244 *Egypt. J. Chem.* **Vol. 67,** No. 5, pp. 597 - 606 (2024)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Surface Modification of Different Woven Structures of Polyester Fabrics using Tio_2nps for Multifunctional Properties

Sarah Yahia [1], Hamada M. Mashaly [2], and Nancy S. El-Hawary [2]*

[1] *Spinning and Weaving Engineering Department, Textile Research and Technology Institute, National Research Centre, 33 El-Behouth St., Dokki, P.O.12622, Giza, Egypt*

[2] *Dyeing, Printing and Textile Auxiliaries Department, Textile Research and Technology Institute, National Research Centre, 33 El- Behouth St., Dokki, P.O.12622, Giza, Egypt*

Abstract

The type of yarn and weave structure have a high impact on fabric properties and affect on dyeing and treatment process. Double weave structure is one of the 3D Fabrics, it is more complicated than the simple weave structure. Polyester is one of the manmade yarns that have different types depending on the spinning way, the cross-section, and its tenacity. The most complete batch staining method is high-temperature dyeing. One of the most significant objectives of this work was to improve polyester fabric by adopting titanium nanoparticle size (TiO_2) to provide it with multifunctional features (such as UV resistance, stain resistance, and antibacterial, self-cleaning). In general, the study was split into two sections: The first part examined the environmental benefits of using high temperatures to dye some dispersed dyes. The second part promoted the fabric's ability to perform multiple tasks after dyeing (post-dyeing with disperse dyes) by using TiO_2NPs (21 nm primary particle size) in a two-step hot process that involved soaking it in a solution of TiO_2NPs at 80°C before curing it at 140°C. This work aims to investigate the impact of various weave patterns and treatments on the back layer.

Keywords: Antimicrobial, Dyeing, Polyester, TiO2, nanoparticles, Dyeing, Fabric Structure

1. Introduction

Fabric properties are affected by many elements, such as the type of yarns, count of yarns, fabric structure, and chemical treatments; the yarn type is an important element. One of the most commonly used types of yarn is polyester, [1] it can be classified according to its spinning way as a stable or continuous yarn, its cross section as circular or trilobal, ex. and its tenacity as regular or high tenacity. [2] It is used in widely different textile fields like sportswear, technical textile, protective textile ex.

The high-tenacity yarn appears in (polyester, polyethylene, polypropylene, and nylon) as a continuous filament and staple fiber. The high tenacity polyester was introduced into the market in the 1950s. [3] The strength of fiber, yarn, and fabric means tenacity. It is the result of dividing the breaking load by its mass per unit or the loading force/yarn density. [4] Tenacity in yarn can be expressed as cN/TeX for single yarn classification of fibers and yarns under the HTSUS Fibers and Yarns. High tenacity technology can improve the physical and mechanical properties of yarn and fabric (tenacity, high modulus and low shrinkage, low elongation at break, and high durability and low fatigue). [5] Woven structure is one of the main factors which affect the fabric properties. It consists of two sets of yarns: warp (the fabric's length direction) and weft (the width direction of the fabric) which interlace together to produce the 2D fabric. [5] 3D fabric is a new term in textile technology; it has 3 dimensions orthogonal weave, angle interlock weave, and multilayer weave (Figure 1). Multilayer weave has more than one set of warp and weft, namely two-layer double weave, three, four, …. etc. Two-layer double weave has 2 warp sets and two weft sets to form the face and back layer and every layer has its woven structure like plain, twill, …. etc.; which provide specific properties through its structure. [6] Polyester is the most widely used man-made fiber which is used in many textile fields like sportswear, medical textile, etc. There are many types of polyester yarn such as high-tenacity polyester which is weight and high strength, and polyester microfiber which is soft and easily transfers temperature and moisture. [7, 8]

*Corresponding author e-mail: nancysobh2014@gmail.com.
Receive Date: 24 August 2023, **Revise Date:** 20 September 2023, **Accept Date:** 31 October 2023
DOI: 10.21608/ejchem.2023.231616.8490

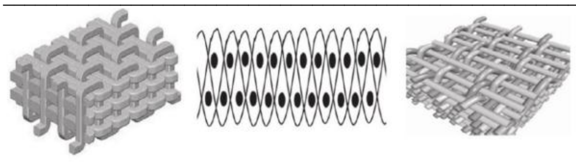


Figure 1: types of 3D fabric

Most of the commercially used polyester fibers are chemically prepared from polyethylene terephthalate (PET). Under its excellent appearance, performance, and comfort attributes, PET fibers constitute more than one-third of all textile and clothing markets. [9-13] Polyester fabrics are usually the proper choice for the manufacture of many sportswear items as they are soft, resilient, crease-resistant, and microbial-resistant. Nevertheless, PET fibers have some unfavorable properties, such as the difficulty of coloration, accumulation of electrostatic charge, and hydrophobicity. [14-16]

Functionalization of textile fabrics was usually conducted to improve their performance, appearance, and comfort attributes. [17, 18] Various chemical, [19] physical [20]' and biological [21-23] methods have been used to provide the finished textile product-specific desired qualities. Within the last couple of decades, many investigations have been conducted to assign the possibility of using titanium IV oxide NPs, as well as other metals or metal oxide NPs as a photocatalyst to impart multifunctional merits to various textile substrates. [24-32] However, to our knowledge, no research investigations have been directed toward studying the effect of variation in the fabric structure on the properties of polyester fabric treated with TiO_2NPs. Therefore, this work is devoted to studying the effect of treatment of two different weave structures of polyester fabrics with nano-sized titanium IV oxide, followed by dyeing with a disperse dye, on their performance and appearance characteristics.

