic and antimicrobial properties of cotton fabrics compared to the reference textiles. In addition, polyvinylsilsesquioxane/ZnO coatings enhanced the mechanical properties of cotton fabrics and did not compromise their thermal stability.

X. Wang *et al.* (2019) successfully prepared UV-protective fabrics via grafted polymer brushes for *in situ* growth of ZnO on modified cotton fiber using the electroless deposition method. According to the results, the functionalized fabrics exhibited UV blocking properties and wash durability due to the presence of the ZnO on the inner wall of cotton fibers and the polymer-tethered structure.

Khan *et al.* (2020) reported a novel microwave hydrothermal method to grow aligned ZnO nanorods on cotton fibers. The ZnO coated cotton fabrics obtained showed greater UPF values than pristine cotton fabric, which indicated that ZnO nanorods improved the UV protection of cotton textile. Moreover, the functionalization of ZnO coated cotton fabrics with non-fluorinated silane provided superhydrophobic properties and oil–water separation performance.

Noorian *et al.* (2020) prepared antibacterial and UV-blocking fabrics by pretreatment of cotton fibers with 4-aminobenzoic acid (PABA) followed by *in situ* sonochemical synthesis of ZnO nanoparticles. The PABA treatment provided significant sites for the growth of the ZnO nanoparticles and maintained cross-linking property between oxidized cellulosic fibers and the ZnO nanoparticles. Synergistic effects from ZnO and PABA association imparted UPF values higher than 65 and antibacterial activity against *E. coli* and *S. aureus* to the cotton fabrics.

Xue *et al.* (2011; 2013), in two different scientific research publications, investigated the superhydrophobic and UV-blocking properties of PET fabrics coated with ZnO/SiO_2 core/shell particles and hexadecyltrimethoxysilane. The coated PET textiles exhibited superhydrophobic surface and UV-blocking ability as seen in water contact angle and UV-VIS spectroscopy results. In addition, the SiO_2 shell inhibited the photocatalytic activity of ZnO ensuring the superhydrophobicity of PET surfaces when exposure to UV radiation. Huang *et al.* (2019) also investigated the superhydrophobic and UV-blocking properties of silk fabrics prepared by combining a one-step *in situ* synthesis of ZnO nanorods on fiber surface and hydrophobic treatment with n-octadecanethiol. The

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

presence of ZnO nanorods in the silk fibers increased surface roughness and induced a rise in UPF values of fabrics indicating the improvement of UV-blocking ability. Also, obtained superhydrophobic surface showed mechanical and chemical stability.

3.3 Graphene compounds

Singular properties of graphene compounds described in the recent literature (Tiwari *et al.*, 2018) explain their several multifunctional applications in different systems and/or devices. In the smart fabric field, UV-blocking, electrical conductivity and/or antibacterial activity are mainly graphene compound properties investigated in the last scientific publications (Babaahmadi and Montazer, 2016; Hasani and Montazer, 2017a; b; Hu *et al.*, 2015; Mirjalili, 2016; Tian *et al.*, 2016; S.-D. Wang *et al.*, 2020). Electrically conducting textiles produce clothes with static dissipation, anti-spark and electromagnetic interference shielding (Varesano and Tonin, 2008) that can be used in the smart clothing design, e.g., innovative sportswear.

Hu *et al.* (2015) prepared multifunctional cotton fabrics coated with graphene and waterborne anionic aliphatic polyurethane composites by pad-dry-cure method. Graphene/polyurethane coatings significantly enhanced the UPF values indicating high UV-blocking capacity of cotton fabrics. In addition, graphene/polyurethane coated cotton fabrics exhibited far-infrared emissivity up to 0.911 in the wavelength range of 4–18 μm and lower electrical resistivity than pristine cotton fabric. Far-infrared emitting fabrics are commonly used in health care and therapeutic clothing manufacturing because the far-infrared radiation (6–15 μm) promotes the enhancement of blood microcirculation and metabolism (Vatansever and Hamblin, 2012).

Mirjalili (2016) investigated the UV-blocking, electrical conductivity, magnetic and antibacterial properties of the reduced graphene oxide/Fe_3O_4 nanocomposite coated cotton fabric. UV-blocking ability of the nanocomposite coated cotton fabric was proved by the increase of the UPF value compared to raw cotton textile. This fabric also displayed a low electrical resistivity, antibacterial activity, and magnetic properties.

Tian *et al.* (2016) successfully prepared cotton fabrics coated with graphene oxide and chitosan by the electrostatic layer-by-layer self-assembly approach. These fabrics showed higher UPF values than control cotton fabric and washing durability even after 10 times water laundering. It is important to emphasize that the water laundering durability test of cotton fabrics was performed by following the American Association of Textile Chemists and Colorists AATCC 61 (2006).

Babaahmadi and Montazer (2016) investigated electrical conductivity and UV-blocking properties of reduced graphene oxide/SnO_2 nanocomposite coated PET textile obtained by modified exhaustion method. Electrical resistivity decreased and UPF value increased with reduced graphene oxide/SnO_2 nanocomposite coating of PET fibers, which indicated the formation of an electroconductive and UV blocking textile. Moreover, electrical resistivity and UV-blocking results demonstrated the good durability of nanocomposites on surface of PET fabrics after 10 washes with deionized water.

In different scientific papers, Hasani and Montazer (2017a; b) reported the multifunctional properties of reduced graphene oxide-coated cotton/nylon fabrics. According to the UV-VIS reflectance results, textile materials showed high UV absorption in the 200–400 nm region indicating their potential as UV-protective fabrics. These fabrics also exhibited lower electrical resistance, antibacterial activity against *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Enterococcus faecalis* bacteria and antifungal activity against eukaryotic fungus *C. albicans*.

S.-D. Wang *et al.* (2020) successfully prepared a multifunctional silk fabric by grafting graphene oxide (GO) nanosheet dispersion onto the fabric surface. The silk fabrics modified with GO showed higher UPF values than control silk, which indicated the enhancement of UV-blocking properties. Furthermore, modified silk fabrics exhibited excellent antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* bacteria.

3.4 MOFs

Zhang *et al.* (2020) developed a series of multifunctional textiles prepared via *in situ* modified MOFs nanocrystals on the cotton surface. Based on structural and spectroscopic characterizations, it was confirmed the existence of chemical bonds between MOFs and hydroxyl and/or carboxyl groups belonging to cotton fibers. In addition, a uniform distribution of MOFs nanocrystals in textile surface was observed. The MOFs/cotton textiles exhibited greater UV blocking activity and acoustic absorption performance than blank cotton that demonstrated their potential use as fabrics for UV protection and noise reduction. According to the literature (Münzel *et al.*, 2020), excessive exposure to the noise environment induces adverse cardiovascular effects and mental annoyance.

Emam *et al.* (2020) investigated the multifunctional properties of cotton fabrics with zeolitic imidazole frameworks (ZIFs). ZIF(Ni), ZIF-8(Zn) and ZIF-67(Co) were *in situ* synthesized into cotton fabrics before or after silicate modification on the fiber surface. When silicate functionalization was performed before the ZIFs formation, the silicate acted as cross-linker between ZIFs and cotton fibers providing the increment of MOFs amount in the fabric surface. Modified cotton fabrics showed higher UPF values than pristine cotton textile and washing durability (AATCC M6, 2010). Also, they exhibited antibacterial activity against *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, and *Candida albicans* bacteria.

Emam and Abdelhameed (2017) reported the incorporation of MIL-68(In)-NH_2 or MIL-125(Ti)-NH_2 (MIL = Matériaux de I′Institut Lavoisier) into cotton or silk textiles using quite simple and one-pot process to produce UV-blocking textiles. All MIL-MOFs incorporated textiles exhibited UV-blocking activity; however, MIL-MOFs and metal contents in natural fibers influenced on the UPF values obtained. After five washing cycles (AATCC M6, 2010), these textiles showed a slight decrease of UPF values, which proved their laundering durability.

G.-P. Li *et al.* (2020) investigated the UV-blocking properties of InOF-1 coated cotton, polyester or aramid textiles prepared by hot-pressing method. Regardless of textile fiber type used, InOF-1 coating provided a significantly increasing in the UV-blocking performance. Moreover, the interactions between InOF-1 and textile fibers, as proven in FTIR results, enhanced the tensile strength and elongation at break of MOF coated textiles.

3.5 Organic compounds

Ibrahim *et al.* (2010a) investigated the transfer printability and UV blocking properties of polyester-based textiles obtained by pretreatment of polyester fibers and polyester/wool, polyester/cotton, and polyester/viscose blend fibers with monochlorotriazinyl β-cyclodextrin (MCT-β-CD), chitosan or ethylenediamine followed by transfer printing with sublimable disperse dyes. Hydrophobic cavities generated via grafting of MCT-β-CD, amine functional groups incorporated via aminolysis of the polyester and/or chitosan fixed onto textile matrix afforded an improvement of UV-blocking capacity, transfer printing and fastness properties of modified post-printed fabric samples. In other scientific publication, Ibrahim *et al.* (2011) reported the development of multifunctional cotton and viscose fabrics printed with reactive dyes through combined reactive printing and MCT-β-CD loading in one-step followed by subsequent treatment with Neem oil. The post-treatment with Neem oil provided the improvement of the antibacterial activity of the treated reactive prints without adversely affecting the UV-blocking properties of the final products.

