Antibacterial And UV Protection Properties Modified Cotton Fabric Using Curcumin/ TiO_2 Nanocomposite For Medical Textile Applications

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Abstract

Medical textiles are one of the most rapidly growing parts of the technical textiles sector of the textile industry. This work was developed for biocompatible materials of curcumin / TiO_2 nanocomposite fabricated on the surface of cotton fabric for medical applications. Cotton fabric was pretreated with three crosslinking agents namely, citric acid, Quat-188, and GPTMS. Applying nanocomposite on modified cotton fabric using pad-dry cure method. The chemistry and morphology of modified fabrics are examined by Fourier-transformed infrared spectroscopy, energy-dispersive X-ray spectroscopy, and scanning electron microscopy. In addition, the chemical mechanism for nanocomposite modified fabric was reported. UV protection (UPF) and antibacterial properties against Gram - positive *S. aureus* and Gram - negative *E. coli* bacterial strains were investigated. The durability of fabrics to 20 washing cycles was also examined. Results demonstrated that nanocomposite modified cotton fabric exhibited superior antibacterial activity against Gram - negative bacteria that Gram - positive bacteria and excellent UV protection properties. Moreover, good durability was obtained, possibly due to the effect of the crosslinker used. Among the three pre-modification of cotton fabric, Quat-188 modified fabric reveals the highest antibacterial activity comparing with citric acid or GPTMS modified fabrics. This outcome suggested that curcumin / TiO_2 nanocomposite Quatt-188 modified cotton fabric could be used in biomedical textile as antibacterial properties.

Introduction

Nowadays, one of the most promising fields of new textile materials is the manufacture of antimicrobial-acting medical textiles. Since too much work is being put into improving substances and procedures that can provide safe and adequate protection against various microorganisms. Usually, chemical materials have been used for antibacterial medical textiles, such as phenols, nitro compound, and formaldehyde derivatives (Czaja, Krystynowicz et al. 2006, Edwards, Buschle-Diller et al. 2006, Gert, Torgashov et al. 2006, Hoenich 2006) .All these compounds have a lot of drawbacks make them under limited using. Toxicity and poor biodegradability are the most important problems faced the environment and health protection. From this point, textiles industry has been applied natural nontoxic active substances which have no side effects to people or the environment (Zemljič, Volmajer et al. 2014, Hashem, Abdalla et al. 2016, Zaghloul, El-shafie et al. 2017, Ibrahim, Zaghloul et al. 2021).

Fabric modification with nanomaterials designed for enhancing textile properties such as antibacterial properties (Hashem, Abdalla et al. 2016, Hebeish, Higazy et al. 2016), UV protection(Abd El-Hady, Sharaf et al. 2020) wound healing, self-cleaning, and military application(Sharaf, Farouk et al. 2016, Montaser, Rehan et al. 2020). Nanoparticles may be incorporated into fabrics for medical applications without affecting their textile properties. In terms of efficacy, certain treatment of antimicrobial agents in the form of nanoparticles can exhibit high levels of antimicrobial activity as well as excellent durability (both in usage and by repetitive laundering cycles), which is far superior to metal salts or adsorbed quaternary ammonium compounds, which operate by leaching from the treated fabric and thus becoming reduced by laundering(El-Shafei, Sharaf et al. 2015, Morris and Murray 2020).

Curcumin is a natural material that is used in medicinal textiles. It's a polyphenolic compound and a yellow pigment derived from the ground rhizomes of the Curcuma longa Linn plant, and it has a wide variety of beneficial properties. It has a wide range of pharmacological properties, including anti-inflammatory, antioxidative, and anti-cancer properties (Bhawana, Buttar et al. 2011, Jaisamut, Wiwattanawongsa et al. 2018). Curcumin contains two phenolic hydroxyl groups and two carbonyl groups in the center, which can form keto-enol tautomers in solution. When it comes to curcumin modifications, the phenolic group is the most important functional group. It is capable of a wide range of reactions, including nucleophilic substitution with organic acids, epoxides, and their derivatives (Bigand, Pinel et al. 2011). Several experimental studies have now concluded that these two groups exist primarily in enolic form at room temperature (Singh, Verma et al. 2010). Pure curcumin, on the other hand, has a low solubility, which limits its use in medical and clinical applications (Jain, Bhawana et al. 2011). In order to, solve this problem, it was used to prepare complex materials that are able to enhance the bioavailability of curcumin (Kuthati, Kankala et al. 2017, Pal and Paul 2019). Curcumin's therapeutic effectiveness is limited because of its low solubility, absorption, metabolism, and bioavailability (Anand, Kunnumakkara et al. 2007). In this regard, curcumin research has recently focused on the production of possible delivery systems to improve its aqueous solubility, stability, and bioavailability, controlled delivery of curcumin at specific sites. For this, curcumin has been attempted to be incorporated into titanium dioxide nanoparticles. In addition, for enhanced antibacterial activity, we chose hydrophilic titanium dioxide nanoparticles to conjugate with hydrophobic curcumin. Titanium dioxide nanoparticles are used in a wide range of consumer products, including sunscreens, cosmetics, pharmaceutical additives, and food coloring agents. They are biodegradable (Anand, Kunnumakkara et al. 2007) and have good biocompatibility with no or little toxicity in vitro and in vivo. As a result, titanium dioxide nanoparticles may be one of the most promising nanoparticles for a broad variety of medical and pharmaceutical applications. Nano-titanium dioxide can be used in biomedical and bioengineering applications due to its special properties and high reactivity (Sherin, Sheeja et al. 2017). Curcumin was recently used to sensitize TiO_2 for improved photodegradation of dye (Buddee, Wongnawa et al. 2014) and photodegradation of phenols(Haghighatzadeh 2020). Also complex of titanium dioxide nanoparticles with curcumin was developed as wound dressing material using chitosan and polypropylene fabric(Marulasiddeshwara, Jyothi et al. 2020). The incorporation of positively charged sites, such as cationization, allows for the creation of an electrostatic attraction between the fiber and negatively charged molecules. Cotton cationization yielded new cotton cellulose, which could lead to new uses in cotton pre-treatment and chemical finishing. Previous reports illustrate that cationization of cotton surfaces has been shown to improve silver nanoparticle adsorption (Khalil-Abad, Yazdanshenas et al. 2009, Refaie, Zaghloul et al. 2020) and dye uptake (Acharya, Abidi et al. 2014, Grancarić, Tarbuk et al. 2021).