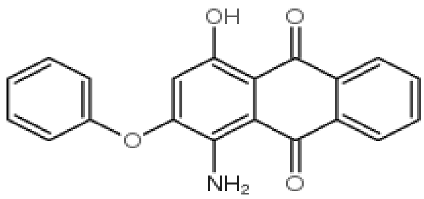
2. Materials and Methods

2.1. Materials

Two samples were produced from 100% polyester fabrics. Double weave structure was used, face structure is plain 1/1 for both samples with two different back structures (plain 1/1 and twill 2/2). Two yarn types of polyester were used (The first one is polyester microfiber with yarn count 150/1 DN and 144 fibers in cross-section as warp and weft yarns and the second is polyester high tenacity with yarn count 300/1 DN and its tenacity is 60 cN/Tex which used as weft yarns). Produced fabrics have 60 ends/cm and 22 picks/cm. Table 1 shows the characterization of the produced samples. The fabric was scoured in an aqueous solution containing 2 g/L non-ionic detergent (Hostapal, Clariant) and 2 g/L sodium carbonate at 50°C for 30 min; the material-to-liquor ratio (MLR) was 1:30.

Six double-woven polyester samples were fabricated (two blank samples, two dyed samples, and two treated and dyed samples).

The disperse dye Resolin Red FB (C.I. Disperse Red 60) was provided by Hang Zhou Fu Cai Co. Ltd., China. Titanium IV oxide NPs (21 nm primary particle size TEM), were purchased from SIGMA-ALDRICH, Germany.



Structure 1: Disperse Red 60

2.2. Methods

2.2.1. Producing of used fabrics

The samples were produced using loom Picanole/GTX/Plus, made in China, 2005 model, 190 cm wide, with a Dobby 2650 (Staubli), its speed about 320 picks per minute.

2.2.2. Woven structure:

Double weave structure used for producing 2 samples. Sample (1) Both the face and back weave structure are plain 1/1. Sample (2) The face weave structure is plain 1/1 and the back weave structure is twill 2/2. Figure (2) shows the double weave structure for the 2 samples.

B	○		●	
F				
B	●			
F			○	
	F	B	F	B

sample (1) (Face and Back plain 1/1)

B	○		○		○		●	
F								
B	○		○		●		○	
F								
B	○		●		○		○	
F								
B	●		○		○		○	
F								
	F	B	F	B	F	B	F	B

sample (2) (Face plain 1/1 and Back twill 2/2)

Figure 2: Double weave structure

Warp face weave structure appears, Warp back weave structure appears, ○, ● are Sign for double weave structure rule

Table 1: Characterization of the fabricated samples

Samples	Warp type	Weft type	Woven structure	Face structure	Back structure
1-B	Polyester microfiber 150/1d 144 fiber/cross-section	Polyester high tenacity 300/1d	Double weave two fabric layers inseparable	Plain 1/1	Plain 1/1
1-D					
1-TD					
2-B					Twill 2/2
2-D					
2-TD					

B: Blank, D: dyed, TD: treated and dyed

2.2.2. Treatment fabrics by TiO_2 NPs

The two kinds of polyester fabric (3 g each) were treated with different amounts of TiO_2NPs (5, 10, 20 mg/g fabric) at 80℃ for 20 min in the presence of a wetting agent using the exhaustion method. The treated materials were then washed at 60 degrees for 20 minutes, cured at 140 degrees for 10 minutes, and dried before dying.

2.2.3. Dyeing process

The fabric dyeing was carried out in an IR dyeing machine (Infrared Colour Dyeing Machine, Mumbai, India) with C.I. Disperse Red 60 (2 % shade) at 125℃ and pH 4.5 for, and the MLR was 1:40. Following dyeing, the samples were washed at 60°C in a bath containing 2 percent non-ionic detergent, rinsed with water, and then allowed to air dry.

2.4. Analyses and characterisation

2.3.1. Mechanical test

Mechanical and physical properties were tested to find out the effect of using two different backweave structures dyed fabric treated with TiO_2NPs.

- Tensile strength and elongation according to ASTM D 2256-2017 [33]
- Thickness test according to ASTM D1777-96:2017. [34]
- Weight test according to ASTM D 3776/D3776M − 09a (Reapproved 2017). [35]
- Air permeability test according to ASTM D 737-2018. [36]
- Water permeability test according to ASTM D4491/D4491M-22. [37]
- UPF test according to AATCC 183:2010. [38, 39]

2.3.2. Self-cleaning activity

The breakdown rate of methylene blue was used to gauge the photocatalytic efficacy of pretreated polyester textiles (Aldrich, United States). Using a Cary Varian 300 ultraviolet-visible (UV-Vis) spectrophotometer in the wavelength range of 320-400 nm, the amount of ultraviolet transmission through textiles was measured. The degradation of methylene blue under UV light at wavelengths of 365 nm was observed to measure the photocatalytic self-cleaning ability. Using a fluorescent bulb (TC-L18W, AC230V-50 Hz, China) the light was provided at a distance of 5 cm and a light intensity of 44 W cm^{-2}.

To achieve an adsorption/desorption equilibrium between the photocatalysis and methylene blue under ambient circumstances, a nano TiO_2 pre-treated polyester sample (0.5 g) was agitated for 30 min in 50 mL of an aqueous solution of methylene blue (0.05 g/L at pH 6.5). The sample was subsequently subjected to radiation for 4, 8, and 12 hours while wearing visible coatings. After continual dilution, 1 mL of the solution was collected after each irradiation interval time and subjected to spectrophotometer analysis. By measuring the absorption maxima at 665 nm as a function of the irradiation period, the concentration of methylene blue was determined. The following equation was used to measure the photocatalytic degradation:

$$\text{Photocatalytic degradation} = \frac{A_o - A_t}{A_o}$$

where A_o is the initial absorption and A_t is the variable absorption at different irradiation periods. [10, 40]

2.3.3. Color Strength K/S

The dyed samples were subjected to a colorimetric examination using a Hunter Lab Ultra Scan PRO spectrophotometer. The Kubelka-Munk equation was used to calculate the K/S values, which represented the color intensity. [41-47]

$$K/S = \frac{(1-R)^2}{2R} - \frac{(1-R_o)^2}{2R_o}$$

Where K is the absorption coefficient, S is the scattering coefficient, and R is the decimal fraction of the reflectance of the dyed cloth. R_o is the decimal fraction of the reflectance of the undyed fabric.