Subramani *et al.* (2017) investigated multifunctional properties of the Aloe vera-chitosan nanocomposite coated cotton fabric prepared by pad-dry-cure method. Cotton fabric coated with herbal nanocomposite exhibited excellent UV-blocking ability (UPF > 52), superhydrophobicity, and antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* bacteria.

In different scientific publications, Khan *et al.* (2018) and Shabbir *et al.* (2018) reported the development of UV-blocking fabrics from natural plant extracts. Khan *et al.* (2018) successfully prepared UV-blocking and antibacterial fabric by wool treatment with aqueous and alkali extracts of *Cinnamomum camphora* leaves. Camphor leaves extract imparted dyeing, UV-blocking and antibacterial properties to wool fabric. Shabbir *et al.* (2018) reported UV-protective and antioxidant finishing of wool fabric dyed with marigold (*Tagetes erecta*) flower extract. Carotenoid compounds of marigold extract are main responsible for UV-blocking and antioxidant properties of this organic dye. Marigold dyed wool fabrics showed UPF values higher than 30 and capacity to capture peroxide reactive species; therefore, dyed fabrics can be used as potential UV-blocking and antioxidant textiles.

3.6 Inorganic compounds, metal nanoparticles, LDH material and coordination compounds

Z. Chen and Yin (2010) investigated the UV-blocking capacity of Eu(III) complex-containing cotton fabrics prepared by pad-dry-cure method. Based on spectroscopic results, Eu(III) complex-cotton fabrics showed higher UPF values than blank cotton fabric and red-light emission. These results are similar to the Eu(III) doped LDH intercalated with cinnamate anions reported by Saito *et al.* (2018). The Eu(III) doped LDH material exhibited UV-shielding ability and low-intensity red emission that could be inducing collagen production (Saito *et al.*, 2018). Thus, Eu(III) complex-containing cotton fabrics can be able to induce the collagen biosynthesis depending on its intensity emission.

Ibrahim *et al.* (2010b) prepared functional finishes of linen-containing fabrics by fiber surface modifications using oxygen or nitrogen plasma followed by subsequent dip-pad-cure process with metal salts, nano-scale metal or metal oxides, ionic dyes, quaternary ammonium salt or antibiotics. The linen-based textile results indicated the loading of metal salts, nano-scale metal or metal

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

oxides or ionic dyes onto the plasma treated substrates provided antibacterial activity and a remarkable improvement in UV blocking capacity. Moreover, these functional properties were retained even after 10 laundering cycles (AATCC 124, 1996). In other scientific publication, Ibrahim *et al.* (2018) reported the multifunctional properties of PET fibers obtained via premodification with sodium hydroxide followed by coating with SiO_2, TiO_2, ZnO or ZrO_2 nanoparticles using gelatin as a green binding agent. The results showed an improvement on antibacterial, UV blocking, self-cleaning and softness properties of PET fabrics, which are maintained after 15 laundering cycles (AATCC 135, 2000).

In a series of scientific papers (Rezaie *et al.*, 2017a; b; c) Rezaie and coworkers reported the multifunctional properties of CuO-containing wool and/or polyester fabrics. Based on the results of the UV protection enhancement (%) method described by Noorian *et al.* (2015) CuO-containing fabrics exhibited higher UV-blocking ability and self-cleaning activity. In addition, these fabrics showed antibacterial activities toward two pathogen bacteria including *Staphylococcus aureus* as Gram-positive and *Escherichia coli* as Gram-negative bacteria with no adverse effects on human dermal fibroblasts based on MMT cytotoxicity test (Montazer *et al.*, 2015). The CuO-containing PET fabrics also exhibited a rapid and effective colorimetric response for ammonia detection indicating their potential as ammonia sensing.

Zhao *et al.* (2013) successfully prepared cotton fabrics coated with amino-functionalized Mg_2Al-HMBS-LDH (HMBS = 2-hydroxy-4-methoxybenzophenone-5-sulfonate anions) by electrostatic layer-by-layer assembly technique. Based on thermal analyses, intercalated HMBS showed higher thermal stability than HMBS pristine due to host-guest interactions in the interlayer region. All cotton fabrics assembled with amino-functionalized Mg_2Al-HMBS-LDH showed water contact angles greater than 150° suggesting superhydrophobic ability. In addition, these superhydrophobic fabrics exhibited the enhancement of UPF values compared to untreated cotton textile demonstrating UV-blocking capacity.

Sedighi *et al.* (2018) investigated the multifunctional properties of 3,4-ethylene dioxythiophene polymer (PEDOT)/magnetite nanoparticles coated PET fabrics. PEDOT/magnetite nanoparticles coating improved the UV-blocking capacity of PET fabric especially in UVB and UVC regions. This nanoparticle coating also provided significant antibacterial activity against *S. aureus* bacteria, electromagnetic interference (EMI) shielding behavior and superparamagnetic properties. In this paper, EMI shielding corresponds to microwave attenuation ability of these multifunctional PET fabrics.

N. Li *et al.* (2018) reported a novel coating technique involving *in situ* self-assembly of the polyoxotitanate (POT) cage $[Ti_{18}Mn_4O_{30}(OEt)_{20}Phen_3]$ to fabricate multifunctional cotton fabrics in a single step. The POT cage coating imparted excellent UV-blocking performance (89% blocked at 350 nm), hydrophobicity (water contact angle > 148°) and antibacterial activity (*Escherichia coli*, *Staphylococcus epidermidis*, and *Staphylococcus aureus* bacteria) to cotton fabrics.

Jin *et al.* (2019) successfully prepared bismuth phosphate ($BiPO_4$) nanorods coated cotton fabrics by two-dip-two-nip technique. Chitosan and acetic acid acted as cross-linking agents between $BiPO_4$ and cotton fibers as seen in UV-VIS absorption and FTIR results. The coated fabrics exhibited UV-blocking ability confirmed by UPF values greater than blank cotton fabric and self-cleaning activity.

A series of scientific publications (Čuk *et al.*, 2021; Nateghi and Shateri-Khalilabad, 2015; Pan *et al.*, 2012; Razmkhah *et al.*, 2021; Shateri-Khalilabad and Yazdanshenas, 2013a; Tang *et al.*, 2017) reported multifunctional features of metal nanoparticles coated smart fabrics. In this perspective, silver nanoparticles had widely used due to their antibacterial ability. Shateri-Khalilabad and Yazdanshenas (2013a) investigated superhydrophobic, antibacterial, and UV-blocking properties of the silver nanoparticles (AgNPs) coated cotton fabric. AgNPs coating was formed on the cotton surface through an alkali preactivation followed by *in situ* reduction of silver nitrate. Then, AgNPs coated cotton fibers were subjected to superhydrophobic treatment with octyltriethoxysilane (OTES). AgNPs coated cotton fabric showed UPF value equal to 266, water contact angle greater than 150° and shedding angle equal to 8°. Also, coated fabric exhibited antibacterial activity against Gram-negative *Escherichia coli* and Gram-positive *Staphylococcus aureus* bacteria.

Nateghi and Shateri-Khalilabad (2015) also investigated multifunctional properties of the silver nanowires (AgNWs) coated cotton fabric prepared by dip-dry method followed by superhydrophobic treatment with Danasylan F 8815. SEM/EDX results indicated a thin and uniform AgNWs coating on the cotton fibers. AgNWs coated cotton fabric also exhibited UV-blocking (UPF > 113), superhydrophobic (water contact angle > 150° and shedding angle < 10°) and antibacterial properties. In other scientific paper about Ag nanoparticles coated textiles, Čuk *et al.* (2021) reported the development of multifunctional fabrics using plant food waste (green tea leaves, avocado seed and pomegranate peel) and alien invasive plant extracts

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

(Japanese knotweed rhizome, goldenrod flowers and staghorn sumac fruit) as reducing agents for the *in-situ* synthesis of silver nanoparticles in cotton fibers. Regardless of the reducing agent used, all silver nanoparticles containing cotton fabrics showed UPF values above 50 and antibacterial activity against *E. coli* and *S. aureus* bacteria.

Pan *et al.* (2012) successfully prepared a superhydrophobic and UV blocking cotton fabric via sol-gel method and self-assembly using inexpensive and ordinary reagents, aluminum nitrate and sodium stearate. The interactions between aluminum coating and sodium stearate in cotton fabrics was confirmed by XPS results. Cotton fabric treated with 1.5% Al sol and 20 mmol L^{-1} sodium stearate exhibited excellent hydrophobic properties (water contact angle > 146°) and UV blocking ability (UPF = 164).

