Improving Performance and Functional Properties of Different Cotton Fabrics by Silicon Dioxide Nanoparticles

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Abstract
The aim of this research is to enhance the functionality of cotton fabric by using Nano finishing technology through applying Silicon Dioxide NPs with different concentrations and different application treatment methods to get optimal result on 100% cotton fabrics (Woven fabric, Indian Cotton, and Egyptian Cotton Giza 86), the best result of treatments of SiO_2 were dyed with Direct dye. The effectiveness of the treatment assessed by using standard tests and influences of the finishing for some general textile properties as weight, thickness, tensile strength, elongation, air permeability, thermal gravimetric analysis, ultraviolet protection factor, anti-bacterial test, contact angle and color fastness properties as well as the durability of the treatments was investigated. The optimal performance reached through pad – dry – cure process for high concentration Silica Dioxide NPs treatment for woven cotton fabric give multifunction properties.
Keywords: Silicon Dioxide, Anti-bacterial, Ultraviolet protection, Cotton fabrics, multifunction properties

ملخص البحث :
يهدف هذا البحث إلى تحسين الخواص الوظيفية للأقمشة القطنية عن طريق التجهيز بتقنية النانو تكنولوجى و ذلك من خلال تطبيق النانوثنائى أكسيد السيليكون على أقمشة القطن المختلفة (قطن منسوج - قطن هندى - قطن جيزة 86) بتركيزات مختلفة و بإستخدام طرق تطبيق مختلفة للحصول على أفضل النتائج لأقمشة 100% قطن , تم صباغة أفضل النتائج لتطبيق النانو ثنائى أكسيد السيليكون بإستخدام الصبغة المباشرة , تم تقييم فاعلية المعالجة باستخدام الاختبارات القياسية وتأثيرات التجهيز لبعض خواص النسيج العامة كالوزن والسمك وقوة الشد والإستطالة ونفاذية الهواء والتحليل الحراري الوزني وعامل الحماية من الأشعة فوق البنفسجية واختبار البكتريا وزاوية التماس والثبات, و تم تحقيق

الخصائص فضلا عن متانة المعالجات ,وتم الحصول على أفضل النتائج من خلال تطبيق تقنية (غمر- تجفيف - تثبيت حرارى) لأعلى تركيز للنانو ثنائى أكسيد السيليكون على القماش القطن المنسوج ليعطى قماش متعدد الخصائص .

الكلمات المفتاحية :
ثنائى أكسيد السيليكون – مضاد للبكتريا – الحماية من الاشعة فوق البنفسجية – الأقمشة القطنية – خصائص متعددة الوظائف .

Aim of work

The main goal of the current research is using silicon dioxide for proper finishing formulation for functionalization of cotton fabric to enhance its properties.

1. Introduction

Application of nanotechnology in textile wet processing as a useful emerging tool for upgrading the product quality, improving the performance as well as increasing added value of textiles made from natural and/or synthetic fibers, taking into consideration the environmental concerns, is growing fast. (Nabil A. Ibrahim 2018)

Fibers are the fundamental building blocks of all products defined as a textile, regardless of application or construction (Cassidy and Goswami 2017). Choosing the right fabric for a textile product means matching the aesthetic and functional properties of fabric to the type of product being made (Lawler and Wilson 2002).

Natural fibers have been used to make textiles since prehistoric times and are still used today. Nowadays, natural fibers including animal (protein) fibers and vegetable (cellulose) fibers make up almost 50% of the textile fibers produced annually in the world. (Sinclair 2015) Generally, the term “Natural vegetable fibers” is used for all types of fibers coming from plant materials produced as a result of photosynthesis (Kalia, Kaith and Kaur 2011).

Also called cellulosic fibers, because they are composed of a woody, vegetable substance called cellulose. Plant fibers include cotton fibers from the cotton plant; hemp, from the stem of the hemp plant; and sisal, from the leaf of the agave plant. (Coward 2002). Cotton is the most important natural textile fiber in the world, used to produce apparel, home furnishings, and industrial products (Wakelyn, Bertoniere and French 2006). Cotton fibers are used to produce 40 per cent of the world’s textiles. Its enduring popularity is its extreme versatility; it can be woven or knitted into a variety of weights (Udale 2008).

Recently a great attention has been focused on functionalization of textiles to impart novel properties such as antibacterial efficiency and ultraviolet protection (UPF) using natural products to impart textile-users protection and safety as well as to complete in the tough global market place. (E. M. R. Elzairy 2017) (Nabil A Ibrahim 2017).

The development of anti-bacterial textiles has been one of the most active and important research areas in recent years, containing activities in the discovery and applications of new anti-bacterial agents, new functional fibers, novel chemical finishes, and nanotechnology (Sun 2016).

Due to their large surface area and ability to maintain moisture, textiles are known as being conducive to microorganisms’ growth, such as bacteria and fungi, which can be found almost everywhere and are able to quickly multiply, depending on the moisture, nutrients and temperature levels (Gao and Cranston 2008).

In order to enhance an anti-bacterial ability to textiles, different approaches have been studied, which can be mainly divided into the inclusion of anti-bacterial compounds in the polymeric fibers that can leach from the polymeric matrix, the grafting of certain moieties onto the polymer surface or the physical modification of the fibers' surface (Simoncic and Tomsic 2010).