2.3.4. Fastnesses properties

Washing fastness

The ISO 105-C01:2006 (E) test technique was used to assess the color fastness of washing. [48] The washing fastness test was carried out in an ATLAS-Germany launder-meter using a 5g/L nonionic detergent at 50°C for 45 minutes using a 1:50 liquor ratio. The composite specimen was taken out, washed under running water, squeezed, opened, and allowed to air dry. It comprised the test specimen and the two adjacent fabrics in contact with the main sample. Gray scale was utilized to evaluate the dyed sample's color shift and the staining of the two nearby white textiles (cotton and wool).

Lightfastness

Using a xenon light, this test was assessed following the ISO 105-B02: 1988 test procedure. [49] To assess the level of color resistance to light photo-degradation, samples were subjected to a continuous light source for 35 hours.

2.3.5. Antibacterial activity

The antibacterial activities of polyester fabrics were tested against the Gram–ve -bacteria Pseudomonas *aeruginosa* (ATCC 27853), the Gram +ve bacteria Staphylococcus aureus (ATCC 6538), and the pathogenic fungus: Candida albicans (ATCC 10231). The qualitative evaluation of the antibacterial activities was carried out in nutrient agar plates according to the method reported [50]

2.3.6. Evaluation of the overall quality of the dyed fabrics treated with TiO_2NPs

An assessment was made of the quality of the fabrics produced under research for their functional suitability, to choose the best sample, multi-axis radar charts were used to express the quality assessment of the samples under research through the use of the following properties:

By converting the results of the average measurements of fabric properties into relative comparison values (without units) ranging from (0-100). [51]

Since the larger comparative value is the best with all the different properties except for weight and thickness, the lower comparative value is the best, and the following equations were used to calculate the relative comparative value.

$$QF = \frac{X}{X_{max}} \times 100 \text{ or } QF = \frac{X_{min}}{X} \times 100$$

Where: X (read each sample separately), X_{Max} (highest reading), and X_{Min} (lowest reading)

3. Results and Discussion

The fabricated samples were classified into two groups according to the back weave structure, each group has three samples (blank, dyed, and dyed treated samples). Various mechanical and physical properties of the modified fabrics were carried out.

3.1. Physio-mechanical properties

3.1.1 Weight and thickness

From Figure (3) the result of the weight and thickness test for plain and twill back weave structures is close together according to the balance and stability of both weave structures and

The fabric weight of the untreated, dyed, and dyed treated samples is shown in Figures 2 and 3. It is obvious in Figure 3 that the higher weight appears in the dyed samples in both the two back weave structures.

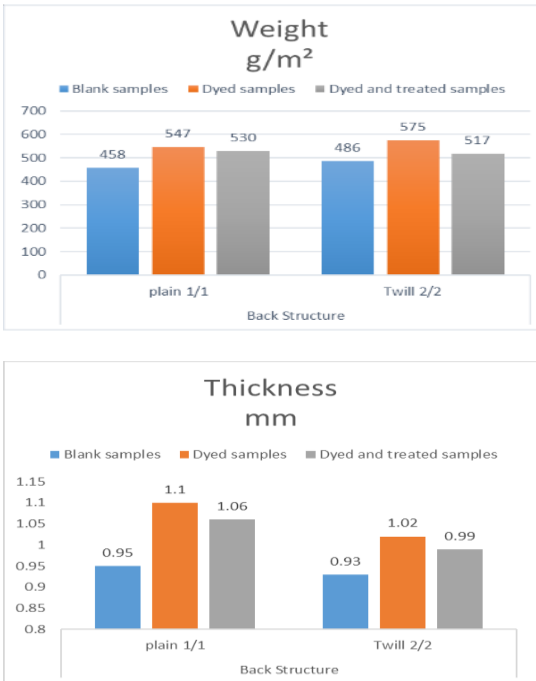


Fig. 3: The sample weight and thickness test

3.1.2 Warp and weft tensile strength

From Figure (4) Warp tensile strength has a high result in blank samples in both plain and twill weave structures, the dye and treatment process weaken the internal links between the fibers in the microfiber polyester yarn. On the other hand, the result of the weft tensile strength convergent is due to the type of the weft yarn, high tenacity polyester resists weakening through the dye and treatment process.

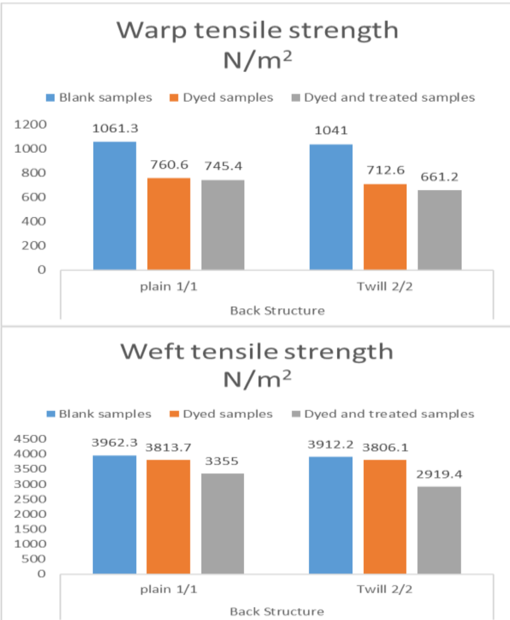


Fig. 4: The samples warp and weft tensile strength test

3.1.3. Warp and weft elongation

From Figure (5) Warp and weft elongation has a high result in dyed and treated samples in both plain and twill weave structures, as a result of the low tensile strength the fibers move freely at the cross-section. Warp elongation is higher than weft elongation due to the number of fibers in the cross-section of the microfiber yarn (144 fiber) that occurs in many interstitial spaces between fibers.