In the current work, we aimed to developed biocompatible material based on cellulose for better and durable antibacterial applications. In order to achieve this, we use curcumin / TiO_2 nanocomposite for fabrication on surface of cotton fabric using pad-dry-cure method. Titanium dioxide nanoparticles was used to enhance the stability and bioavailability of curcumin. For enhancing the attraction force between nanocomposite and cotton fabric, modification of pretreated cotton fabric by cationic agent namely, 3-Chloro-2-hydroxypropyl trimethyl ammonium chloride (Quatt- 188). For comparing of pre catonized cotton fabric, two other pretreatments were applied using [(3 glycidyloxy) propyltrimethoxysilane (GPTMS) and citric acid. The pretreatment process act both as a binding and stabilizing for curcumin / TiO_2 nanocomposite. In addition, chemical mechanism of modified fabric reported. Also, durability and mechanical properties of the modified cotton fabric were investigated.

Experimental

2.1 Materials

Mill bleached pure 100% cotton fabric (138 g/m^2) were supplied by Misr Company for spinning and weaving Mehalla El-Kobra, Egypt.

2.2 Chemicals

3-Chloro-2-hydroxypropyl trimethyl ammonium chloride (69%) of technical grade chemicals (known as Quatt-188) was purchased under the commercial name CR-2000 from Aldrich. Titanium dioxide P25 powder was provided by Degussa. 3- glycidyloxypropyltrimethoxysilane (GPTMS, 95%) were purchased from ABCR (Germany). Curcumin powder (99.8% pure and anhydrous) was purchased from Sigma-Aldrich (Taufkirchen, Germany). Sodium hydroxide, acetic acid, ethanol, sodium hypophosphite and hydrochloric acid were of laboratory grade chemicals.

2.3 Preparation of GPTMS sol

GPTMS sol was prepared by mixing GPTMS (10 ml) with isopropanol water (20/80 ml) and stirred at 25 ^{o}C for 20 min then 1.22 ml of 0.01 M hydrochloric acid solution were dropwise added to GPTMS solution and stirred for 1 hr at room temperature to obtain the silica sol form (Shang, Li et al. 2010).

2.4 Preparation of curcumin - TiO_2 nanocomposites

Solution of 0.5% TiO_2 nanoparticles were resuspended in 50 ml of isopropyl alcohol. Then 5% (w/v) curcumin powder in isopropyl alcohol was prepared with stirring. 0.5 ml of this solution was added drop wise to solution of TiO_2 with continuous stirring for 3–4 hr.

2.5 Cationization of cotton fabric

Chemical modification of the cotton fabric through cationization was carried out using the pad-dry-cure method. The experimental procedures adopted were as follows: 3-Chloro-2-hydroxypropyl trimethyl ammonium chloride (Quatt-188) was mixed with sodium hydroxide solution at a NaOH/Quatt-188 M ratio of 2:1. The cotton fabric was padded in this mixture in two dips and two nips, and then squeezed to a wet pick-up of about 100%. The fabric was dried at 40°C for10 min and cured at 120°C for 3 min. Finally cotton fabric was washed with cold water and 1% acetic acid, followed by several washing cycles and dried under the normal laboratory conditions.

2.6 Coating of cationized cotton fabric with TiO_2 / Curcumin nanocomposite

Cationized cotton fabrics were padded in the 0.5 % (w/v) solution of TiO2 /curcumin nanocomposite prepared solution in two dip and nip and then squeezed to a wet pick-up of 100%. Padded fabrics were dried at 80^{o}C for 5 min and then cured at 180^{o}C for 3 min. Treated fabrics were rinsed with hot water then with cold water and finally dried at room temperature.

2.7 Coating of cotton fabric with GPTMS / Curcumin/ TiO_2 nanocomposite

Solution of 2 % (w/v) GPTMS sol was added to 0.5 % (w/v) solution of TiO_2 /curcumin nanocomposite with continuous stirring under sonication for 2 hr. Cotton fabrics were padded in the previously prepared solution in two dip and nip and then squeezed to a wet pick-up of 100%. Padded fabrics were dried at 80^{o}C for 5 min and then cured at 180 ^{o}C for 3 min. Treated fabrics were rinsed with hot water then with cold water and finally dried at room temperature.

2.8 Coating of cotton fabric with Citric acid / Curcumin /TiO_2nanocomposite

Aqueous solution of citric acid (30 g/l) with sodium hypophosphite (6% w/w) was added to 0.5 % (w/v) solution of TiO_2 /curcumin nanocomposite. Cotton fabrics were padded in the previously prepared solution in two dip and nip and then squeezed to a wet pick-up of 100%. Padded fabrics were dried at 80^{o}C for 5 min and then cured at 180^{o}C for 3 min. Treated fabrics were rinsed with hot water then with cold water and finally dried at room temperature.

Characterization

3.1 Fourier-transformed infrared spectroscopy (FT-IR)

FTIR spectroscopy has been extensively used in cellulose research, since it presents a relatively easy method of obtaining direct information on chemical changes that occur during various chemical treatments. ATR-FTIR instrument (JASCO, Model IR 4700 Japan) and scanned from 4000 to 400 cm − 1 in ATR mode using KBr as supporting material

3.2 Scanning electron micrograph SEM/EDX analysis

Samples for SEM/EDX were taken using FEI INSPECTS Company, Philips, Holland environmental scanning without coating. Elemental micro-probe and elemental distribution mapping techniques were used for analyzing the elemental constitution of solid samples. An elemental analysis of the particles was implemented by a SEM equipped with an energy dispersive spectroscope (EDX), to get rapid quantitative and qualitative analysis of the elemental composition.