In other scientific publication about nanoparticle-containing cotton fabrics, Tang *et al.* (2017) reported the development of gold nanoparticles (AuNPs) coated cotton fabrics prepared by *in situ* synthesis of AuNPs onto fiber surface using a heating method. The localized surface plasmon resonance of the AuNPs imparted the cotton fabric with colors, showing good colorfastness to washing and rubbing. It is important to highlight that the colorfastness to washing and rubbing were evaluated in accordance with Australian Standard AS 2001.4.15–2006 and Australian Standard AS 2001.4.3–1995, respectively. The AuNPs coating improved the UV-blocking ability of cotton textiles and resulted in UV-protective fabrics with remarkable antibacterial activity. In addition, AuNPs coated cotton fabrics exhibited catalytic activity, which did not influence on their dyeing with reactive dyes.

Razmkhah *et al.* (2021) reported the UV-blocking and antibacterial properties of selenium nanoparticles coated wool fabrics. Based on the results of the UV protection enhancement (%) method (Noorian *et al.*, 2015), the coated fabrics exhibited UV-blocking ability. In addition, these fabrics showed reasonable bactericidal and fungicidal performances toward *Escherichia coli*, *Staphylococcus aureus* and *Candida albicans*.

For comparative purposes, Fig. 5 and 6 were made to analyze and discuss the main scientific information of UV-protective compound-containing smart fabrics described above. Thus, Fig. 5 shows the number of scientific publications for each UV-protective compound class presented in the chemical composition of smart fabrics and Fig. 6 illustrates the UV-blocking range of UV-protective compound-containing fabrics. It is important to highlight that UV-blocking range corresponds to the UV-shielding performance of compound class including specific UV spectral region of each compound.

Analyzing the number of scientific publications about UV-protective compound-containing smart fabrics in the period from 2010 to 2021 (Fig. 5), it is observed that TiO_2, ZnO and nanocomposites based on TiO_2 or ZnO were the most used in the development of UV-blocking fabrics. Probably, low human skin toxicity (Abuçafy *et al.*, 2016) and UV-shielding (Abuçafy *et al.*, 2016; Flor *et al.*, 2007; Seixas and Serra, 2014), self-cleaning (Banerjee *et al.*, 2015; Qi *et al.*, 2017) and antibacterial (Qi *et al.*, 2017; Yadav *et al.*, 2016) properties of these oxides and/or nanocomposites combined with several synthetic methods used to obtain them (Montazer and Pakdel, 2011; Montazer and Amiri, 2014) encouraged this great number of scientific studies. In general, synthetic approaches use low-cost and easy-to-obtain reagents and, depending on the synthetic route, allow to control the morphology, surface, and particle size of TiO_2, ZnO and/or nanocomposites based on TiO_2 or ZnO. Despite the smaller number of scientific papers, other UV-protective compounds, mainly LDH, MOFs and Graphene compounds, demonstrate growing potential to be used in the development of novel smart fabrics due to their new multifunctional features, increasingly reported in the recent literature. Thus, a promise increasing of scientific publications about this type of smart fabrics could be expected.

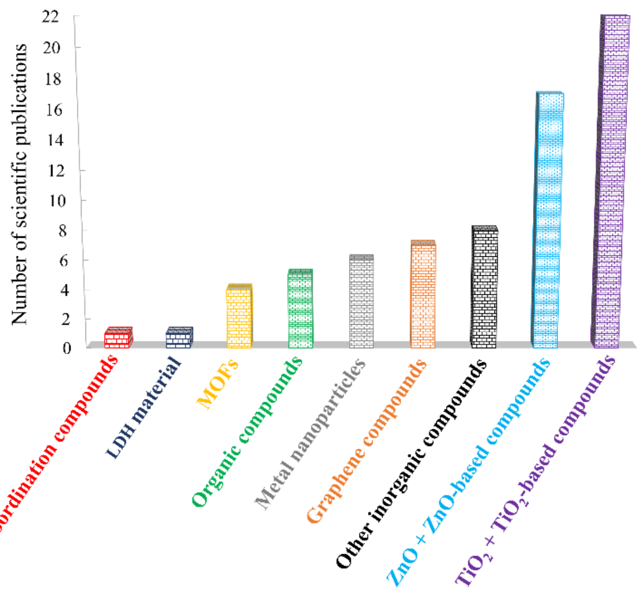


Figure 5. Number of scientific publications of the UV-protective compound-containing smart fabrics per UV-protective compound class in the period from 2010 to 2021.

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

Another relevant aspect to be considered is that the smart fabrics with LDH, MOFs or graphene compounds exhibited UV-blocking range situated in the UVB and UVA regions (Fig. 6) indicating broad-spectrum action, i.e., capacity to protect the human skin from both UVB and UVA radiation. Organic compounds or metal nanoparticles containing smart fabrics also had same broad-spectrum behavior, while other fabrics showed UVB-blocking capacity (Fig. 6). Therefore, UV-protective compound presented in the textile composition determines the UV radiation region that smart fabrics have higher protection efficiency.

Although organic compounds can undergo decomposition under certain conditions, e.g., high temperature and/or oxidizing environment, the synergistic effects from interactions between these compounds and textile fibers improve their thermal, chemical and/or photochemical stability. Moreover, synergistic properties reduce the fiber photodegradation of smart fabrics. In this perspective, molecular interactions between textile fibers and UV-protective compounds provide specific physicochemical properties to textile materials and ensure lower occurrence of skin allergies by fabric contact.

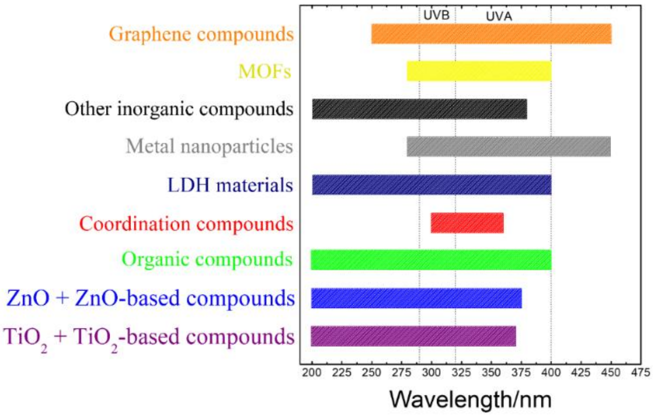


Figure 6. UV-blocking range of the UV-protective compound-containing smart fabrics per compound class.

Besides the UV-blocking range, UPF values are commonly used to indicate the UV protection of smart fabrics. Analogous to sun protection factor (SPF) of sunscreens, UPF is a parameter defined as the ratio of the average effective UV irradiance calculated for unprotected skin to the average effective UV irradiance calculated for skin protected by the smart fabric (Hoffmann *et al.*, 2001). Many scientific publications have shown that UV-VIS spectroscopic measurements are accurate and reproducible *in vitro* test method to determining UPF (Montazer and Amiri, 2014), which is obtained by Eq. 1:

$$\mathrm{UPF} = \frac{\int_{290}^{400} E_\lambda S_\lambda d_\lambda}{\int_{290}^{400} E_\lambda S_\lambda T_\lambda d_\lambda} \quad (1)$$

where E_λ is the relative erythemal spectral effectiveness and S_λ is the solar spectral irradiance of the source. The T_λ corresponds to spectral transmission of the test fabric as a function of wavelength (λ) and the wavelength integration limits refers to the combined UVB and UVA wavelength range.

According to Hoffmann *et al.* (2001), UPF values between 15 to 24 (ratings 15 and 20, respectively) indicate a good UV-protection, UPFs of 25 to 39 (ratings 20, 30 and 35, respectively) demonstrate a very good UV-protection, and UPFs ≥ 40 correspond to an excellent UV-protection (ratings 40, 45, 50 and 50+). Analyzing the UPF values of scientific publications cited in this review, it is observed that more than 90% of them exhibited UPF values higher than 40. Therefore, smart fabrics had an excellent UV-protection regardless on the UV-protective compound presented in the textile fibers. However, some precautions must be considered in the analysis and interpretation of these UPF results. One of the most important aspects is the UV-VIS transmission measurements, which undergo spectral changes and/or deviations depending on the experimental conditions used and/or optical properties of smart fabrics. In this perspective, opaque and translucent smart fabrics, which exhibit nonlinear behavior of Lambert–Beer law, must be carefully analyzed to avoid mistakes in the interpretation of UPF results.