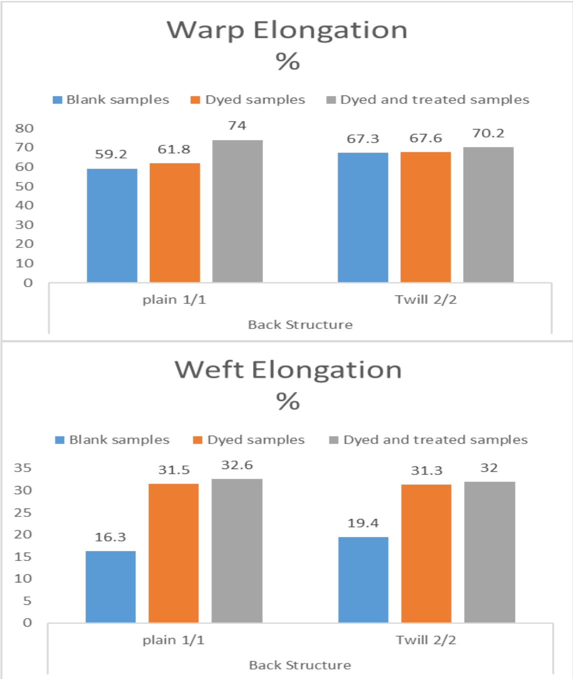


Fig. 5: The samples warp and weft elongation test

3.1.4. Spray test

figure (6) shows the result of the spry test 0% indicates full water absorption, 50% indicates half water absorption, and 70% indicates low water absorption. The blank sample has a high ability of water absorption in both plain and twill which refers to the ability of treatment to raise the water insulation.

The interstitial spaces between yarns in the twill structure led to more water being absorbeded in these samples

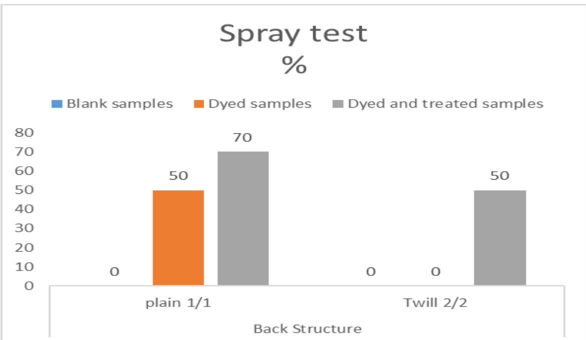


Fig. 6: The sample spray test results

3.1.5. water and Air permeability test

figure (7) shows that the blank sample has a high ability of water permeability in both plain and twill. That means the importance of the treatment to add a value of insulation which is important in many applications

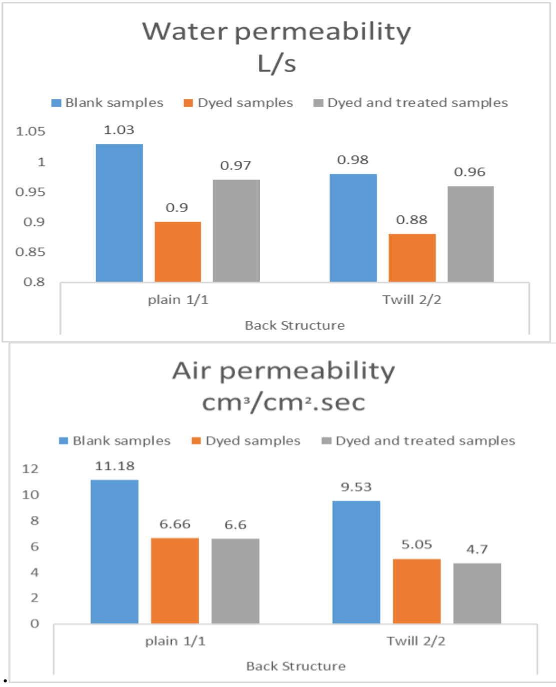


Fig. 7: water and air permeability test results

3.2. UPF test

figure (8) showed that the dyed and treated samples have a higher resistance to the effect of UV radiations as indicated by their higher UPF than the corresponding unmodified fabrics. TiO_2NPs have been reported by many authors as one of the most effective UV blockers. [13]

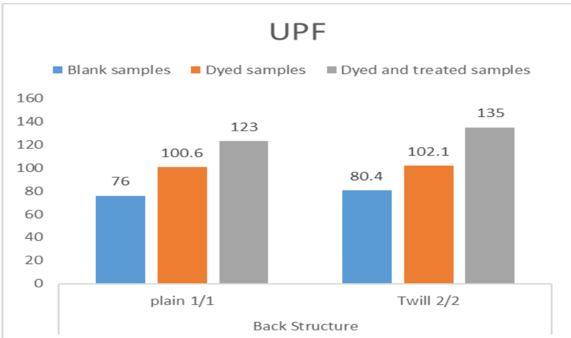


Fig. 8: UPF of treated and dyed samples

3.3. Self-Cleaning of Treated Polyester Fabrics using TiO_2 Nanoparticles

One of the susceptibilities of fibers treated with TiO_2 nanoparticles is the conversion of the absorbed light into the self-cleaning components to break down its stain. After 24 hours of UV exposure, Table 2 displays the impact of C.I. RO 14 on untreated and TiO_2NPs-treated polyester fabric.

Table 2: Self-cleaning % of polyester fabric treated with TiO_2 NPs

Samples	Dye removal %
Blank (Plain 1/1)	0
Dyed fabric (Plain 1/1)	25
Treated fabric (Plain 1/1)	85
Blank (Twill 2/2)	0
Dyed fabric (Twill 2/2)	25
Treated fabric (Twill 2/2)	83

The UV-light-affected hue of the TiO_2NPs-striated polyester fabric showed a partial shift. Thin layer TiO_2NPs were created by treating polyester, increasing its hydrophilic qualities. On the treated cloth, the strong decay impact of TiO_2NPs has been noticed. The two different surfaces that are produced when polyester is treated with TiO_2NPs may help to explain why polyester is self-cleaning. Different processes can be used by both hydrophilic and hydrophobic surfaces to remove the color from polyester. A hydrophobic surface prevents dirt from adhering and keeps the fabric's surface clean all the time. On hydrophilic surfaces, on the other hand, water droplets are dispersed, and as a result, a flood of water that is already present on the surface of polyester expels the contaminants.