3.3 Antibacterial test

The antibacterial activity of the treated samples against *Staphylococcus aureus*, (G + ve) and *Escherichia coli* (G − ve) bacteria were determined using agar plate. The antibacterial activity of fabric samples was evaluated using, (ATCC 1533) bacteria using disk diffusion method. A mixture of nutrient broth and nutrient agar in 1 L distilled water at pH 7.2 as well as the empty Petri plates were autoclaved. The agar medium was then cast into the Petri plates and cooled in laminar airflow. Approximately 105 colony-forming units of bacteria were inoculated on plates, and then 292 cm^2 of each fabric samples was planted onto the agar plates. All the plates were incubated at 37^{o}C for 24 h and examined if a zone of inhibition was produced around samples.

3.4 UV Protection factor

UV−vis spectrum was recorded on Perkin Elmer Lambda 3B UV-Vis spectrometer. Ultraviolet protection factor (UPF) was measured using UV Shimadzu 3101 Spectrophotometer. UV Protection and classification according to AS/NZS 4399:1996 were evaluated with a scan range of 200−600nm.

3.5 The add-on (%) loading

The add-on (%) loading was calculated as follows:

$$\text{Add-on}\ (\%) = \frac{W_2 - W_1}{W_1} \times 100$$

Where W_1 and W_2 are the weights of the fabric specimens before and after treatment respectively.

3.6 Durability test

The treated fabric samples were subjected to 20 laundering cycles according the ASTM standard test method (D 737 – 109 96) to determine the antibacterial durability to washing.

3.7 Tensile strength

The tensile strength of the fabric samples was determined by the ASTM Test Method D-1682-94 (1994). Two specimens for each treated fabric were tested in the warp direction and the average value was recorded to represent the fabric breaking load (Lb).

3.8 Statistical analysis

Results were expressed as a mean value with its standard deviation (mean ± S.D.) of each sample that is repeated three times (n = 3). Statistical analysis was performed with Student's t-test and differences were considered as significant at p-values below 0.05.

Results And Discussion

4.1 Mechanism of deposition of curcumin / TiO_2 nanocomposite on surface of cotton fabric

Figure 1 illustrated the schematic mechanism of formation and fixation of curcumin / TiO_2 on the surface of cotton fabric. According to the experimental section, firstly, the formation of curcumin /TiO_2 nanocomposite. As presented in figure 1 (a) upon addition of curcumin solution to TiO_2 nanoparticles solution that suggests the dispersion of curcumin particles on the surface of titanium nanoparticles. This is because the -diketone functional group, which is located in the center of the curcumin molecule, has a high metal chelating potential. By forming charge transfer complexes, the -diketone group effectively chelated TiO_2 nanoparticles (Buddee, Wongnawa et al. 2014). Pretreatment of cotton fabric then adjusted. Figure 1 (b) represented the fixation of curcumin / TiO_2 nanocomposite on fabric modified with citric acid. The fabric treated with citric acid in the presence of sodium hypophosphite via the formation of ester carbonyl linkages as reported previously (Al Sarhan and Salem 2018). Upon treatment of citric acid modified fabric with curcumin /TiO_2 nanocomposite, the –OH groups of curcumin in composite get attached to the functionalized carboxylic group of citric acid modified fabric. This resulting in strong electrostatic interaction of opposite charges between both particles (Wani, Kitture et al. 2011) . On the other hand, negative surface charges induced by the existence of carboxylic acid moieties improved the adsorption affinity of the curcumin/ TiO_2 nanocomposite (Lee, Loo et al. 2019). Moreover, TiO_2 nanoparticles have strong binding to carboxylic group of citric acid modified fabric by the combination of number of different forms of binding including weak anion–cation type attractions, hydrogen bonding ,and coordination type (Wijesena, Tissera et al. 2015). Fabrication of curcumin / TiO_2 nanocomposite on fabric modified with Quatt-188 was presented in figure 1(c). The development of an ether linkage between Quatt-188 and cellulose would result from the reaction of Quatt-188 with cotton fabrics (Farouk, Sharaf et al. 2013). Deposition of curcumin/ TiO_2 nanocomposite on Quatt-188 modified fabric by strong the ionic and van der Waals forces between – OH groups of curcumin molecule and quaternary ammonium modified cotton fabric. Figure 1 (d) illustrated the final treatment of GPTMS modified cotton fabric by Curcumin/TiO_2 nanocomposite. GPTMS was pre-hydrolyzed for conversion of the alkyl oxygen groups (-OCH_3) to hydroxyl groups (-OH) . The fabric was modified by GPTMS through ether crosslinking within cotton fabric via the reaction of epoxy groups of GPTMS with hydroxyl groups of cellulose structure (Shang, Li et al. 2010). The hydrogen bonds were generated between GPTMS modified cotton fabric and hydroxyl groups of curcumin molecule (Ahmadi Nasab, Hassani Kumleh et al. 2018).