4. Conclusions

In this review, recent literature on UV-blocking textiles have been reported to give an overview of their importance and prospects in sun-protective methods. UV-protective compounds incorporated, anchored, or coated textile fibers compose a useful class of UV-blocking materials for the development of smart fabrics as proved by the large number of scientific publications in the last years. Different UV-protective compounds, mainly TiO_2 and ZnO, are used to improve UV-blocking ability of fabrics and, often, they also impart to additional fabric properties, e.g., antibacterial, and self-cleaning activities. Analyzing from spectroscopic point of view, the elucidation of UV-blocking mechanisms gives an important information about electronic structure and optical properties of UV-protective textiles; therefore, it can be more investigated and discussed in the literature. A remarkable point is the reduced number of scientific papers that reported the use of organic filters in smart fabrics although these UV-protective compounds have

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

high UV absorption capacity and, depending on their molecular structure, can interact to fiber surface without the presence of cross-linker compounds. UPF is a good parameter to indicate the UV-blocking ability of UV-protective compound-containing smart fabrics, however, some aspects must be considered in the analyses and interpretation of UPF results. Among them, (i) the amount of the UV-protective compound per textile area, (ii) textile thickness, and (iii) textile properties changed by the incorporation, coating and/or anchorage with UV-protective compounds, e.g., textile roughness. In this perspective, new scientific studies need to be undertaken to know the effective contribution of UV-protective compounds in the UPF values. Considering the growing requirement for simple, cheap, and practical sun-protective products, UV-blocking textiles are one of the best alternatives. Thus, scientific research in the field of smart fabric and/or UV-blocking textile, especially UV-protective compounds incorporated, anchored, or coated textile fibers, must be encourage in order to promote new insights in sun-protective clothing and future applications of multifunctional textiles.

Authors' contribution

Conceptualization: Lupino, J. H. B.; Saito, G. P.; Cebim, M. A.; Davolos, M. R.
Data curation: Lupino, J. H. B.; Saito, G. P.; Cebim, M. A.; Davolos, M. R.
Formal Analysis: Not applicable.
Funding acquisition: Davolos, M. R.
Investigation: Not applicable.
Methodology: Not applicable.
Project administration: Not applicable.
Resources: Not applicable.
Software: Not applicable.
Supervision: Davolos, M. R.
Validation: Lupino, J. H. B.; Saito, G. P.; Cebim, M. A.; Davolos, M. R.
Visualization: Lupino, J. H. B.; Saito, G. P.; Cebim, M. A.; Davolos, M. R.
Writing – original draft: Lupino, J. H. B.
Writing – review & editing: Saito, G. P.; Cebim, M. A.; Davolos, M. R.

Data availability statement

Data sharing is not applicable. In this review, all scientific publications reported were found in the Web of Science™ database (https://www-webofscience.ez87.periodicos.capes.gov.br).

Funding

Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). Grant No: 317610/2021.
Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) - Programa Institucional de Bolsas de Iniciação Científica (PIBIC). J.H.B.L Scholarship No: 1127 – Edital 01/2020.

Acknowledgments

The authors acknowledge the Instituto de Química - Universidade Estadual Paulista (Unesp) for the institutional infrastructure and technical support.

References

AATCC 124. *Appearance of durable press fabrics after repeated home laundering*. American Association of Textile Chemists and Colorists, 1996. https://law.resource.org/pub/us/cfr/ibr/001/aatcc.tm.124.1996.pdf (accessed 2021-01-21).

AATCC 135. *Dimensional change*. American Association of Textile Chemists and Colorists, 2000. https://global.ihs.com/doc_detail.cfm?&item_s_key=00157760&item_key_date=991231&input_doc_number=&input_doc_title= (accessed 2021-01-21).

AATCC 61. *Colorfastness to laundering, home and commercial: Accelerated*. American Association of Textile Chemists and Colorists, 2006. https://global.ihs.com/doc_detail.cfm?&input_doc_number=&input_doc_title=&document_name=AATCC%2061&item_s_key=00255811&item_key_date=931231&origin=DSSC (accessed 2021-01-21).

AATCC M6. *Standardization of home laundry test conditions*. American Association of Textile Chemists and Colorists, 2010. https://global.ihs.com/doc_detail.cfm?&input_doc_number=&input_doc_title=&document_name=AATCC%20M6&item_s_key=00490394&item_key_date=891231&origin=DSSC (accessed 2021-01-21).

Abuçafy, M. P.; Manaia, E. B.; Kaminski, R. C. K.; Sarmento, V. H.; Chiavacci, L. A. Gel based sunscreen containing surface modified TiO2 obtained by sol-gel process: Proposal for a transparent UV inorganic filter. *J. Nanomater.* **2016**, *2016*, 8659240. https://doi.org/10.1155/2016/8659240

Ahmedova, A.; Mantareva, V.; Enchev, V.; Mitewa, M. 2-Acetylindan-1,3-dione and its Cu^{2+} and Zn^{2+} complexes as promising sunscreen agents. *Int. J. Cosmet. Sci.* **2002**, *24* (2), 103–110. https://doi.org/10.1046/j.1467-2494.2002.00126.x

Alebeid, O. K.; Zhao, T. Review on: Developing UV protection for cotton fabric. *J. Text. Inst.* **2017**, *108* (12), 2027–2039. https://doi.org/10.1080/00405000.2017.1311201

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

Antoniou, C.; Kosmadaki, M. G.; Stratigos, A. J.; Katsambas, A. D. Sunscreens – What's important to know. *J. Eur. Acad. Dermatology Venereol.* **2008**, *22* (9), 1110–1119. https://doi.org/10.1111/j.1468-3083.2007.02580.x

Ates, E. S.; Unalan, H. E. Zinc oxide nanowire enhanced multifunctional coatings for cotton fabrics. *Thin Solid Films*. **2012**, *520* (14), 4658–4661. https://doi.org/10.1016/j.tsf.2011.10.073

Babaahmadi, V.; Montazer, M. Reduced graphene oxide/SnO_2 nanocomposite on PET surface: Synthesis, characterization and application as an electro-conductive and ultraviolet blocking textile. *Colloids Surfaces A Physicochem. Eng. Asp.* **2016**, *506*, 507–513. https://doi.org/10.1016/j.colsurfa.2016.07.025

Bagde, A.; Mondal, A.; Singh, M. Drug delivery strategies for chemoprevention of UVB-induced skin cancer: A review. *Photodermatol. Photoimmunol. Photomed.* **2018**, *34* (1), 60–68. https://doi.org/10.1111/phpp.12368

Baker, L. A.; Marchetti, B.; Karsili, T. N. V.; Stavros, V. G.; Ashfold, M. N. R. Photoprotection: extending lessons learned from studying natural sunscreens to the design of artificial sunscreen constituents. *Chem. Soc. Rev.* **2017**, *46* (12), 3770–3791. https://doi.org/10.1039/C7CS00102A

Banerjee, S.; Dionysiou, D. D.; Pillai, S. C. Self-cleaning applications of TiO_2 by photo-induced hydrophilicity and photocatalysis. *Appl. Catal.* **2015**, *176-177*, 396–428. https://doi.org/10.1016/j.apcatb.2015.03.058

Bouazizi, N.; Abed, A.; Giraud, S.; El Achari, A.; Campagne, C.; Morshed, M. N.; Thoumire, O.; El Moznine, R.; Cherkaoui, O.; Vieillard, J.; Le Derf, F. Development of new composite fibers with excellent UV radiation protection. *Phys. E Low-Dimensional Syst. Nanostructures.* **2020**, *118*, 113905. https://doi.org/10.1016/j.physe.2019.113905

BS EN ISO 105-C06:2010. Textiles. Tests for colour fastness Colour fastness to domestic and commercial laundering. International Organization for Standardization, 2010. https://www.en-standard.eu/bs-en-iso-105-c06-2010-textiles-tests-for-colour-fastness-colour-fastness-to-domestic-and-commercial-laundering/?gclid=CjwKCAiAheacBhB8EiwAItVO2-iHqcpqedUsYMAtalfWKiCYHqy7ARvxEnufx5sl3ILFxrU9ntnrLBoCEtcQAvD_BwE (accessed 2021-01-21).

Çakir, B. A.; Budama, L.; Topel, Ö.; Hoda, N. Synthesis of ZnO nanoparticles using PS-b-PAA reverse micelle cores for UV protective, self-cleaning and antibacterial textile applications. *Colloids Surfaces A Physicochem. Eng. Asp.* **2012**, *414*, 132–139. https://doi.org/10.1016/j.colsurfa.2012.08.015

Chau, C.-F.; Wu, S.-H.; Yen, G.-C. The development of regulations for food nanotechnology. *Trends Food Sci. Technol.* **2007**, *18* (5), 269-280. https://doi.org/10.1016/j.tifs.2007.01.007

Chen, Z.; Yin, G. Suitability of a rare earth organic light conversion agent of Eu(III) complex to improve ultraviolet protection properties of cotton fabrics. *Text. Res. J.* **2010**, *80* (18), 1982–1989. https://doi.org/10.1177/0040517510373631

Chen, D.; Mai, Z.; Liu, X.; Ye, D.; Zhang, H.; Yin, X.; Zhou, Y.; Liu, M.; Xu, W. UV-blocking, superhydrophobic and robust cotton fabrics fabricated using polyvinylsilsesquioxane and nano-TiO_2. *Cellulose*. **2018**, *25* (6), 3635–3647. https://doi.org/10.1007/s10570-018-1790-7

Chimeh, A. E.; Montazer, M. Fabrication of nano-TiO_2/carbon nanotubes and nano-TiO_2/nanocarbon black on alkali hydrolyzed polyester producing photoactive conductive fabric. *J. Text. Inst*. **2016**, *107* (1), 95–106. https://doi.org/10.1080/00405000.2015.1012881

Costa, M. Nanotecnologia. O que é? *Química Têxtil*. **2012**, *106*, 3–11.