3.3. Color measurements (color strength K/S)

The effect of the treatment of polyester fabrics with TiO_2NPs on the color strength of polyester fabric dyed with Disperse Red 60 was investigated and Table 3 provides a summary of the outcomes which indicates that the treatment of the dyed samples with TiO_2NPs enhanced their color intensities, presumably due to the glittering action of TiO_2 on the fabrics, which resulted in increasing the K/S of the dyed fabrics. [52-54]

Table 3: Polyester textiles' color intensity after being dyed with C.I. Disperse Red 60 and then treated with various TiO2 concentrations

Concentration of TiO_2 NPs (mg/g fabric)	Color intensity (K/S)	
	Plain 1/1	Twill 2/2
0	13.50	12.45
5	17.36	16.42
10	17.40	17.82
20	17.55	18.18

3.4. Fastness properties

Using the grey scale as given in Table 4, the durability of colors on polyester textiles treated with TiO2NPs generated using a typical heating process was assessed in terms of fastness against washing and light fastness. TiO2NPs pretreated polyester fabrics had better color fastness than untreated fabrics with the same TiO_2NPs. The TiO_2NPs-pretreated polyesters varied from 4 to 6. Additionally, we can see that the light fastness varies from good to exceptional in every situation.

Table 4: Fastness properties of the untreated andTiO_2NPs-treated dyed cotton fabrics

Samples	Washing Fastness	Light fastness
Blank dyed	3	4-5
Treated fabric (Plain 1/1)	5	6-7
Blank dyed	3	4-5
Treated fabric (Twill 2/2)	4	6-7

3.5. Antimicrobial activity

The antibacterial property of the material, which is intended for biomedical applications, is a key feature. TiO_2 and TiO_2NPs have strong antibacterial effects on both gram-positive and gram-negative bacteria and are extremely hazardous to microorganisms. A well-known test organism is the bacteria (P. *aeruginosa*) that causes contamination of the urinary system and wounds. The hazardous bacteria (S. aureus) are to blame for many illnesses, including toxic shock, fibrin coagulation, and endocarditis. Table 1 shows the calculated bacterial effects of unmodified and NPs-modified polyester against both *P. aeruginosa* and *S. aureus pathogens* (5).

The primary cause of TiO_2NPs' antibacterial action is their photo-catalytic effect, which produces a variety of active oxygen species, including superoxide anions, hydrogen peroxide, singlet oxygen, and hydroxyl radicals, which are responsible for destroying bacterial cells. Due to the G+ve bacteria having an exterior cell wall membrane, which makes them more resistant to the antibacterial action, the fabric treated with TiO_2NPs exhibits a larger antibacterial impact on G+ve bacteria than on Gve bacteria.

Table (5): Present reduction (%) of bacterial strain cells after 24-hour incubation

Samples / bacteria	Treated sample					
	Plain 1/1			Twill 2/2		
	Blank	Dyed	Treated	Blank	Dyed	Treated
Pseudomonas aeruginosa (B. s.)	18.00	32.5	47.00	23.76	40.88	58.00
Staphylococcus aureus (S. a.)	12.79	15.21	17.66	19.40	27.61	35.82
Candida albicans	7.82	36.25	64.69	63.62	66.96	70.35

3.1.1. Determining the best sample properties using a radar chart

The produced samples were evaluated by radar chart in mechanical properties, Evaluation of the results showed that the sample 2-DT (*c.f.* Table 1), weaved in twill 2/2 woven structure at the back layer achieved the best in terms of all functional properties with a quality coefficient 87.5 (see table 6) and provide the largest Radar area which shown in Figure 8.

From Table (6) and Figure (8), we conclude the following: The sample No. (2-DT) executed with the structural composition weaved in twill 2/2 woven structure at the back layer is the best on the release of all functional properties of the fabrics produced under research using variables and various study factors with a quality factor of 87.5 %, while the sample No. (1-DT) implemented with the structural composition weaved in a plain 1/1 woven structure at the back layer has a quality factor of 87.1 %.

Table 6: the quality factor of investigated produced fabrics

	Weight	Thickness	Tensile strength		Elongation		Permeability		Spray test	UPF	Self-Cleaning	K/S	Antibacterial			overall QF
			warp	weft	warp	weft	Air	Water					B. s.	S. a.	C. a.	
Blank (plain 1/1)	79.7	86.4	100.0	100.0	80.0	50.0	100.0	100.0	0.0	56.3	0.0	0.0	31.0	35.7	11.1	55.3
Dyed (plain 1/1)	95.1	100.0	71.7	96.2	83.5	96.6	59.6	87.4	71.4	74.5	29.4	74.3	56.0	42.5	51.5	72.7
Dyed and treated (plain 1/1)	92.2	96.4	70.2	84.7	100.0	100.0	59.0	94.2	100.0	91.1	100.0	96.5	81.0	49.3	92.0	87.1
Blank (twill 2/2)	84.5	84.5	98.1	98.7	90.9	59.5	85.2	95.1	0.0	59.6	0.0	0.0	41.0	54.2	90.4	62.8
Dyed (twill 2/2)	100.0	92.7	67.1	96.6	91.4	96.0	45.2	85.4	0.0	75.6	29.4	68.5	70.5	77.1	95.2	72.7
Dye and treated (twill 2/2)	89.9	90.0	62.3	73.7	94.9	98.2	42.0	93.2	71.4	100.0	97.6	100.0	100.0	100.0	100.0	87.5

Pseudomonas aeruginosa (B. s.), Staphylococcus aureus (S. a.), Candida albicans (C. a.)