Special attention has been focused recently on the ultraviolet (UV) transmission of textile because of the growing demand in the marketplace for lightweight apparel that offers to human's protection from UV radiation (UVR) (Wei 2009).

The ultraviolet radiation (UVR) band consists of three regions: UV-A (320 to 400 nm), UV-B (290 to 320 nm), and UV-C (100 to 290 nm). UV-C is totally absorbed by the atmosphere and does not reach the earth. UV-A causes little visible reaction on the skin but has been shown to decrease the immunological response of skin cells. UV-B is most responsible for the development of skin cancers (Capjack, et al. 1994).

The application of nano particles to textile materials has been on going several studies, aimed at producing finished fabrics with different functional performances. These ingredients are safe and non-toxic and chemically stable under exposure to high temperature. (Rahman and Manickam 2015).

The development of super-hydrophobic has been designed by many systems and uses some of new Nano technologies. Hydrophobicity has gained much scientific and industrial attention because of applications in water repellency, self-cleaning, friction reduction, anti-fouling, etc. Super-hydrophobic surfaces (Song and Rojas 2013).

Super hydrophobic surfaces, on which contact angles are more than 150° and sliding angles are less than 10°, exhibit strong water repellence and possess self-cleaning, anti-adhesive, and anti-contamination functions. Manufacture of a superhydrophobic surface needs the combination of micro and nanoscale hierarchical structures with low surface energy materials (Chen, et al. 2015).

Cotton is possibly the most common natural fiber in textile industry. For many applications producing a hydrophobic surface on cotton textiles is a major challenge. Most of the synthetic fibers that are usually used in textile industry are mostly hydrophobic. Thus, most of the time, water-repellent finishing is applied on natural fibers (Elsner, Hatch and Wigger-Alberti 2003).

Thermal properties are the properties of materials that change with temperature. Generally, the combination of nanometre-sized inorganic particles into the polymer matrix can improve thermal stability by acting as a superior insulator and mass transport barrier to the volatile products released during decomposition (Zou, Wu and Shen 2008).

Although cotton fabrics have advantages of eco-friendliness, bio-degradability, softness, hygroscopicity and breathability, their inherent flammability limits their applications (Bosco, et al. 2013). In Recent years the application of thermogravimetry (TG), differential scanning calorimetry (DSC) and differential thermal analysis (DTA) to study the combustion and pyrolysis performance of textiles has gained a wide acceptance (Muralidhara and Sreenivasan 2010).

2. Experimental

2.1. Materials

Mill-scoured and bleached woven cotton (100%, 240 g/m^2), knitted cotton "EGYPTIAN COTTON GIZA 86" (100%, 76.7 g/m^2), and knitted cotton "Indian cotton" (100%, 140 g/m^2) were used and supplied from Giza Spinning and Weaving Co. Egypt.

We used SiO_2 NPs (powder) (Sigma Aldrich) [powder, size 10-20 nm particle size (BET), 99.5% trace metals basis], Polyethylene glycol [PEG 1000] (Sisco Research Laboratories, SRL), and textile binder [TUBIFAST AS 4510] (CHT Bezema).

We used Direct dye (Orange 34) (Solophenyl, TGL 182%)(Huntsman) and used as received without further purification.

2.2. Method

2.2.1. The Pad – Dry – Cure

Mill-scoured and bleached woven cotton, knitted cotton (Egyptian Cotton Giza 86), knitted cotton (Indian cotton) fabric were immerged in padding liquor at room temperature for 15 minutes and then passed through laboratory padding mangle, which was running at a speed of 15 rpm with a pressure of 1.75 kg/cm^2 using 2-dip 2-nip padding sequence at pick up 80% expression.

The padded substrate was dried at 110°C for 5 minutes and thermosetting at 160°C temperature for 3 minutes.

This method was used with three different compositions: High Concentration SiO_2, low Concentration SiO_2, and finally high Concentration SiO_2 without PEG.

2.2.2. Exhausting Process

Mill-scoured and bleached woven cotton, knitted cotton (Egyptian Cotton Giza 86), knitted cotton (Indian cotton) fabric were immerged in small liquor ratio (1:10) and adjust PH value up to ~6 with acetic or citric acid. Add corresponding amount of SiO_2 NPs then perform a short run: 5 min at 30°C and heat up at a rate of 1-3°C/min and keep 60 minutes at 70°C.

Add the other compatible textile chemicals after 15-20 min then cool down at rate of 1-3°C/min. finally remove bath liquor and gentle rinsing.

2.2.3. Dyeing Procedure for Direct Dyes

Samples of high concentration SiO_2 were selected to be dyed as they were giving best results for treated samples. So we can test the chemical stability of treatment and its durability.

Temperature in the dye bath (dyestuff - 1% on the weight of fabric, Glauber's salt - 15 g/dm3, liquor ratio - 1:15) was raised from 40°C to 95°C at 1°C/min, maintained for 45 min, then decreased to 80°C and maintained at the final temperature for 20 min. Then rinse, 2 x 10 min and air dried.