Čuk, N.; Šala, M.; Gorjanc, M. Development of antibacterial and UV protective cotton fabrics using plant food waste and alien invasive plant extracts as reducing agents for the in-situ synthesis of silver nanoparticles. *Cellulose*. **2021**, *28* (5), 3215–3233. https://doi.org/10.1007/s10570-021-03715-y

Curtzwiler, G. W.; Williams, E.B.; Maples, A. L.; Davis, N.W.; Bahns, T. L.; De Leon, J. E.; Vorst, K. L. Ultraviolet protection of recycled polyethylene terephthalate. *J. Appl. Polym. Sci.* **2017**, *134* (32), 45181. https://doi.org/10.1002/app.45181

Dastjerdia, R.; Montazer, M.; Shahsavan, S. A novel technique for producing durable multifunctional textiles using nanocomposite coating. *Colloids Surf. B*. **2010**, *81* (1), 32–41. https://doi.org/10.1016/j.colsurfb.2010.06.023

El-Naggar, M. E.; Shaarawy, S.; Hebeish, A. A. Multifunctional properties of cotton fabrics coated with in situ synthesis of zinc oxide nanoparticles capped with date seed extract. *Carbohydr. Polym.* **2018**, *181*, 307–316. https://doi.org/10.1016/j.carbpol.2017.10.074

Emam, H. E.; Bechtold, T. Cotton fabrics with UV blocking properties through metal salts deposition. *Appl. Surf. Sci.* **2015**, *357* (Part B), 1878–1889. https://doi.org/10.1016/j.apsusc.2015.09.095

Emam, H. E.; Abdelhameed, R. M. Anti-UV radiation textiles designed by embracing with nano-MIL (Ti, In)-metal organic framework. *ACS Appl. Mater. Interfaces.* **2017**, *9* (33), 28034–28045. https://doi.org/10.1021/acsami.7b07357

Emam, H. E.; Darwesh, O. M.; Abdelhameed, R. M. Protective cotton textiles via amalgamation of cross-linked zeolitic imidazole frameworks. *Ind. Eng. Chem. Res.* **2020**, *59* (23), 10931–10944. https://doi.org/10.1021/acs.iecr.0c01384

Fakin, D.; Veronovski, N.; Ojstršek, A.; Božič, M. Synthesis of TiO_2-SiO_2 colloid and its performance in reactive dyeing of cotton fabrics. *Carbohydr. Polym.* **2012**, *88* (3), 992–1001. https://doi.org/10.1016/j.carbpol.2012.01.046

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

Faure, B.; Salazar-Alvarez, G.; Ahniyaz, A.; Villaluenga, I.; Berriozabal, G.; De Miguel, Y. R.; Bergström, L. Dispersion and surface functionalization of oxide nanoparticles for transparent photocatalytic and UV-protecting coatings and sunscreens. *Sci. Technol. Adv. Mater.* **2013**, *14* (2), 023001. https://doi.org/10.1088/1468-6996/14/2/023001

Ferreira, A. J. S.; Ferreira, F. B. N.; Oliveira, F. R. Têxteis inteligentes: Uma breve revisão da literatura. *REDIGE*. **2014**, *5* (1), 1–22.

Flor, J.; Davolos, M. R.; Correa, M. A. Protetores solares. *Quim. Nova*. **2007**, *30* (1), 153–158. https://doi.org/10.1590/S0100-40422007000100027

Forestier, S. Rationale for sunscreen development. *J. Am. Acad. Dermatol*. **2008**, *58* (5), S133–S138. https://doi.org/10.1016/j.jaad.2007.05.047

Fourtanier, A.; Moyal, D.; Seite, S. UVA filters in sun-protection products: regulatory and biological aspects. *Photochem. Photobiol.* **2012**, *11* (1), 81–89. https://doi.org/10.1039/c1pp05152k

Franco, J. G.; Ataide, J. A.; Ferreira, A. H. P.; Mazzola, P. G. Lamellar compounds intercalated with anions with solar protection function: A review. *J. Drug Deliv. Sci. Technol.* **2020**, *59*, 101869. https://doi.org/10.1016/j.jddst.2020.101869

Frizzo, M. S.; Feuser, P. E.; Berres, P. H.; Ricci-Júnior; E.; Campos, C. E. M.; Costa, C.; Araújo, P. H. H.; Sayer, C. Simultaneous encapsulation of zinc oxide and octocrylene in poly (methyl methacrylate-co-styrene) nanoparticles obtained by miniemulsion polymerization for use in sunscreen formulations. *Colloids Surf., A Physicochem. Eng. Asp.* **2019**, *561*, 39–46. https://doi.org/10.1016/j.colsurfa.2018.10.062

Giokas, D. L.; Salvador, A.; Chisvert, A. UV filters: From sunscreens to human body and the environment. *TrAC - Trends Anal. Chem.* **2007**, *26* (5), 360–374. https://doi.org/10.1016/j.trac.2007.02.012

Hasani, M.; Montazer, M. Electro-conductivity, bioactivity and UV protection of graphene oxide-treated cellulosic/polyamide fabric using inorganic and organic reducing agents. *J. Text. Inst*. **2017a**, *108* (10), 1777–1786. https://doi.org/10.1080/00405000.2017.1286700

Hasani, M.; Montazer, M. Cationization of cellulose/polyamide on UV protection, bio-activity, and electro-conductivity of graphene oxide-treated fabric. *J. Appl. Polym. Sci*. **2017b**, *134* (44), 45493. https://doi.org/10.1002/app.45493

Hoffmann, K.; Laperre, J.; Avermaete, A.; Altmeyer, P.; Gambichler, T. Defined UV protection by apparel textiles. *Arch. Dermatol.* **2001**, *137* (8), 1089−1094.

Hu, X.; Tian, M.; Qu, L.; Zhu, S.; Han, G. Multifunctional cotton fabrics with graphene/polyurethane coatings with far-infrared emission, electrical conductivity, and ultraviolet-blocking properties. *Carbon.* **2015**, *95*, 625–633. https://doi.org/10.1016/j.carbon.2015.08.099

Huang, J.; Yang, Y.; Yang, L.; Bu, Y.; Xia, T.; Gu, S.; Yang, H.; Ye, D.; Xu, W. Fabrication of multifunctional silk fabrics via one step in-situ synthesis of ZnO. *Mater. Lett*. **2019**, *237*, 149–151. https://doi.org/10.1016/j.matlet.2018.11.035

Ibrahim, N. A.; El-Zairy, E. M. R.; El-Zairy, M. R.; Khalil, H. M. Improving transfer printing and ultraviolet-blocking properties of polyester-based textiles using MCT-β-CD, chitosan and ethylenediamine. *Color. Technol.* **2010a**, *126* (6), 330–336. https://doi.org/10.1111/j.1478-4408.2010.00265.x

Ibrahim, N. A.; Eid, B. M.; Hashem, M. M.; Refai, R.; El-Hossamy, M. Smart options for functional finishing of linen-containing fabrics. *J. Ind. Text.* **2010b**, *39* (3), 233–265. https://doi.org/10.1177/1528083709103144

Ibrahim, N. A.; Eid, B. M.; El-Zairy, E. R. Antibacterial functionalization of reactive-cellulosic prints via inclusion of bioactive Neem oil/βCD complex. *Carbohydr. Polym.* **2011**, *86* (3), 1313–1319. https://doi.org/10.1016/j.carbpol.2011.06.032

Ibrahim, N. A.; Eid, B. M.; Khalil, H. M.; Almetwally, A. A. A new approach for durable multifunctional coating of PET fabric. *Appl. Surf. Sci.* **2018**, *448*, 95–103. https://doi.org/10.1016/j.apsusc.2018.04.022

Ioelovich, M.; Leykin, A. Structural investigations of various cotton fibers and cotton celluloses. *Bioresources*. **2008**, *3* (1), 170–177.