4.2 FTIR analysis

The existence of functional groups on treated cotton fabric investigated by fourier-transform infrared spectrum. Figure 2 illustrated the FTIR spectrum for untreated cotton fabric (a), curcumin /TiO_2 –citric modified cotton fabric (b), curcumin /TiO_2 –Quatt 188 modified cotton fabric (c), curcumin /TiO_2 –GPTMS modified cotton fabric (d) and curcumin powder (e). In the untreated cotton fabric spectrum (a), a band emerged in the range of 3200–3500 cm^{-1}, which is attributed to O-H stretching. The presence of C-

H, O-H, C-O, and C-O-C vibrations caused the characteristic bands in the range of 1500–800 cm^{-1} (Farouk, Saeed et al. 2020). On other hand, the absorption peak at 3310 cm^{-1}, which corresponded to the stretching vibration of phenolic O-H, was described by spectrum (e) for pure curcumin. Furthermore, sharp absorption peaks at the region range 1430 to 1630 cm^{-1}. These peaks belong to the groups -OH, C = O, and C = C, respectively (enol). Other peaks were observed in region between 1000 cm^{-1} and 1300 cm^{-1}. All peaks are ascribed to the configuration of the symmetric and asymmetric C-O-C groups (El-Hady and Saeed 2020). As can be seen in the spectrums (b), (c), and (d) are looked similar to untreated cotton fabric and curcumin patterns with little significant changes. This is attributable to the partial interaction of nanocomposite with modified cotton fabric. In addition, strong peaks at the region 400–600 cm^{-1} are noticeable in spectrums b, c and d which characterized by the Ti–O stretching vibration (Buddee, Wongnawa et al. 2014). This is confirmed the deposition of curcumin / TiO_2 nanocomposite on surface of modified fabric. Spectrum (b) showed a developed peak at 1720 cm^{-1} assigned to carbonyl group implying that cellulose was successfully crosslinked with citric acid via the formation of ester carbonyl linkages (Boonroeng, Srikulkit et al. 2015) .It's obvious from spectrum (c) a new peak at 1570 cm^{-1}, which could be attributed to the quaternary ammonium groups. Spectrum (d) reveled two new bands at 2905 cm^{-1} and 2860 cm^{-1}, which were aligined with the stretching of the methylene groups from the GPTMS molecules.

4.3 Surface morphology of the cotton fabrics

SEM images are used to study the morphology of the fabric surface (Gashti, Alimohammadi et al. 2012). Figure 3 was displayed the variations in unmodified and modified cotton fabric morphology. Figure 3(a) shows that unmodified cotton fabric has a fiber with smooth surface. While Fig. 3 (b, c, and d) reveal the deposition of different modifications of cotton fabric. All modified samples showed homogenous distribution of curcumin /TiO_2 nanocomposite with less agglomeration in some points. In addition, no bridges between cotton adjacent fibers, which is desirable as air and vapor permeability is required for their potential application as wound dressings and medical materials. Figure 3(b) shows the curcumin/TiO_2 nanocomposite citric acid modified cotton fabric has cracked fibers. This could be attributed to the effect of crosslinking with citric acid. On the other hand, Fig. 3 (c) shows higher dense layer of curcumin/TiO_2 nanocomposite Quatt-188 modified cotton fabric in comparing with curcumin/TiO_2 nanocomposite–GPTMS modified cotton fabric Fig. 3 (c). This may be due to cationic modification of cellulosic fibers bearing positive charge resulting in higher deposition of curcumin/TiO_2 nanocomposite on their surfaces (Cheng, He et al. 2018).

4.4 EDX Analysis:

The elemental analysis of cotton fabric after modification was determined using the EDX spectrum. Figure 4 (a) shows the atomic percentage of carbon as 57.30 %, oxygen as 40.61% along with titanium element as 1.41 % for curcumin /TiO_2 –citric modified cotton fabric. However, Fig. 4 (b) illustrates the modified cotton fabric by curcumin /TiO_2–Quatt-100. It shows the atomic percentage of carbon at 55.97, oxygen at 36.76%, titanium at 2.42 % and a new peak for nitrogen as 4.84 %. Thus reveals the etherification reaction of cationization process on cotton fabric. On the other hand, cotton fabric modified by curcumin /TiO_2 –GPTMS is showed in Fig. 4 (c). It shows the atomic percentage of carbon as 65.91 %, oxygen as 28.55 %, titanium 0.66 % and new peak for silicon at 4.04 %. On the basis of the above results, the higher peaks of observed titanium element in Fig. 4(b) related to higher content of curcumin /TiO_2 nanocomposite deposited on the Quatt-100 modified cotton fabric.

4.5. Antibacterial activity

The antibacterial activity of curcumin / TiO_2 nanocomposite modified cotton fabric with various treatment was analyzed against representative microorganisms of open interest, both Gram-positive (*S. aureus*) and Gram-negative (*E. coli*) strains using agar diffusion method. The antibacterial effect for all treatments is ranging from 10 mm to 20 mm of clear zone of inhibition. Results mentioned in Table 1 indicated that *Escherichia coli* has higher response than *Staphylococcus Aureus.* This may be due to variations in bacterial cell wall organization structure. Gram-positive bacteria have a thicker layer cell than Gram-negative bacteria, which serves as a barrier to the spread of active ingredient into the cytoplasm and protects the cell wall (Kim, Kuk et al. 2007). On the other hand, TiO_2 nanoparticles coated modified cotton fabric showed higher antimicrobial activity. This attributed to the effect of metal ion may cause cytoplasmic leakage, protein denaturation, and enzyme malfunction. Reactive oxygen species (ROSs) are generated by photoactive metal oxides, which can cause oxidative stress, cell content leakage, and DNA damage (Behnam, Emami et al. 2018, Marulasiddeshwara, Jyothi et al. 2020). Since microbes are inhibited, these ROS can oxidize lipids and lipopolysaccharides. In addition, curcumin molecule in modified cotton fabric with curcumin / TiO_2 nanocomposite resulted in higher antibacterial activity. As reported before, curcumin being a lipophilic molecule, it can intercalate into the lipopolysaccharide containing cell membrane and increase the permeability of gram-negative bacteria. Further, it has been reported that the key mechanism involved in the killing action of curcumin is the disordering of 1,2-dipalmitoyl- sn-glycero-3-phosphocholine (DPPC) membranes found in both *S. aureus* and *E. coli* (Saha, Pramanik et al. 2021). Since, curcumin can easily form a complex with titania, so it may be able to break through bacteria's cell wall and enter the cell. Cell organelles will be disrupted, and bacteria will be killed by lysis. (Marulasiddeshwara, Jyothi et al. 2020). In addition, cotton fabric modified with Quatt – 188 had higher antibacterial properties compared with fabric modified by either citric acid or GPTMS. From the above results, the hindrance against pathogenic strains was accomplished in the following order: Curcumin /TiO_2 nanocomposite modified Quatt-188 cationized fabric > Curcumin/TiO_2 nanocomposite modified crosslinked fabric with citric acid /SHP> Curcumin/TiO_2 nanocomposite modified fabric with GPTMS.