2.3. Samples Coding

Table 1 Coding for Treatment Samples

Treatment	Code
Blank	B
SiO_2 High Concentration	SH
SiO_2 Low Concentration	SL
SiO_2 Without PEG	SP
SiO_2 with Exhaust Method	SE
SiO_2 High Concentration with Dyeing	SD
SiO_2 High Concentration after washing	SW

2.4. Testing and Analysis

- The determination of weight is done according to ASTM D3776/ D3376M (Standard Test Methods for Mass per unit area (weight) of fabric)
- The determination of thickness is done according to ASTM D1777, ISO 3616/5084/9073.
- The determination of tensile strength is done according to EN ISO 13934-1999 (Maximum Force and Elongation – Stripe Method).
- Air permeability was tested using air permeability tester (21443, FRANK) according to ASTM D737-18.
- Thermogravimetric analysis was tested according to ASTM E1131 (ASTM E1131 - 08 2018) and ISO 11358.
- UPF was measured using UV-VIS double beam spectrophotometer (Perkin-Elmer, Lambda 35, diffuse transmission technique) according to the American standard ASTM D6604-2000 and AATCC test method AATCC 183-2000.
- Anti-bacterial was tested according to disc diffusion method for filamentous fungi tested by using approved standard method (M38–A) developed by the National Committee for Clinical Laboratory Standards (**NCCLS**).
- Contact angle was tested according to ASTM D 5725: Standard Test Method for Surface Wettability and Absorbency of Sheeted Materials Using an Automated Contact Angle Tester.
- The color fastness to washing was determined according to International Standardization Organization (ISO) 105-C01. The test samples were tested for washing fastness at 60±2°C for 45 minutes at 42 rpm
- Fastness to both alkaline and acidic artificial perspiration was evaluated for the test samples according to (ISO) 105-C04 by using the Perspirometer of type M231, UK
- The light fastness to washing was determined according to International Standardization Organization (ISO) 105-B02.

3. Results and Discussion

3.1. Physical Properties Testing

3.1.1. Fabric Weight

There was a slight increase on weight of fabrics after different treatment applications due to the absorbance of chemicals while woven fabric was the highest due to its fabric structure, and a slight more increase when dyed as the fabric also absorbs the dye.

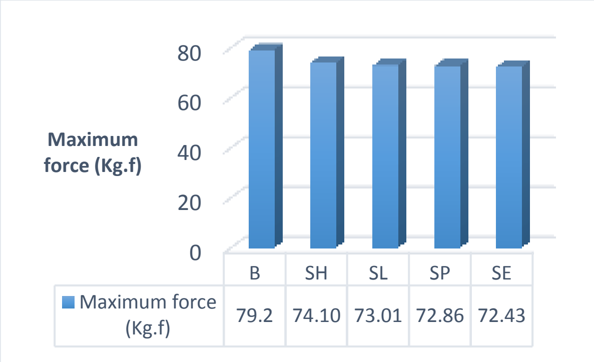
3.1.2. Fabric Thickness

There was a slight increase on thickness of fabrics after different treatment applications, as the different treatment applications produce very thin coatings on the fabric surface. While a slight more increase when dyed as the fabric also absorbs the dye

3.2. Mechanical Properties testing

3.2.1. Textile Tensile Strength and Elongation

3.2.1.1. Tensile Strength



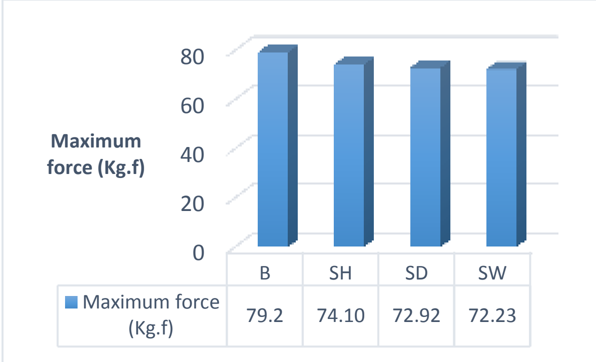
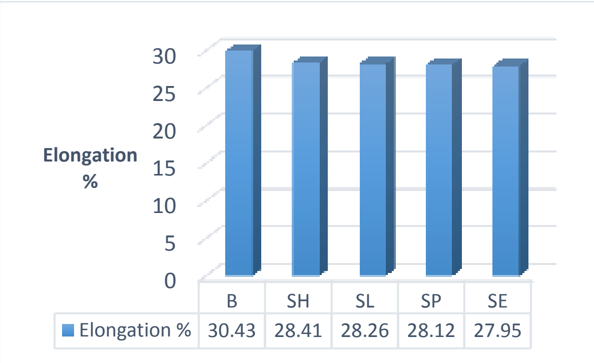


Figure 1 Effect of The Different Treatment Applications on Tensile Strength for Mill-scoured and Bleached Woven Cotton Fabric