Jabbar, M.; Shaker, K. Textile Raw Materials. In *Textile engineering*: An introduction. Nawab, Y. Ed.; De Gruyter Oldenbourg, 2016; pp 7-24. https://doi.org/10.1515/9783110413267-004

Jaffe, M.; Easts, A. J.; Feng, X. Polyester fibers. In *Thermal analysis of textiles and fibers*: The Textile Institute Book Series. Jaffe, M., Menczel, J. D., Eds.; Woodhead Publishing, 2020; pp 133-150. https://doi.org/10.1016/B978-0-08-100572-9.00008-2

Jain, S. K.; Jain, N. K. Multiparticulate carriers for sun-screening agents. *Int. J. Cosmet. Sci.* **2010**, *32* (2), 89–98. https://doi.org/10.1111/j.1468-2494.2010.00547.x

Jin, J., Li, N.; Xie, Y. Photocatalysis and UV-blocking properties of cotton fabric functionalized with $BiPO_4$ nanorods. *J. Eng. Fiber. Fabr.* **2019**, *14*. https://doi.org/10.1177/1558925019888816

Khan, A.; Hussain, M. T.; Jiang, H.; Gul, S. Development of functional wool fabric by treatment with aqueous and alkaline extracts of *Cinnamomum camphora* plant leaves. *J. Nat. Fibers.* **2018**, *17* (4), 472–481. https://doi.org/10.1080/15440478.2018.1500339

Khan, M. Z.; Militky, J.; Baheti, V.; Fijalkowski, M.; Wiener, J.; Voleský, L.; Adach, K. Growth of ZnO nanorods on cotton fabrics via microwave hydrothermal method: effect of size and shape of nanorods on superhydrophobic and UV-blocking properties. *Cellulose.* **2020**, *27* (17), 10519–10539. https://doi.org/10.1007/s10570-020-03495-x

Kockler, J.; Oelgemöller, M.; Robertson, S.; Glass, B. D. Photostability of sunscreens. *J. Photochem. Photobiol. C Photochem. Rev.* **2012**, *13* (1), 91–110. https://doi.org/10.1016/j.jphotochemrev.2011.12.001

Li, Y.; Zou, Y.; Hou, Y. Fabrication and UV-blocking property of nano-ZnO assembled cotton fibers via a two-step hydrothermal method. *Cellulose*. **2011**, *18* (6), 1643–1649. https://doi.org/10.1007/s10570-011-9600-5

Li, Y.; Hou, Y.; Zou, Y. Microwave assisted fabrication of Nano-ZnO assembled cotton fibers with excellent UV blocking property and water-wash durability. *Fibers Polym.* **2012**, *13* (2), 185–190. https://doi.org/10.1007/s12221-012-0185-x

Li, S.; Zhu, T.; Huang, J.; Guo, Q.; Chen, G.; Lai, Y. Durable antibacterial and UV-protective Ag/TiO_2@fabrics for sustainable biomedical application. *Int. J. Nanomedicine.* **2017**, *12*, 2593–2606. https://doi.org/10.2147/IJN.S132035

Li, N.; Pranantyo, D.; Kang, E.-T.; Wright, D. S.; Luo, H.-K. In situ self-assembled polyoxotitanate cages on flexible cellulosic substrates: Multifunctional coating for hydrophobic, antibacterial, and UV-blocking applications. *Adv. Funct. Mater.* **2018**, *28* (23), 1800345. https://doi.org/10.1002/adfm.201800345

Li, G.-P.; Cao, F.; Zhang, K.; Hou, L.; Gao, R.-C.; Zhang, W.-Y.; Wang, Y.-Y. Design of anti-UV radiation textiles with self-assembled metal–organic framework coating. *Adv. Mater. Interfaces.* **2020**, *7* (1), 1901525. https://doi.org/10.1002/admi.201901525

Liu, Y. Chemical composition and characterization of cotton fibers. In *Cotton fiber*: Physics, chemistry and biology. Fang, D. Ed.; Springer, 2018; pp 75-94. https://doi.org/10.1007/978-3-030-00871-0_4

Mai, Z.; Xiong, Z.; Shu, X.; Liu, X.; Zhang, H.; Yin, X.; Zhou, Y.; Liu, M.; Zhang, M.; Xu, W.; Chen, D. Multifunctionalization of cotton fabrics with polyvinylsilsesquioxane/ZnO composite coatings. *Carbohydr. Polym.* **2018**, *199*, 516–525. https://doi.org/10.1016/j.carbpol.2018.07.052

Mihailović, D.; Šaponjić, Z.; Molina, R.; Puač, N.; Jovančić, P.; Nedeljković, J.; Radetić, M. Improved properties of oxygen and argon RF plasma-activated polyester fabrics loaded with TiO2 nanoparticles. *ACS Appl. Mater. Interfaces.* **2010**, *2* (6), 1700–1706. https://doi.org/10.1021/am100209n

Mihailović, D.; Šaponjić, Z.; Molina, R.; Radoičić, M.; Esquena, J.; Jovančić, P.; Nedeljković, J.; Radetić, M. Multifunctional properties of polyester fabrics modified by corona discharge/air RF plasma and colloidal TiO_2 nanoparticles. *Polym. Compos.* **2011**, *32* (3), 390–397. https://doi.org/10.1002/pc.21053

Mirjalili, M. Preparation of electroconductive, magnetic, antibacterial, and ultraviolet-blocking cotton fabric using reduced graphene oxide nanosheets and magnetite nanoparticles. *Fibers Polym.* **2016**, *17* (10), 1579–1588. https://doi.org/10.1007/s12221-016-6689-z

Mohammed, U.; Lekakou, C.; Dong, L.; Bader, M. G. Shear deformation and micromechanics of woven fabrics. *Compos. - A: Appl. Sci.* **2000**, *31* (4), 299–308. https://doi.org/10.1016/S1359-835X(99)00081-0

Mondal, S. Nanomaterials for UV protective textiles. *J. Ind. Text.* **2022**, 51 (4), 5592S–5621S. https://doi.org/10.1177/1528083721988949

Montazer, M.; Pakdel, E. Reducing photoyellowing of wool using nano TiO_2. *Photochem. Photobiol*. **2010**, *86* (2), 255–260. https://doi.org/10.1111/j.1751-1097.2009.00680.x

Montazer, M.; Seifollahzadeh, S. Enhanced self-cleaning, antibacterial and UV protection properties of nano TiO_2 treated textile through enzymatic pretreatment. *Photochem. Photobiol*. **2011**, *87* (4), 877–883. https://doi.org/10.1111/j.1751-1097.2011.00917.x

Montazer, M.; Pakdel, E. Functionality of nano titanium dioxide on textiles with future aspects: Focus on wool. *J. Photochem. Photobiol*. **2011**, *12* (4), 293–303. https://doi.org/10.1016/j.jphotochemrev.2011.08.005

Montazer, M.; Amiri, M. M. ZnO nano reactor on textiles and polymers: ex situ and in situ synthesis, application, and characterization. *J. Phys. Chem. B.* **2014**, *118* (6), 1453−1470. https://doi.org/10.1021/jp408532r

Montazer, M.; Dastjerdi, M.; Azdaloo, M.; Rad, M. M. Simultaneous synthesis and fabrication of nano Cu_2O on cellulosic fabric using copper sulfate and glucose in alkali media producing safe bio-and photoactive textiles without color change. *Cellulose*. **2015**, *22* (6), 4049–4064. https://doi.org/10.1007/s10570-015-0764-2

Morabito, K.; Shapley, N. C.; Steeley, K. G.; Tripathi, A. Review of sunscreen and the emergence of non-conventional absorbers and their applications in ultraviolet protection. *Int. J. Cosmet. Sci.* **2011**, *33* (5), 385–390. https://doi.org/10.1111/j.1468-2494.2011.00654.x

Morshed, M. N.; Shen, X.; Deb, H.; Azad, S. A.; Zhang, X.; Li, R. Sonochemical fabrication of nanocryatalline titanium dioxide (TiO_2) in cotton fiber for durable ultraviolet resistance. *J. Nat. Fibers*. **2018**, *17* (1), 41–54. https://doi.org/10.1080/15440478.2018.1465506

Münzel, T.; Kröller-Schon, S.; Oelze, M.; Gori, T.; Schmidt, F. P.; Steven, S.; Hahad, O.; Röösli, M.; Wunderli, J.-M.; Daiber, A.; Sørensen, M. Adverse cardiovascular effects of traffic noise with a focus on nighttime noise and the new WHO noise guidelines. *Annu. Rev. Public Health*. **2020**, *41*, 309–328. https://doi.org/10.1146/annurev-publhealth-081519-062400

Nateghi, M. R.; Shateri-Khalilabad, M. Silver nanowire-functionalized cotton fabric. *Carbohydr. Polym.* **2015**, *117*, 160–168. https://doi.org/10.1016/j.carbpol.2014.09.057

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

Nazari, A.; Montazer, M.; Mirjalili, M.; Nazari, S. Polyester with durable UV protection properties through using nano TiO_2 and polysiloxane softener optimized by RSM. *J. Text. Inst*. **2013**, *104* (5), 511–520. https://doi.org/10.1080/00405000.2012.746577

Noorian, S. A.; Hemmatinejad, N.; Bashari, A. One-Pot Synthesis of Cu_2O/ZnO Nanoparticles at present of folic acid to improve UV-protective effect of cotton fabrics. *Photochem. Photobiol*. **2015**, *91* (3), 510–517. https://doi.org/10.1111/php.12420