Table 1
Antibacterial activity and durability properties

Treatment of cotton fabric	Inhibition zone (mm /1cm sample)			
	G- *Escherichia coli*		G+ *Staphylococcus aureus*	
(No. of washing cycle)	**1**	**20**	**1**	**20**
Untreated cotton fabric	0	0	0	0
TiO_2 coated crosslinked fabric with citric acid /SHP	17	16	15	14
Curcumin /TiO_2 nanocomposite modified crosslinked fabric with citric acid /SHP	18	16	16	14
TiO_2 coated Quatt 188 cationized fabric	19	17	14	13
Curcumin /TiO_2 nanocomposite modified Quatt 188 cationized fabric	22	19	16	14
TiO_2 coated pretreated fabric with GPTMS	12	10	11	10
Curcumin/TiO_2 nanocomposite modified fabric with GPTMS	14	13	12	10

Durability to washing cycles was also showed in table (1). According to the results, raising the number of washing cycles to 20 causes a small decrease in the antibacterial properties of the washed treated fabrics. This could be attributed to the effect of crosslinker (citric acid, Quatt 188, and GPTMS) used (Hao, An et al. 2012). Crosslinker was used to enhance the bonding between curcumin / TiO_2 nanocomposite and cellulosic chains of cotton fabric. Thus, favorable washing durability was obtained.

4.6 UV Blocking

UPF values were measured to determine the UV-radiation protection characteristics of untreated cotton fabrics and nanocomposite modified fabrics, and the results are shown in Table 2. Textile material can be classified into three protection groups, according to BS EN 13758-2:2003 (EN 2003): good (UPF range 20–29), very good (UPF range 30–40), and excellent (UPF range > 40).

The calculated UPF values of untreated cotton fabric is 4.5. The UPF of coated cotton fabric is varied from 20 to 55 which is higher than the untreated fabric. Also, the results in Table 2 indicated that curcumin /TiO_2 modified cotton fabric increases the UPF values. Results of Table 2 represented that, the UPF value of TiO_2 coated cotton fabric is 20. The increased UPF is attributed to the semi-conductive properties of the TiO_2 nanoparticles which can absorb ultraviolet photons (Al Sarhan and Salem 2018).

On the other hand, there is significant increase in UPF values for TiO_2 modified cotton fabric. The values varied from 23 to 30 due to the effect of different treatment according to the following order:

TiO_2 coated cationized cotton fabric > TiO_2 coated crosslinked fabric with citric acid /SHP > TiO_2 coated pretreated cotton fabric with GPTMS.

Moreover, the results in Table 2 indicated that curcumin/TiO_2 modified cotton fabric increases the UPF values which varied from 38 to 55 and were graded from very good to excellent protection. This could be a result of curcumin molecule is effective in increasing the ultraviolet protection of cotton fabric.

UPF values of curcumin/TiO2 modified cotton followed the order:

Curcumin /TiO_2 nanocomposite modified Quatt – 188 cationized fabric > TiO_2 coated crosslinked cotton fabric with citric acid /SHP > Curcumin /TiO_2 nanocomposite modified cotton fabric with GPTMS.

Table 2
UPF values of cotton fabric treated with different conditions

Treatment	UPF value	UV-A	UV-B	UV protection
Untreated cotton fabric	4.5	26	18.8	Non-ratable
TiO_2 coated cotton fabric	20	15.29	13.69	good
TiO_2 coated crosslinked cotton fabric with citric acid /SHP	27	7.74	6.11	Good
Curcumin /TiO_2 nanocomposite modified crosslinked cotton fabric with citric acid /SHP	50	3.5	3.1	Excellent
TiO_2 coated cationized cotton fabric	30	5.24	5.23	very Good
Curcumin /TiO_2 nanocomposite modified Quatt 100 cationized fabric	55	2.7	2.5	Excellent
TiO_2 coated pretreated cotton fabric with GPTMS	23	14.1	12.2	good
Curcumin /TiO_2 nanocomposite modified cotton fabric with GPTMS	38	6.1	4.5	Very good

4.7 Add-on and tensile strength measurements

Table 3 shows the percentage of values for add-on measurements and mechanical properties of chemically modified cotton fabric. The amount of chemicals deposited on the cotton fabric during modification is indicated by the add-on values. The results show that for GPTMS modified cotton fabric, the add-on values are between 8.45–12.57%, whereas the modification of samples with citric acid and cationized agent causes a significant increase in the add-on ranging between 8.65 % to 18.87 % and 9.55–15.45% respectively.

On the other hand, table I shown significant decrease in values of tensile strength. This may be attributed to the effect of different modification and crosslinking agents resulting in damaged of cellulose chains.

Table 3
Add – on measurements and tensile strength of treated cotton fabric

Treatment	Add on (%)	Tensile Strength (Kg f)
Untreated cotton fabric	0	55
TiO_2 coated crosslinked fabric with citric acid /SHP	9.55	48
Curcumin /TiO_2 nanocomposite modified crosslinked fabric with citric acid /SHP	15.45	45
TiO_2 coated cationized fabric	8.65	47
Curcumin /TiO_2 nanocomposite modified cationized fabric	18.87	44
TiO_2 coated pretreated fabric with GPTMS	11.2	51
Curcumin /TiO_2 nanocomposite modified fabric with GPTMS	12.57	47

Conclusion

In this work, biocompatible materials based on curcumin/ TiO_2 nanocomposite fabricated on the surface of cotton fabric for medical applications were successfully prepared. For achieving this goal, cotton fabric was per modified with citric acid, Quatt – 188, and GPTMS. The prepared nanocomposite modified fabrics were confirmed using FTIR, SEM, and EDX. It has been concluded that curcumin /TiO_2 nanocomposite modified Quatt-188 cationized fabric shows the highest antibacterial activity compared with either curcumin/TiO_2 nanocomposite modified crosslinked fabric with citric acid /SHP or curcumin/TiO_2 nanocomposite modified fabric with GPTMS. Moreover, Curcumin /TiO_2 nanocomposite modified Quatt-188 cationized fabric exhibited higher efficiency against Gram - negative bacteria that Gram-positive ones. Cationic modification can be used for the modification of cotton fabric for increasing curcumin / TiO_2 nanocomposite adsorption on their surfaces and producing stronger antibacterial activity. The results of UV protection also reveal that curcumin /TiO_2 nanocomposite modified Quatt-188 cationized fabric acquired the UPF value higher than 50, classified the excellent UV protection properties.