3.2.1.2. Elongation at Break



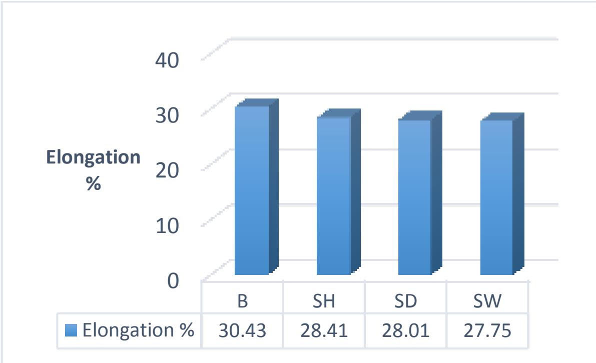
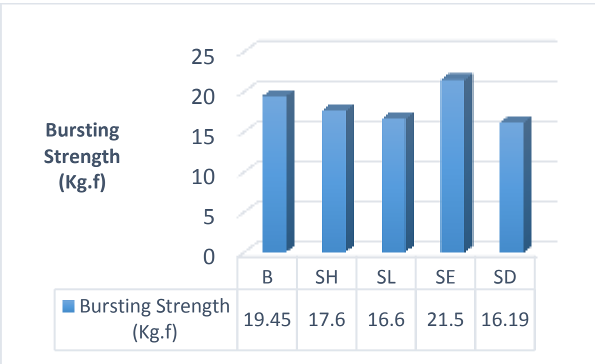


Figure 2 Effect of The Different Treatment Applications on Elongation at Break % for Mill-scoured and Bleached Woven Cotton Fabric

3.2.1.3. Bursting Strength



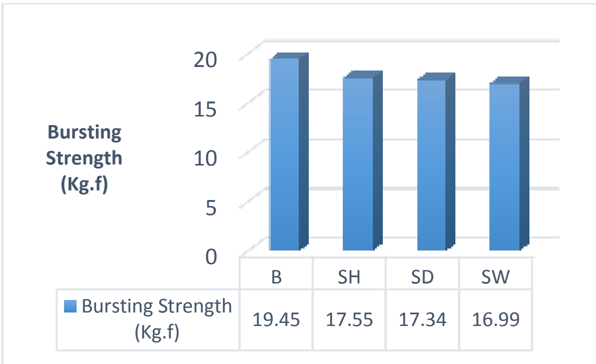


Figure 3 Effect of The Different Treatment Applications on Bursting Strength for Knitted Cotton Fabric (Egyptian Cotton Giza 86)

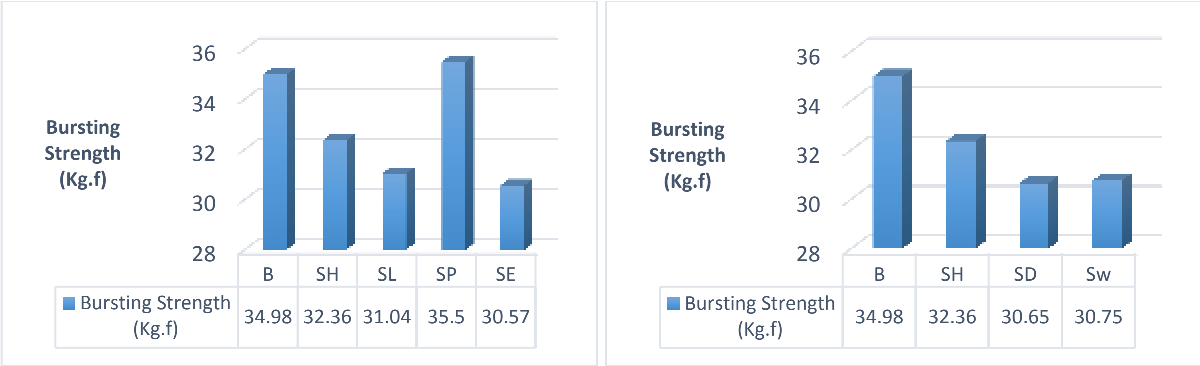


Figure 4 Effect of The Different Treatment Applications on Bursting Strength for Knitted Cotton Fabric (Indian Cotton)

There was a slight decrease on tensile strength and elongation of fabrics after different treatment applications, and it has been noticed that the decreasing ratio for woven fabric was 9-10% but in the two knitted fabrics were 10-15%; and thus because the nature of fabric structure of knitted fabric which is weaker than the woven fabric.

Also after testing the effect of dyeing and washing it was found a slight difference occurred.

The decreasing values is accepted and wouldn't affect the properties of fabric and the treatment doesn't have negative effect on fabric.

3.3. Comfort Properties Testing

3.3.1. Air Permeability

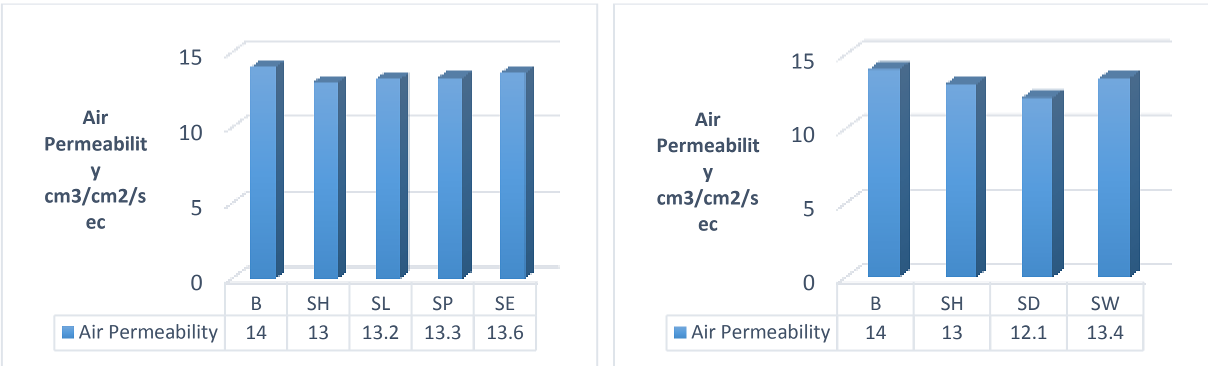


Figure 5 Effect of The Different Treatment Applications on Air Permeability for Mill-scoured and Bleached Woven Cotton Fabric