Noorian, S. A.; Hemmatinejad, N.; Navarro, J. A. R. Ligand modified cellulose fabrics as support of zinc oxide nanoparticles for UV protection and antimicrobial activities. *Int. J. Biol. Macromol*. **2020**, *154*, 1215–1226. https://doi.org/10.1016/j.ijbiomac.2019.10.276

Pakdel, E.; Naebe, M.; Kashi, S.; Cai, Z.; Xie, W.; Yuen, A. C. Y.; Montazer, M.; Sun, L.; Wang, X. Functional cotton fabric using hollow glass microspheres: Focus on thermal insulation, flame retardancy, UV-protection and acoustic performance. *Prog. Org. Coat.* **2020**, *141*, 105553. https://doi.org/10.1016/j.porgcoat.2020.105553

Pan, C.; Shen, L.; Shang, S.; Xing, Y. Preparation of superhydrophobic and UV blocking cotton fabric via sol-gel method and self-assembly. *Appl. Surf. Sci.* **2012**, *259*, 110–117. https://doi.org/10.1016/j.apsusc.2012.07.001

Pant, H. R.; Bajgai, M. P.; Nam, K. T.; Seo, Y. A.; Pandeya, D. R.; Hong, S. T.; Kim, H. Y. Electrospun nylon-6 spider-net like nanofiber mat containing TiO_2 nanoparticles: A multifunctional nanocomposite textile material. *J. Hazard. Mater.* **2011**, *185* (1), 124–130. https://doi.org/10.1016/j.jhazmat.2010.09.006

Parisi, O. I.; Aiello, D.; Casula, M. F.; Puoci, F.; Malivindi, R.; Scrivano, L.; Testa, F. Mesoporous nanocrystalline TiO_2 loaded with ferulic acid for sunscreen and photo-protection: safety and efficacy assessment. *RSC Adv*. **2016**, *6* (87), 83767–83775. https://doi.org/10.1039/C6RA07653J

Parwaiz, S.; Khan, M. M.; Pradhan, D. CeO_2-based nanocomposites: An advanced alternative to TiO_2 and ZnO in sunscreens. *Mater. Express*. **2019**, *9* (3), 185–202. https://doi.org/10.1166/mex.2019.1495

Pettinari, R.; Marchetti, F.; Petrini, A.; Pettinari, C.; Lupidi, G.; Smoleński, P.; Scopelliti, R.; Riedel, T.; Dyson, P. J. From sunscreen to anticancer agent: Ruthenium(II) arene avobenzone complexes display potent anticancer activity. *Organometallics*. **2016**, *35* (21), 3734−3742. https://doi.org/10.1021/acs.organomet.6b00694

Pezzolo, D. B. *Tecidos*: História, tramas, tipos e usos; Editora Senac-São Paulo, 2007.

Powers, J. M.; Murphy, J. E. J. Sunlight radiation as a villain and hero: 60 years of illuminating research. *Int. J. Radiat. Biol.* **2019**, *95* (7), 1043–1049. https://doi.org/10.1080/09553002.2019.1627440

Qi, K.; Cheng, B.; Yu, J.; Ho, W. Review on the improvement of the photocatalytic and antibacterial activities of ZnO. *J. Alloys Compd.* **2017**, *727*, 792–820. https://doi.org/10.1016/j.jallcom.2017.08.142

Rana, M.; Hao, B.; Mu, L.; Chen, L.; Ma, P.-C. Development of multi-functional cotton fabrics with Ag/AgBr-TiO_2 nanocomposite coating. *Compos. Sci. Technol.* **2016**, *122*, 104–112. https://doi.org/10.1016/j.compscitech.2015.11.016

Raza, Z. A.; Anwar, F.; Ahmad, S.; Aslam, M. Fabrication of ZnO incorporated chitosan nanocomposites for enhanced functional properties of cellulosic fabric. *Mater. Res. Express.* **2016**, *3* (11), 115001. https://doi.org/10.1088/2053-1591/3/11/115001

Razmkhah, M.; Montazer, M.; Rezaie, A. B.; Rad, M. M. Facile technique for wool coloration via locally forming of nano selenium photocatalyst imparting antibacterial and UV protection properties. *J. Ind. Eng. Chem*. **2021**, *101*, 153–164. https://doi.org/10.1016/j.jiec.2021.06.018

Rezaie, A. B.; Montazer, M.; Rad, M. M. Photo and biocatalytic activities along with UV protection properties on polyester fabric through green *in-situ* synthesis of cauliflower-like CuO nanoparticles. *J. Photochem. Photobiol. B, Biol*. **2017a**, *176*, 100–111. https://doi.org/10.1016/j.jphotobiol.2017.09.021

Rezaie, A. B.; Montazer, M.; Rad, M. M. A cleaner route for nanocolouration of wool fabric via green assembling of cupric oxide nanoparticles along with antibacterial and UV protection properties. *J. Clean. Prod*. **2017b**, *166*, 221–231. https://doi.org/10.1016/j.jclepro.2017.08.046

Rezaie, A. B.; Montazer, M.; Rad, M. M. Antibacterial, UV protective and ammonia sensing functionalized polyester fabric through *in situ* synthesis of cuprous oxide nanoparticles. *Fibers Polym*. **2017c**, *18* (7), 1269–1279. https://doi.org/10.1007/s12221-017-7263-z

Riaz, S.; Ashraf, M.; Hussain, T.; Hussain, M. T.; Younus, A.; Raza, M.; Nosheen, A. Selection and optimization of silane coupling agents to develop durable functional cotton fabrics using TiO_2 nanoparticles. *Fibers Polym.* **2021**, *22* (1), 109–122. https://doi.org/10.1007/s12221-021-9245-4

Sadr, F. A.; Montazer, M. In situ sonosynthesis of nano TiO_2 on cotton fabric. *Ultrason. Sonochem*. **2014**, *21* (2), 681–691. https://doi.org/10.1016/j.ultsonch.2013.09.018

Saito, G. P.; Romero, J. H. S.; Cebim, M. A.; Davolos, M. R. Eu(III) doped LDH intercalated with cinnamate anion as multifunctional sunscreens. *J. Lumin.* **2018**, *203*, 160–164. https://doi.org/10.1016/j.jlumin.2018.06.039

Saito, G. P.; Bizari, M.; Cebim, M. A.; Correa, M. A.; Jafelicci Junior, M.; Davolos, M. R. Study of the colloidal stability and optical properties of sunscreen creams. *Eclet. Quim.* **2019**, *44* (2), 26–36. https://doi.org/10.26850/1678-4618eqj.v44.2.2019.p26-36

Saito, G. P.; Matsumoto, A. C. L.; Assis, R. P.; Brunetti, I. L.; Cebim, M. A.; Davolos, M. R. Zn(Ferulate)-LSH systems as multifunctional filters. *Molecules*. **2021**, *26* (8), 2349. https://doi.org/10.3390/molecules26082349

Sambandan, D. R.; Ratner, D. Sunscreens: An overview and update. *J. Am. Acad. Dermatol.* **2011**, *64* (4), 748–758. https://doi.org/10.1016/j.jaad.2010.01.005

Sánchez, J. C. Têxteis inteligentes. *Química Têxtil*. **2006**, *82*, 58–77.

SEBRAE. Tecidos inteligentes. Resposta Técnica, 2014. https://bibliotecas.sebrae.com.br/chronus/ARQUIVOS_CHRONUS/bds/bds.nsf/aece3e5bd45d5ececd32418a25f27f56/$File/2014_06_30_RT_Maio_Moda_Tecidosinteligentes_pdf.pdf (accessed 2021-01-21).

Sedighi, A.; Montazer, M.; Mazinani, S. Fabrication of electrically conductive superparamagnetic fabric with microwave attenuation, antibacterial properties and UV protection using PEDOT/magnetite nanoparticles. *Mater. Des.* **2018**, *160*, 34–47. https://doi.org/10.1016/j.matdes.2018.08.046

Seixas, V. C.; Serra, O. A. Stability of Sunscreens Containing $CePO_4$: Proposal for a New Inorganic UV Filter. *Molecules*. **2014**, *19* (7), 9907–9925. https://doi.org/10.3390/molecules19079907

Serpone, N.; Dondi, D.; Albini, A. Inorganic and organic UV filters: Their role and efficacy in sunscreens and suncare products. *Inorganica Chim. Acta*. **2007**, 360 (3), 794–802. https://doi.org/10.1016/j.ica.2005.12.057

Serre, C.; Busuttil, V.; Botto, J.-M. Intrinsic and extrinsic regulation of human skin melanogenesis and pigmentation. *Int. J. Cosmet. Sci.* **2018**, *40* (4), 328–347. https://doi.org/10.1111/ics.12466

Shabbir, M.; Rather, L. J.; Mohammad, F. Economically viable UV-protective and antioxidant finishing of wool fabric dyed with *Tagetes erecta* flower extract: Valorization of marigold. *Ind. Crops Prod*. **2018**, *119*, 277–282. https://doi.org/10.1016/j.indcrop.2018.04.016