Declarations

Conflicts of interests

The authors have no conflicts of interest to declare that are relevant to the content of this article.

There are no animal studies or human participants involved in the study.

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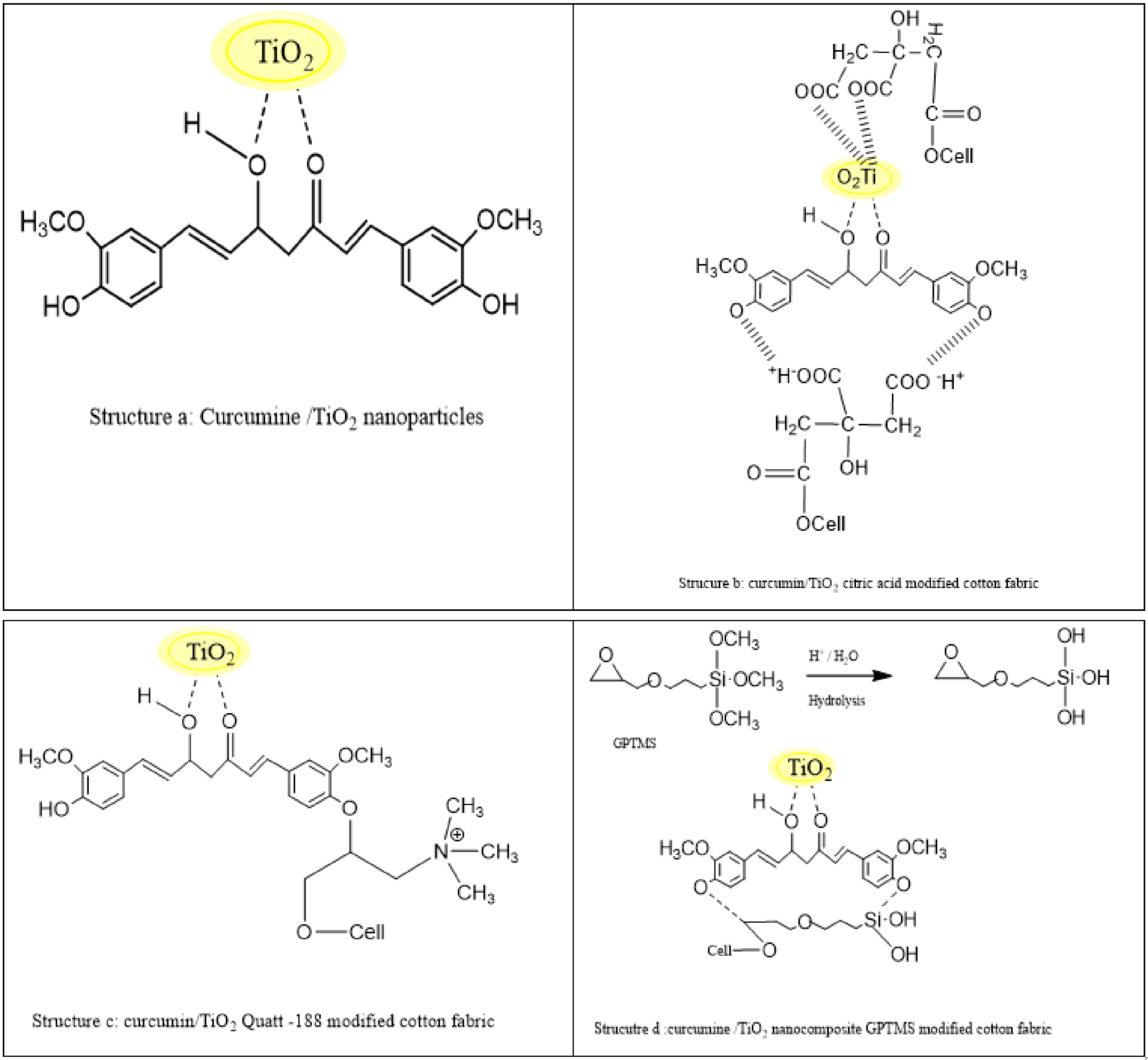
Figures



Structure a: Curcumine /TiO_2 nanoparticles

Strucure b: curcumin/TiO_2 citric acid modified cotton fabric

Structure c: curcumin/TiO_2 Quatt -188 modified cotton fabric

Strucutre d :curcumine /TiO_2 nanocomposite GPTMS modified cotton fabric

Figure 1

The schematic mechanism for deposition of curcumin/TiO2 nanocomposite on cotton fabric