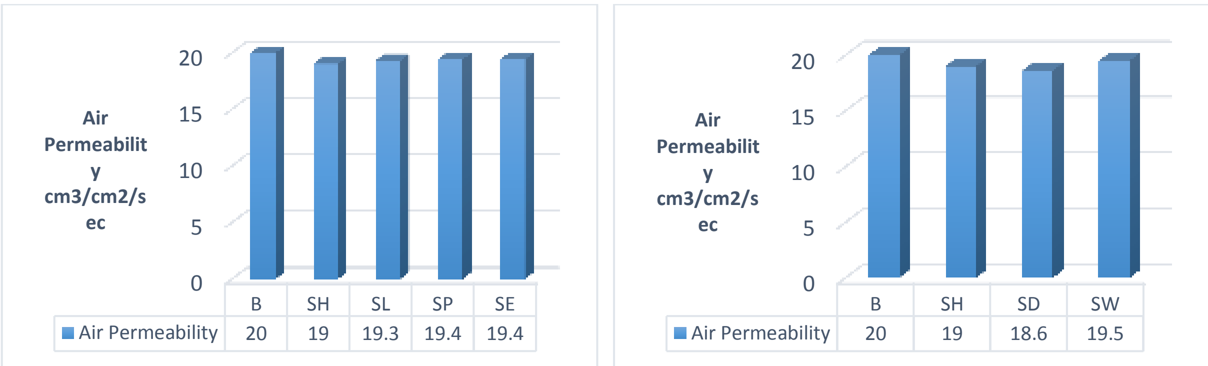


Figure 6 Effect of The Different Treatment Applications on Air Permeability for Knitted Cotton Fabric (Egyptian Cotton Giza 86)

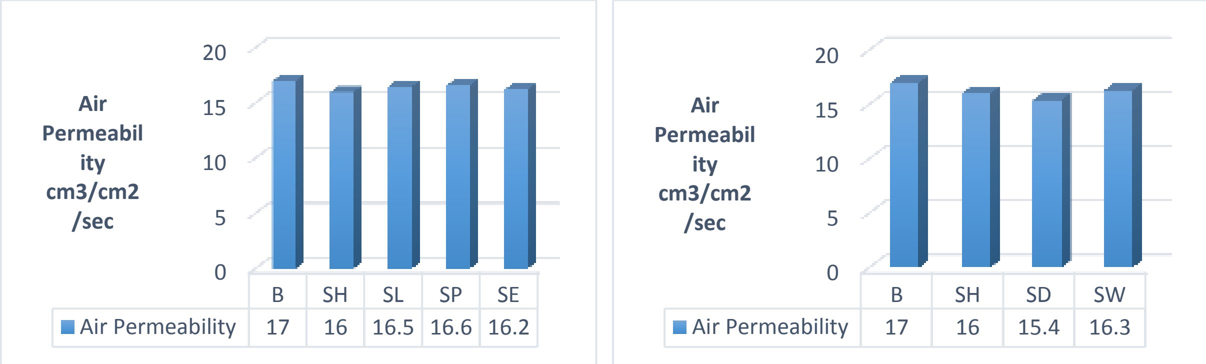


Figure 7 Effect of The Different Treatment Applications on Air Permeability For Knitted Cotton Fabric (Indian Cotton)

There was a slight decrease in air permeability results in the different fabrics from the blank samples and the different treatment applications, and this occurs because the NPs got into the pores of fabric during different treatment application.

This indicates a good treatment occurred and the NPs got successfully into the fabrics, and this slight difference does not affect the fabric comfort.

The results of dyeing and washing compared to the blank sample have also a slight decrease with less decrease for the washed sample compared with the treated and dyed sample because of the washing effect on both dyeing and treatment.