Shateri-Khalilabad, M.; Yazdanshenas, M. E. Fabrication of superhydrophobic, antibacterial, and ultraviolet-blocking cotton fabric. *J. Text. Inst.* **2013a**, *104* (8), 861–869. https://doi.org/10.1080/00405000.2012.761330

Shateri-Khalilabad, M.; Yazdanshenas, M. E. Bifunctionalization of cotton textiles by ZnO nanostructures: antimicrobial activity and ultraviolet protection. *Text. Res. J.* **2013b**, *83* (10), 993–1004. https://doi.org/10.1177/0040517512468812

Subbiah, D. K.; Mani, G. K.; Babu, K. J.; Das, A.; Rayappan, J. B. B. Nanostructured ZnO on cotton fabrics – A novel flexible gas sensor & UV filter. *J. Clean. Prod.* **2018**, *194*, 372–382. https://doi.org/10.1016/j.jclepro.2018.05.110

Subramani, K.; Shanmugam, B. K.; Rangaraj, S.; Palanisamy, M.; Periasamy, P.; Venkatachalam, R. Screening the UV-blocking and antimicrobial properties of herbal nanoparticles prepared from *Aloe vera* leaves for textile applications. *IET Nanobiotechnol.* **2017**, *12* (4), 459–465. https://doi.org/10.1049/iet-nbt.2017.0097

Suryaprabha, T.; Sethuraman, M. G. A facile approach for fabrication superhydrophobic and UV-blocking cotton fabrics with self-cleaning properties. *Fibers Polym.* **2021**, *22* (4), 1033–1040. https://doi.org/10.1007/s12221-021-0648-z

Tang, B.; Lin, X.; Zou, F.; Fan, Y.; Li, D.; Zhou, J.; Chen, W.; Wang, X. In situ synthesis of gold nanoparticles on cotton fabric for multifunctional applications. *Cellulose*. **2017**, *24* (10), 4547–4560. https://doi.org/10.1007/s10570-017-1413-8

Thi, V. H. T.; Lee, B.-K. Development of multifunctional self-cleaning and UV blocking cotton fabric with modification of photoactive ZnO coating via microwave method. *J. Photochem. Photobiol. A Chem.* **2017**, *338*, 13–22. https://doi.org/10.1016/j.jphotochem.2017.01.020

Tian, M.; Hu, X.; Qu, L.; Du, M.; Zhu, S.; Sun, Y.; Han, G. Ultraviolet protection cotton fabric achieved via layer-by-layer self-assembly of graphene oxide and chitosan. *Appl. Surf. Sci.* **2016**, *377*, 141–148. https://doi.org/10.1016/j.apsusc.2016.03.183

Tiwari, S. K.; Mishra, R. K.; Ha, S. K.; Huczko, A. Evolution of graphene oxide and graphene: From imagination to industrialization. *Chem. Nano. Mat.* **2018**, *4* (7), 598–620. https://doi.org/10.1002/cnma.201800089

Varesano, A.; Tonin, C. Improving electrical performances of wool textiles: Synthesis of conducting polypyrrole on the fiber surface. *Text. Res. J.* **2008**, *78* (12), 1110–1115. https://doi.org/10.1177/0040517507077488

Vatansever, F.; Hamblin, M. R. Far infrared radiation (FIR): Its biological effects and medical applications. *Photon. Lasers Med.* **2012**, *1* (4), 255–266. https://doi.org/10.1515/plm-2012-0034

Velasco, M. V. R.; Sarruf, F. D.; Salgado-Santos, I. M. N.; Haroutiounian-Filho, C. A.; Kaneki, T. M.; Baby, A. R. Broad spectrum bioactive sunscreens, *Int. J. Pharm.* **2008**, *363* (1–2), 50–57. https://doi.org/10.1016/j.ijpharm.2008.06.031

Wang, S. Q.; Balagula, Y.; Osterwalder, U. Photoprotection: A review of the current and future technologies. *Dermatol. Ther.* **2010**, *23* (1), 31–47. https://doi.org/10.1111/j.1529-8019.2009.01289.x

Wang, L.; Zhao, J.; Liu, H.; Huang, J. Design, modification and application of semiconductor photocatalysts. *J. Taiwan Inst. Chem.* **2018**, *93*, 590–602. https://doi.org/10.1016/j.jtice.2018.09.004

Wang, X.; Chen, X.; Cowling, S.; Wang, L.; Liu, X. Polymer brushes tethered ZnO crystal on cotton fiber and the application on durable and washable UV protective clothing. *Adv. Mater. Interfaces.* **2019**, *6* (14), 1900564. https://doi.org/10.1002/admi.201900564

ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40

Wang, S.-D.; Wang, K.; Ma, Q.; Qu, C.-X. Fabrication of the multifunctional durable silk fabric with synthesized graphene oxide nanosheets. *Mater. Today Commun.* **2020**, *23*, 100893. https://doi.org/10.1016/j.mtcomm.2020.100893

Wang, H.; Memon, H. *Cotton science and processing technology: Gene, ginning, garment and green recycling*; Springer, 2020.

Xu, L.; Shen, Y.; Ding, Y.; Wang, L. Superhydrophobic and ultraviolet-blocking cotton fabrics based on TiO_2/SiO_2 composite nanoparticles. *J. Nanosci. Nanotechnol.* **2018**, *18* (10), 6879–6886. https://doi.org/10.1166/jnn.2018.15463

Xue, C.-H.; Yin, W.; Jia, S.-T.; Ma, J.-Z. UV-durable superhydrophobic textiles with UV-shielding properties by coating fibers with ZnO/SiO_2 core/shell particles. *Nanotechnology*. **2011**, *22* (41), 415603. https://doi.org/10.1088/0957-4484/22/41/415603

Xue, C.-H; Yin, W.; Zhang, P.; Zhang, J.; Ji, P.-T.; Jia, S.-T. UV-durable superhydrophobic textiles with UV-shielding properties by introduction of ZnO/SiO_2 core/shell nanorods on PET fibers and hydrophobization. *Colloids Surfaces A Physicochem. Eng. Asp.* **2013**, *427*, 7–12. https://doi.org/10.1016/j.colsurfa.2013.03.021

Yadav, H. M.; Kim, J.-S.; Pawar, S. H. Developments in photocatalytic antibacterial activity of nano TiO_2: A review. *Korean J. Chem. Eng.* **2016**, *33* (7), 1989–1998 https://doi.org/10.1007/s11814-016-0118-2

Yildirim, K.; Kanber, A.; Karahan, M.; Karahan, N. The solar properties of fabrics produced using different weft yarns. *Text. Res. J.* **2000**, *88* (13), 1543–1558. https://doi.org/10.1016/S1359-835X(99)00081-0

Yue Y.; Zhou, C.; French, A. D.; Xia, G.; Han, G.; Wang, Q.; Wu, Q. Comparative properties of cellulose nano-crystals from native and mercerized cotton fibers. *Cellulose*. **2012**, *19* (4), 1173–1187. https://doi.org/10.1007/s10570-012-9714-4

Zhang, D.; Chen, L.; Fang, D.; Toh, G. W.; Yue, X.; Chen, Y.; Lin, H. In situ generation and deposition of nano-ZnO on cotton fabric by hyperbranched polymer for its functional finishing. *Text. Res. J.* **2013**, *83* (15), 1625–1633. https://doi.org/10.1177/0040517512474362

Zhang, K.; Yang, Z.; Mao, X.; Chen, X.-L.; Li, H.-H.; Wang, Y.-Y. Multifunctional textiles/metal-organic frameworks composites for efficient ultraviolet radiation blocking and noise reduction. *ACS Appl. Mater. Interfaces*. **2020**, *12* (49), 55316–55323. https://doi.org/10.1021/acsami.0c18147

Zhao, Y.; Xu, Z.; Wang, X.; Lin, T. Superhydrophobic and UV-blocking cotton fabrics prepared by layer-by-layer assembly of organic UV absorber intercalated layered double hydroxides. *Appl. Surf. Sci.* **2013**, *286*, 364–370. https://doi.org/10.1016/j.apsusc.2013.09.092

Zhou, S.; Wang, F.; Balachandran, S.; Li, G.; Zhang, X.; Wang, R.; Liu, P.; Ding, Y.; Zhang, S.; Yang, M. Facile fabrication of hybrid PA6-decorated TiO_2 fabrics with excellent photocatalytic, anti-bacterial, UV light-shielding, and super hydrophobic properties. *RSC Adv.* **2017**, *7* (83), 52375–52381. https://doi.org/10.1039/C7RA09613E

Zohoori, S.; Payvandy, P.; Bekrani, M. Antibacterial, self-cleaning and UV blocking of wool fabric coated with nano Ce/ZnO and Ce/TiO_2. *Indian J. Fibre Text. Res.* **2021**, *46* (1), 57–62. https://doi.org/10.56042/ijftr.v46i1.25171

Eclética Química, vol. 48, n. 1, 2023, 16-40
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p16-40