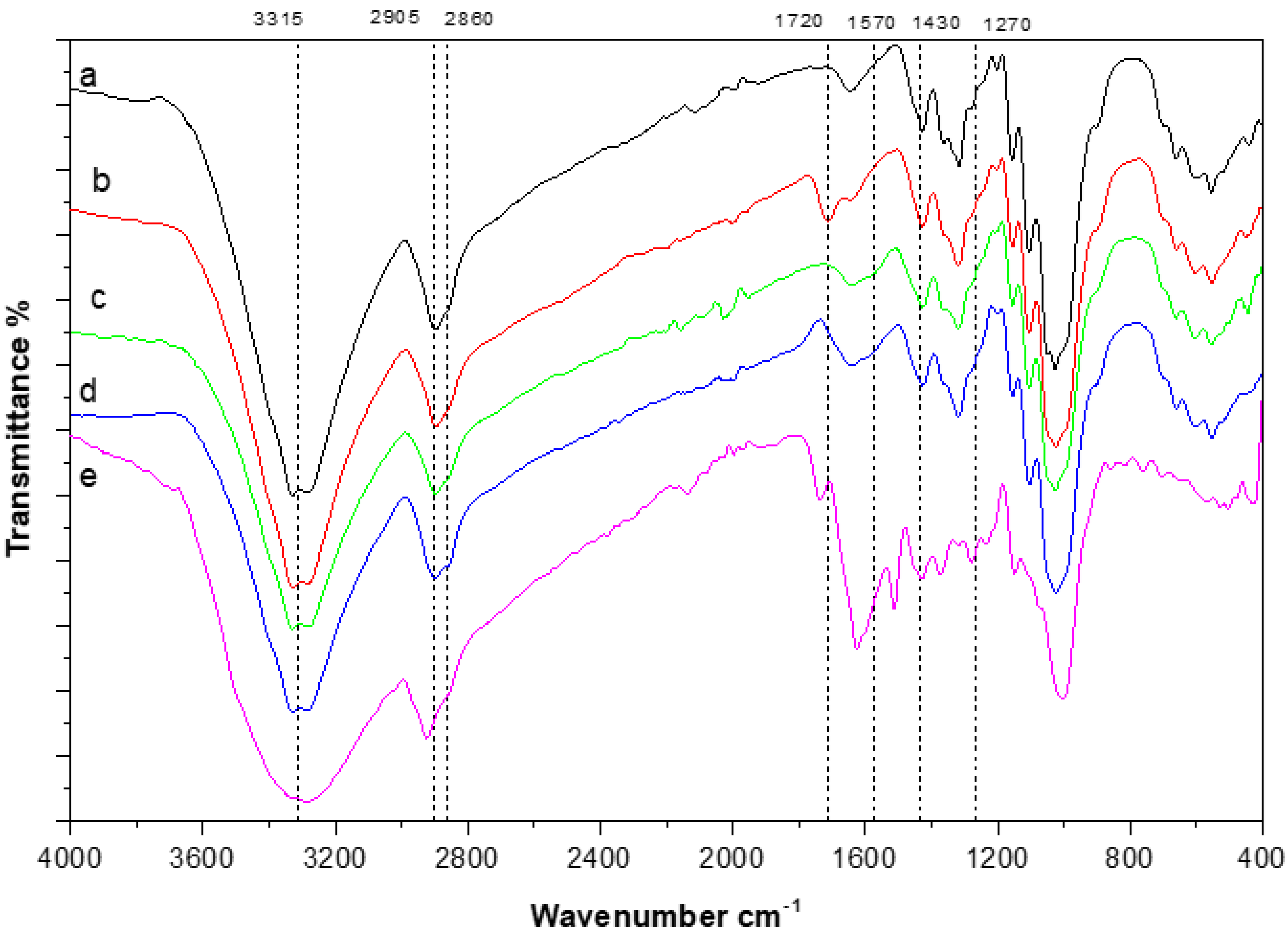


Figure 2

FTIR spectrum of untreated cotton fabric (a), curcumin /TiO2 –citric modified cotton fabric (b), curcumin / TiO2 – Quatt 188 modified cotton fabric (c), curcumin /TiO2 –GPTMS modified cotton fabric (d) and curcumin powder (e).