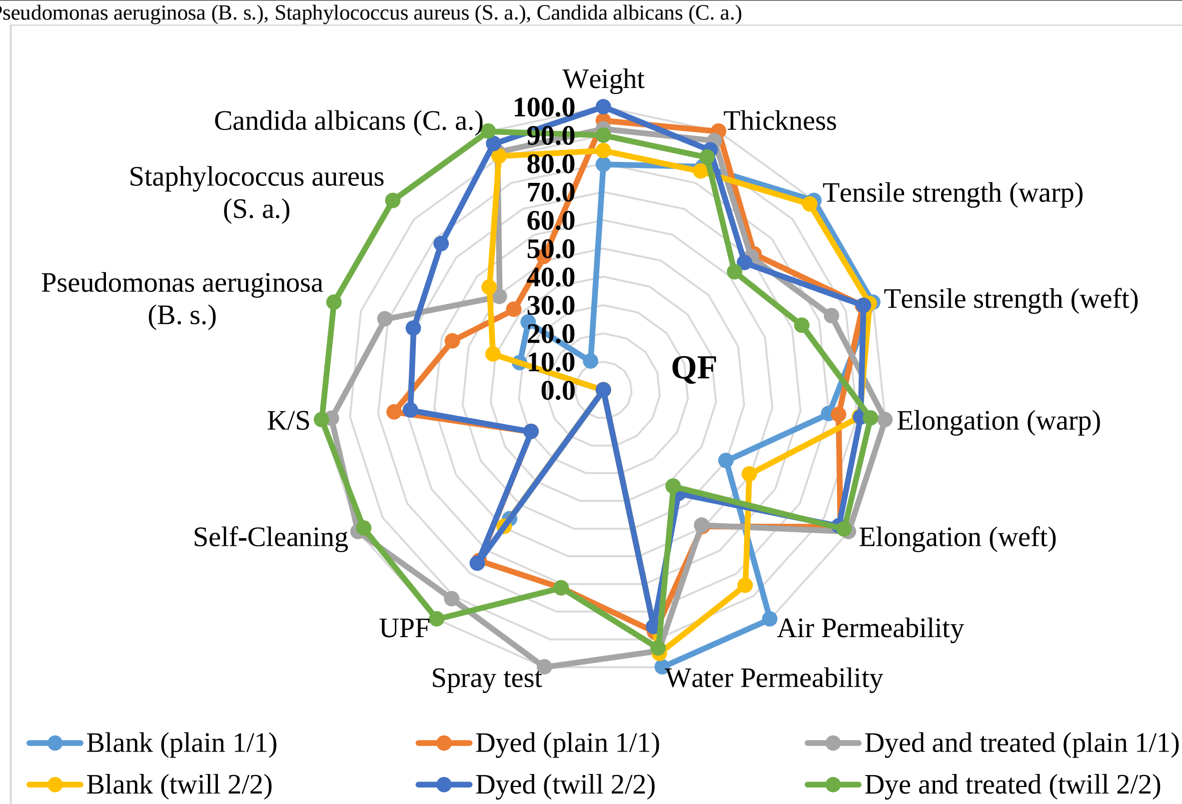


Fig. 8: Radar chart for the quality factor of investigated produced fabrics

4. Conclusions

Double weave structures were used, one face structure (plain 1/1) and two back structures (plain 1/1 and twill 2/2). Two material types were used (The first one is polyester microfiber with a yarn count of 150/1 DN and 144 fibers in cross-section as warp and the second is polyester high tenacity with yarn count of 300/1 DN and its tenacity is 60 cN/tex which is used as weft yarns, Physio-mechanical properties of produced fabrics were tested and discussion, so it can be concluded that using two different types of yarns as warp and weft enhance some properties of the fabric, Microfiber polyester improves the elongation, water, and air permeability in other hand polyesters high tenacity improves the tensile strength property. Different back weave structures (plain 1/1 and twill 2/2) affect some fabric properties like elongation, even if both of them is balanced structure.

5. Conflict of Interest

There is no conflict of interest in the publication of this article.

6. Acknowledgment

The authors are gratefully grateful to acknowledge the Central Labs Services (CLS) and Centre of Excellence for Innovative Textiles Technology (CEITT) in Textile Research and Technology Institute (TRTI) at the National Research Centre (NRC) for the facilities provided.

7. Funds

The authors are grateful to the National Research Centre, Giza, Egypt for the facilities and support of this work

8. References

[1]. M.A. Saad, F. Metwaly, S.Y. Gad, K.M. Mansour, M.A. Ali, Effect of using trilobal® polyester on the functional performance of fencing suit, RJTA (2020).

[2]. S. Yahia, F.A. Metwally, M.A. Saad, K. Nassar, M.H. Kasem, M.A. Ali, Enhancing functional performance of sportswear fabrics using polyester micro-fibers yarn, Journal of Textile Association (November-December) (2018) 266-275.

[3]. M.B. Bastos, Improved high tenacity/high modulus polyester for stiffer mooring ropes, 2013 MTS/IEEE OCEANS-Bergen, IEEE, 2013, pp. 1-5.

[4]. C.J. Del Vecchio, J.M. Carter, Load-elongation characteristics of high tenacity polyamide yarns, The Brazilian technical community working in the field of Solid Mechanics has longed for a special-ized conference. Hence, the Technical Committee on Solid Mechanics, from the Brazilian Society of Mechanical Sciences and Engineering, ABCM, set as its main task to organize this conference, with the present book reflecting the effort of the committee to maintain the scientific standards attained in the first conference., 2009, p. 239.

[5]. J.M. Crook, Manufacture of high-tenacity yarns, 19 (2004) 70-71.

[6]. N. Gokarneshan, Fabric structure and design, New Age International 2004.

[7]. B. Kumar, J. Hu, Woven fabric structures and properties, Engineering of high-performance textiles, Elsevier2018, pp. 133-151.

[8]. D.H. Elgohary, S. Yahia, K. Seddik, Characterization the properties of blended single jersey fabrics using different microfiber yarn cross-sections and gauges machine, Egy. J. Chem. 64(6) (2021) 3041-3048.