3.4. Thermo Comfort Properties Testing

3.4.1. Effect on Thermal Gravimetric Analysis (TGA)

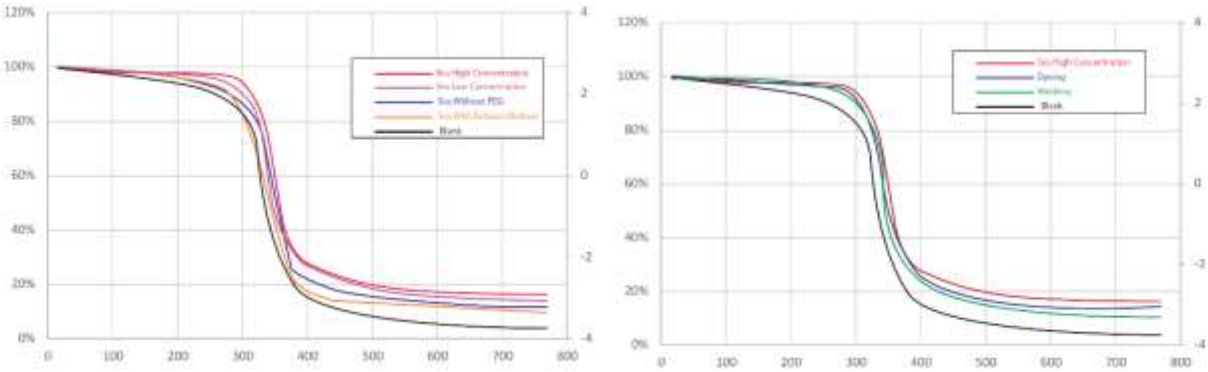


Figure 8 TGA Effect of The Different Treatment Applications on Mill-Scoured and Bleached Woven Cotton Fabric

The TGA effect for Mill-scoured and bleached woven cotton fabric shows weight loss in fabric until 100°C is due to water evaporation while is thermally stable until 270°C. Sharp decomposition stage between 270°C to 380°C was very fast and significant. At temperature 380°C - 600°C the loss is mainly due to pyrolysis of the char rest. Where blank sample sharp decomposition loss was 68.63% and started at 230°C compared to best treatment application result of SiO_2 high concentration treatment where loss was 55.18% started at 300°C, and this indicates the treatment was successful and improved the thermal stability of the treated woven cotton fabric much higher that of the untreated woven cotton fabric.

When washing and dyeing was applied there was a slight decrease compared to treated sample while washing was more affected.

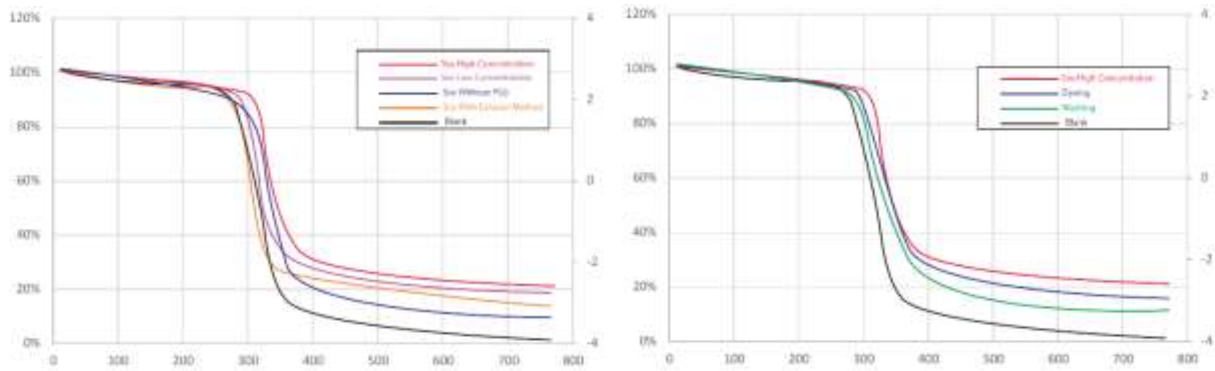


Figure 9 TGA Effect of The Different Treatment Applications on Knitted Cotton Fabric (Egyptian Cotton Giza 86)

The TGA effect for knitted cotton fabric (Egyptian Cotton Giza 86) shows weight loss in fabric until 100°C is due to water evaporation while is thermally stable until 290°C. Sharp decomposition stage between 290°C to 370°C was very fast and significant. At temperature 370°C - 600°C the loss is mainly due to pyrolysis of the char rest. Where blank sample sharp decomposition loss was 70.74% and started at 260°C compared to best treatment application result of SiO_2 high concentration treatment where loss was 54.48% started at 310°C, and this indicates the treatment was successful and improved the thermal stability of the treated Egyptian cotton (Giza 86) fabric much higher that of the untreated Egyptian cotton (Giza 86) cotton fabric.

When washing and dyeing was applied there was a slight decrease compared to treated sample while washing was more affected.

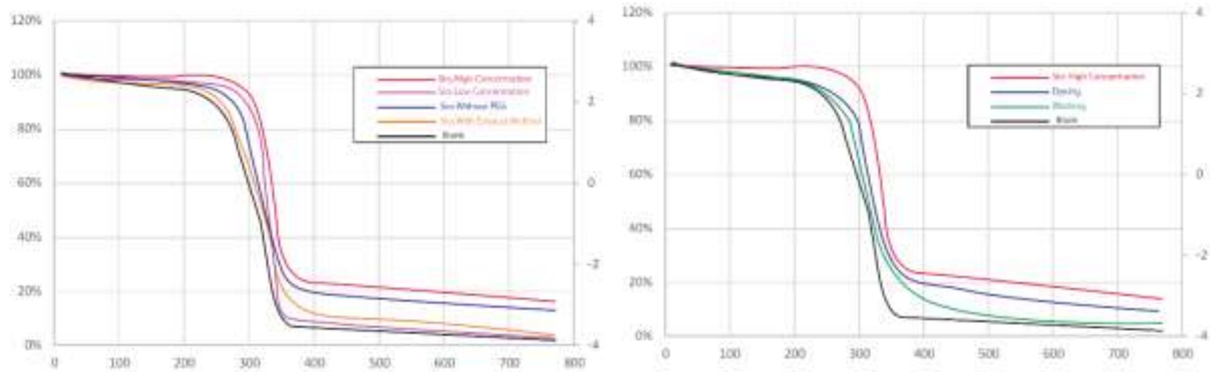


Figure 10 TGA Effect of The Different Treatment Applications on Knitted Cotton Fabric (Indian Cotton)