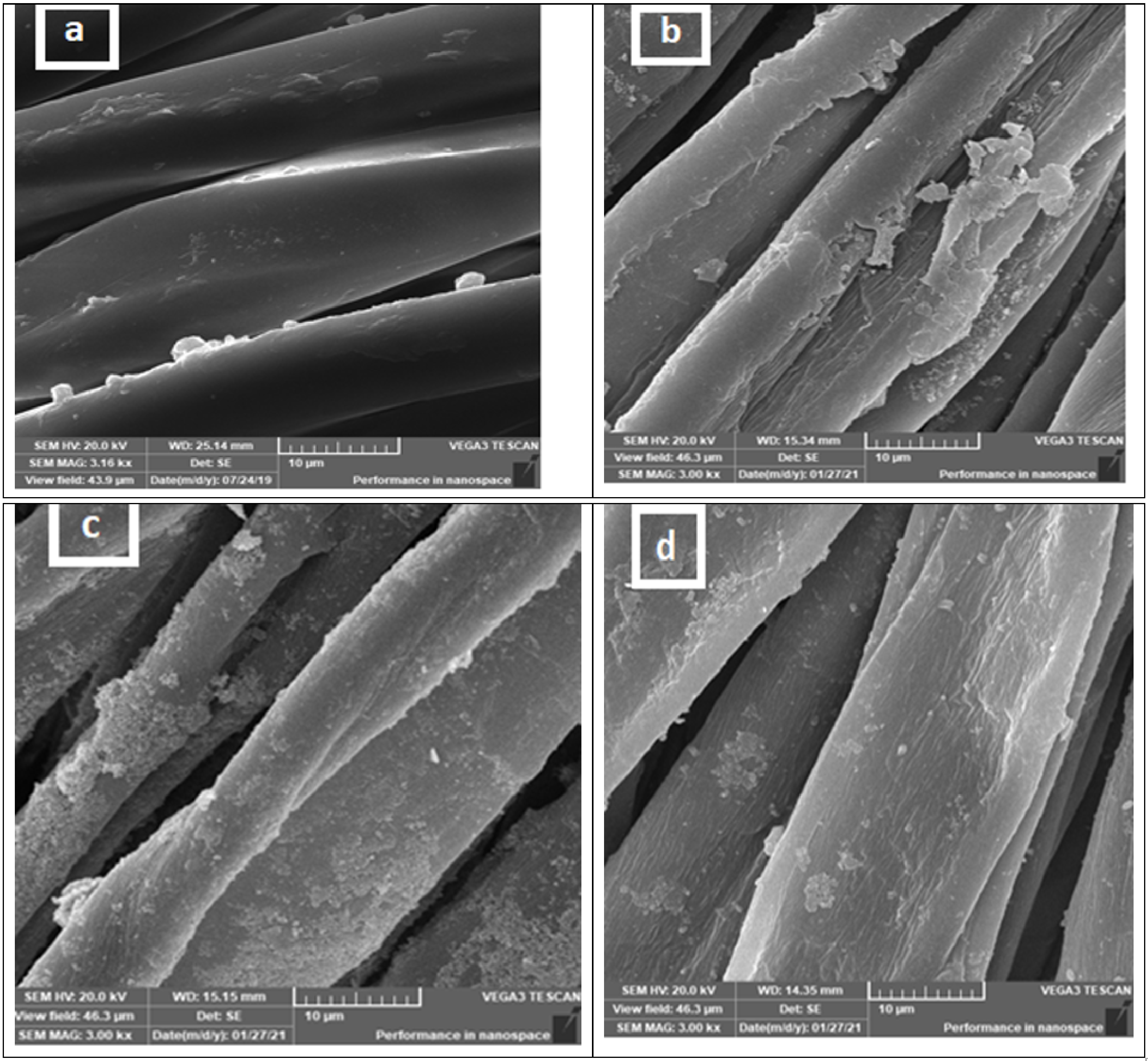


Figure 3

SEM images of control cotton fabric (a), curcumin /TiO2 –citric modified cotton fabric (b), curcumin / TiO2 – Quatt-188 modified cotton fabric (c), curcumin /TiO2 –GPTMS modified cotton fabric.

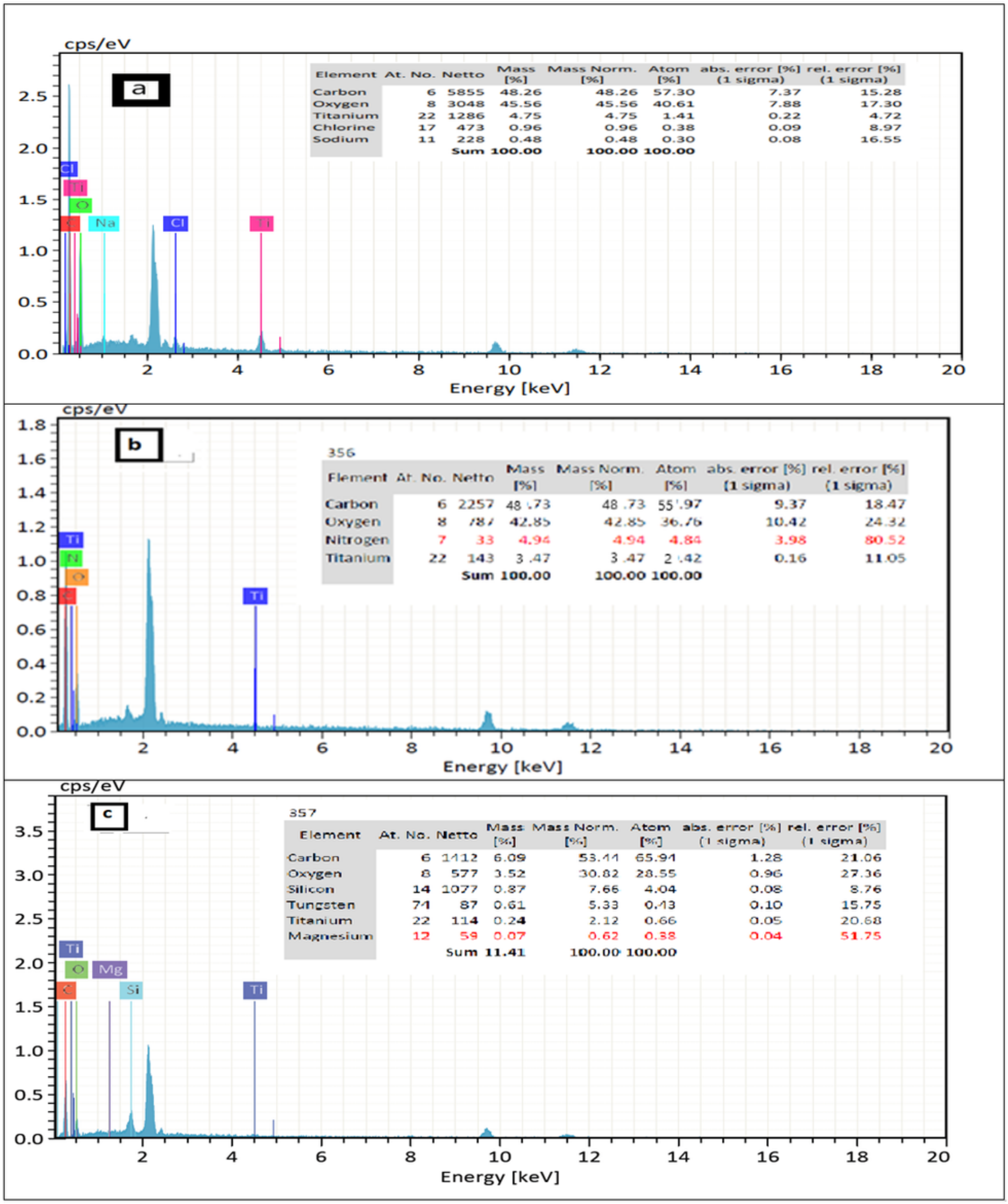


Figure 4

EDX analysis of (a) curcumin /TiO2 –citric modified cotton fabric (b), curcumin / TiO2 –Quatt 188 modified cotton fabric (c), curcumin /TiO2 –GPTMS modified cotton fabric