[9]. C. Palacios-Mateo, Y. Van der Meer, G. Seide, Analysis of the polyester clothing value chain to identify key intervention points for sustainability, Environmental Sciences Europe 33(1) (2021) 2.

[10]. M.A. Ali, A.G. Hassabo, K.M. Seddik, s. yahia, N. Mohamed, Characterization of the thermal and physico-mechanical properties of cotton and polyester yarns treated with phase change materials composites, Egy. J. Chem. (2022) -.

[11]. E. Abd El-Aziz, M. Zayed, A.L. Mohamed, A.G. Hassabo, Enhancement of the functional performance of cotton and polyester fabrics upon treatment with polymeric materials having different functional groups in the presence of different metal nanoparticles, Polymers 15(14) (2023) 3047.

[12]. A.I. Fathallah, H. El-Sadek, B.Y. Youssef, M.G. Amin, Y.M. El-Kambashawy, B.M. Abd El-Kader, O. Halawa, A.G. Hassabo, Intelligent pcm composite for enhancing the thermoregulated properties of different cotton/polyester fabric constructions, J. Text. Color. Polym. Sci. 20(1) (2023) 113-123.

[13]. M.A. Ali, K.M. Seddik, A.G. Hassabo, Polyester fibres enhanced with phase change material (pcm) to maintain thermal stability, Egy. J. Chem. 64(11) (2021) 6599 - 6613.

[14]. M.Y. Soliman, H.A. Othman, A.G. Hassabo, A recent study for printing polyester fabric with different techniques, J. Text. Color. Polym. Sci. 18(2) (2021) 247-252.

[15]. A.I. Fathallah, B.Y. Youssef, H. El-Sadek, M.G. Amin, B.M. Abd El-Kader, Y.M. El-Kambashawy, O.E. Halawa, A.G. Hassabo, Alginic/stearic/octadecane as phase change material (pcm) for enhancing the thermal comfort-ability of different polyester fabrics constructions, Egy. J. Chem. 66(4) (2023) 167-177.

[16]. R.F. Gouveia, F. Galembeck, Electrostatic charging of hydrophilic particles due to water adsorption, Journal of the American chemical society 131(32) (2009) 11381-11386.

[17]. N. El-Hawary, N. Elshemy, H. El-Sayed, New thiol-disulfide exchangers as anti-setting agents for wool fabric during dyeing, Fibers and Polymers 17 (2016) 1391-1396.

[18]. B. Cortese, D. Caschera, G. Padeletti, G.M. Ingo, G. Gigli, A brief review of surface-functionalized cotton fabrics, Surface Innovations 1(3) (2013) 140-156.

[19]. A. Hebeish, M. Kamel, H. Helmy, N. El Hawary, Innovative technology for multifunctionalization of cotton fabric through cellulase biotreatment, reactive dyeing and easy care finishing, Egy. J. Chem. 56(5) (2013) 367-377.

[20]. N. Elshemy, M. Elshakankery, S. Shahien, K. Haggag, H. El-Sayed, Kinetic investigations on dyeing of different polyester fabrics using microwave irradiation, Egy. J. Chem. 60(Conference Issue (The 8th International Conference of The Textile Research Division (ICTRD 2017), National Research Centre, Cairo 12622, Egypt.)) (2017) 79-88.