The TGA effect for knitted cotton fabric (Indian Cotton) shows weight loss in fabric until 110°C is due to water evaporation while is thermally stable until 250°C. Sharp decomposition stage between 250°C to 350°C was very fast and significant. At temperature 350°C –580°C the loss is mainly due to pyrolysis of the char rest. Where blank sample sharp decomposition loss was 70.74% and started at 260°C compared to best treatment application result of SiO_2 high concentration treatment where loss was 54.48% started at 310°C, and this indicates the treatment was successful and improved the thermal stability of the treated Indian cotton fabric much higher that of the untreated Indian cotton fabric.

When washing and dyeing was applied there was a slight decrease compared to treated sample while washing was more affected.

3.5. Functional Properties Testing

3.5.1. Ultraviolet Protection Factor

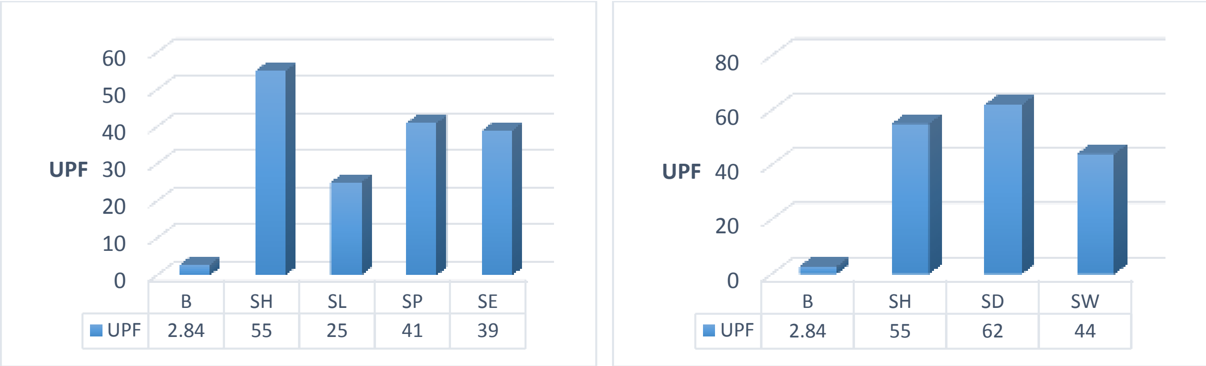


Figure 11 Effect of The Different Treatment Applications on Ultraviolet Protection Factor for Mill-Scoured and Bleached Woven Cotton Fabric

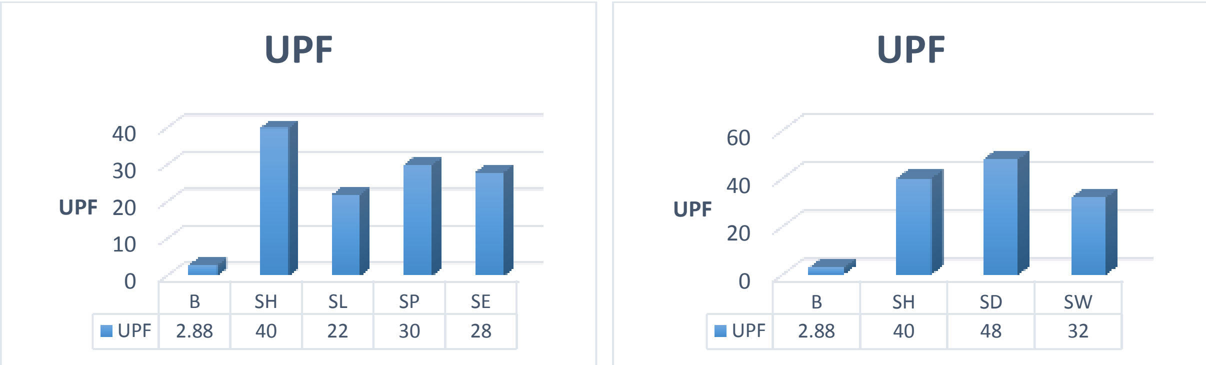


Figure 12 Effect of The Different Treatment Applications on Ultraviolet Protection Factor for Knitted Cotton Fabric (Egyptian Cotton Giza 86)