[21]. H. Kafafy, a. shahin, h. mashaly, H. Helmy, A. Zaher, Treatment of cotton and wool fabrics with different nanoparticles for multifunctional properties, Egy. J. Chem. 64(9) (2021) 5255-5267.
[22]. A.A. El-Halwagy, H.M. Mashaly, K.A. Ahmed, H.M. Ahmed, Treatment of cotton fabric with dielectric barrier discharge (dbd) plasma and printing with cochineal natural dye, Indian Journal of Science and Technology 10(10) (2017) 1-10.
[23]. A.L. Mohamed, S. Shaarawy, N. Elshemy, A. Hebeish, A.G. Hassabo, Treatment of cotton fabrics using polyamines for improved coloration with natural dyes extracted from plant and insect sources, Egy. J. Chem. 66(3) (2023) 1-19.
[24]. S. S., S. A., S. A., A. S., D. Maamoun, A.G. Hassabo, S.A. Mahmoud, T.A. Khattab, Self-cleaning finishing of polyester fabrics using znonps, J. Text. Color. Polym. Sci. (Accept 2023) -.
[25]. E.F. Attia, T.W. Helal, L.M. Fahmy, M.A. Wahib, M.M. Saad, S. Abd El-Salam, D. Maamoun, S.A. Mahmoud, A.G. Hassabo, T.A. Khattab, Antibacterial, self-cleaning, uv protection and water repellent finishing of polyester fabric for children wheelchair, J. Text. Color. Polym. Sci. 20(2) (2023) 181-188.
[26]. M. Mahmoud, N. Sherif, A.I. Fathallah, D. Maamoun, M.S. Abdelrahman, A.G. Hassabo, T.A. Khattab, Antimicrobial and self-cleaning finishing of cotton fabric using titanium dioxide nanoparticles, J. Text. Color. Polym. Sci. 20(2) (2023) 197-202.
[27]. D. Tarek, A. Mohmoud, Z. Essam, R. Sayed, A. Maher, D. Maamoun, S.H. Abdel Salam, H. Mohamed, A.G. Hassabo, T.A. Khattab, Development of wrinkle free and self-cleaning finishing of cotton and polyester fabrics, J. Text. Color. Polym. Sci. 20(2) (2023) 175-180.
[28]. M. Adel, M. Mohamed, M. Mourad, M. Shafik, A. Fathallah, D. Maamoun, M.S. Abdelrahman, A.G. Hassabo, T.A. Khattab, Enhancing the self-cleaning properties of polyester fabric with rtv – silicone rubber, J. Text. Color. Polym. Sci. (Accept 2023) -.
[29]. M. Diaa, A.G. Hassabo, Self-cleaning properties of cellulosic fabrics (a review), Biointerf. Res. Appl. Chem. 12(2) (2022) 1847 - 1855.
[30]. A.M. Al-Etaibi, M.A. El-Apasery, Nano tio2 imparting multifunctional performance on dyed polyester fabrics with some disperse dyes using high temperature dyeing as an environmentally benign method, Int. J. Environ. Res. Public. Health 17(4) (2020) 1377.
[31]. H. Ghazal, H. Helmy, H. Mashaly, T.A. Khattab, Development of multifunctional cotton/nylon blended fabrics using nanoparticles of different metal oxides, Egy. J. Chem. 64(8) (2021) 4391-4400.
[32]. M. Fernandes, J. Padrão, A.I. Ribeiro, R.D. Fernandes, L. Melro, T. Nicolau, B. Mehravani, C. Alves, R. Rodrigues, A. Zille, Polysaccharides and metal nanoparticles for functional textiles: A review, Nanomaterials 12(6) (2022) 1006.
[33]. ASTM Standard Test Method (ASTM D 2256-02), Standard test method for tensile properties of yarns by the single-strand method, ASTM International, 2017.
[34]. ASTM Standard Test Method (D1777 - 96) (Reapproved 2002), Standard test method for thickness of textile materials, ASTM International, 2017.
[35]. ASTM Standard Test Method (D3776/D3776M − 09a (Reapproved 2017)), Standard test methods for mass per unit area (weight) of fabric, ASTM International, West Conshohocken, PA, 2018.
[36]. ASTM Standard Test Method (D737 - 18), Standard test method for air permeability of textile fabrics, ASTM International, West Conshohocken, PA, 2018.
[37]. ASTM Standard Test Method (ASTM D4491/D4491M-22), Standard test methods for water permeability of geotextiles by permittivity, ASTM International, West Conshohocken, PA, 2022.
[38]. ASTM Standard Test Method (D6603 - 00), Standard guide for labeling of uv-protective textiles, ASTM International, 2012.
[39]. AATCC Test Method (183-2004), Transmittance or blocking of erythemally weighted ultraviolet radiation through fabrics, Technical Manual Method American Association of Textile Chemists and Colorists, 2010, pp. 317-321.
[40]. M. Hakeim, M. El Zawahry, N. Aly, N. El-Hawary, H. Diab, A. Marwa, Anti static and fungtional properties of asminosilsesquioxane oligomer treated and dye fabrics, J. Text. Assoc. (2015) 90-101.
[41]. P. Kubelka, F. Munk, Ein beitrag zur optik der farbanstriche, Z. Tech. Phys. 12 (1931) 593.
[42]. K.T. Mehta, M.C. Bhavsar, P.M. Vora, H.S. Shah, Estimation of the kubelka--munk scattering coefficient from single particle scattering parameters, Dyes Pigm. 5(5) (1984) 329-340.
[43]. A. Waly, M.M. Marie, N.Y. Abou-Zeid, M.A. El-Sheikh, A.L. Mohamed, Process of single – bath dyeing, finishing and flam – retarding of cellulosic textiles in presence of reactive tertiary amines, 3rd International Conference of Textile Research Division, NRC; Textile Processing: State of the Art & Future Developments, Cairo, Egypt, 2006, pp. 529 – 543.

[44]. A. Waly, M.M. Marie, N.Y. Abou-Zeid, M.A. El-Sheikh, A.L. Mohamed, Flame retarding, easy care finishing and dyeing of cellulosic textiles in one bath, Egy. J. Text. Polym. Sci. Technol. 12(2) (2008) 101-131.
[45]. A.G. Hassabo, Synthesis and deposition of functional nano-materials on natural fibres RWTH Aachen University, Germany, 2011, p. 154.
[46]. A.L. Mohamed, A.G. Hassabo, Cellulosic fabric treated with hyperbranched polyethyleneimine derivatives for improving antibacterial, dyeing, ph and thermo-responsive performance, Int. J. Biol. Macromol. 170 (2021) 479-489.
[47]. A.G. Hassabo, Preparation, characterisation and utilization of some textile auxiliaries, El-Azhar University, Cairo, Egypt, 2005.
[48]. ISO 105-C01:2006, Textiles — tests for colour fastness — part c01: Colour fastness to washing: Test 1, Deutsches Institut fur Normung E.V. (DIN), 2006.
[49]. ISO 105-B02:1988, Textiles — tests for colour fastness — part b02: Colour fastness to artificial light : Xenon arc fading lamp test, Deutsches Institut fur Normung E.V. (DIN), 1995.
[50]. R. Khan, M. Fulekar, Biosynthesis of titanium dioxide nanoparticles using bacillus amyloliquefaciens culture and enhancement of its photocatalytic activity for the degradation of a sulfonated textile dye reactive red 31, J. Colloid Interface Sci. 475 (2016) 184-191.
[51]. M.S. Kamal, E. Mahmoud, A.G. Hassabo, M.M. Eid, Effect of some construction factors of bi-layer knitted fabrics produced for sports wear on resisting ultraviolet radiation, Egy. J. Chem. 63(11) (2020) 4369 - 4378.
[52]. A. Madhu, N. Singh, A. Kaur, O.P. Sahu, Uv protective fabric for face covering utility article using tio2 nanoparticles, Materials Today: Proceedings 68 (2022) 1022-1029.
[53]. N. Elshemy, S. Mahmoud, H. Mashaly, K. Haggag, Efficient one pot synthesis of tio2-induced nanoparticles via microwave irradiation and its application in cotton dyeing with some acid dyes, Int. J. Pharm. Sci. Rev. Res 41(2) (2016) 41-47.
[54]. A.G. Hassabo, S. Galal, A. Elmekawy, N. El-Taieb, N. Elshemy, Effect of different dyed fabrics on the adsorption of air pollution in residential and industrial atmosphere in cairo-egypt, Letters in Applied NanoBioScience 13(1) (2024).