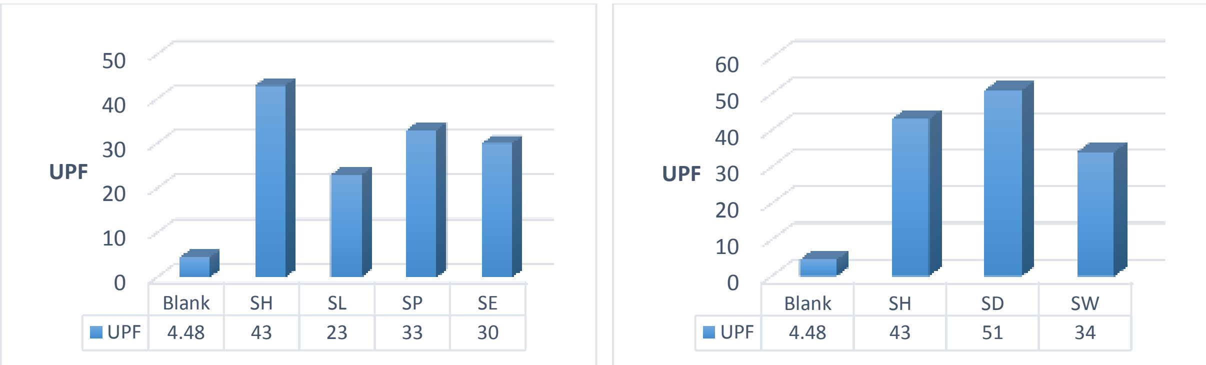


Figure 13 Effect of The Different Treatment Applications on Ultraviolet Protection Factor for Knitted Cotton Fabric (Indian Cotton)

The UPF results got better with treatment; the best UPF result was for SiO_2 high concentration treatment especially for the woven cotton fabric.

While for other treatment methods, padding with SiO_2 was the best then padding with SiO_2 without PEG and the treatment with exhaust method was the lowest. In addition, it was noticed that as we increase the concentration of SiO_2 the UPF results got better.

When dyeing was applied on samples padded with high concentration SiO_2 the UPF results got better also as dyeing increase the UVR absorption characteristics, while washing affects the UPF with a slight decrease which means the treatment was durable.

3.5.2. Anti-bacterial Test

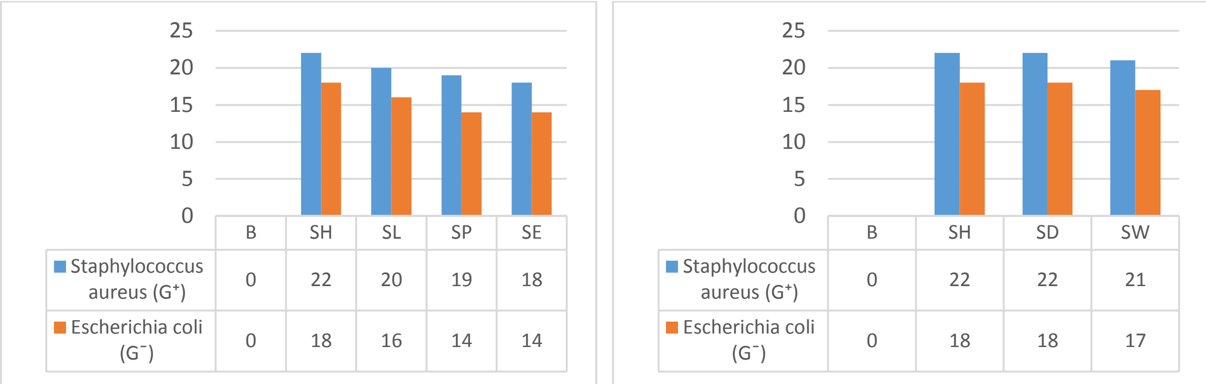


Figure 14 Effect of The Different Treatment Applications on Anti-bacterial for Mill-Scoured and Bleached Woven Cotton Fabric

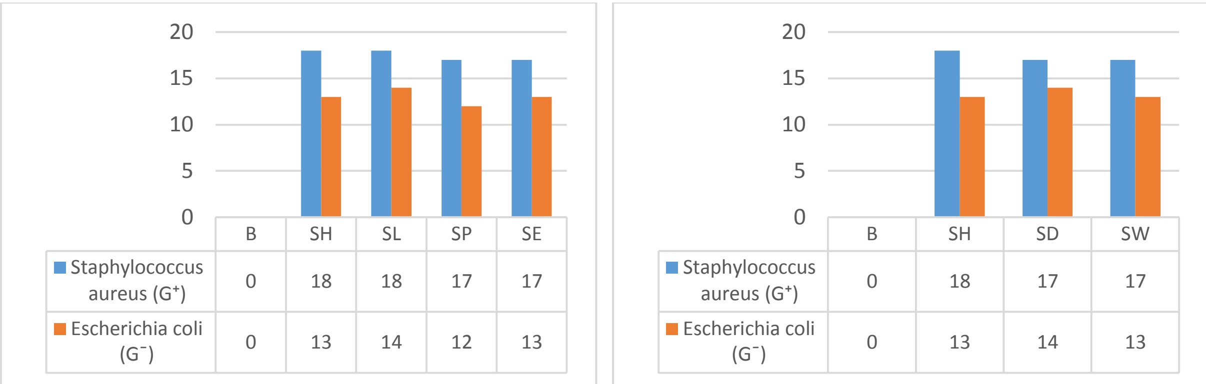


Figure 15 Effect of The Different Treatment Applications on Anti-bacterial for Knitted Cotton Fabric (Egyptian Cotton Giza 86)

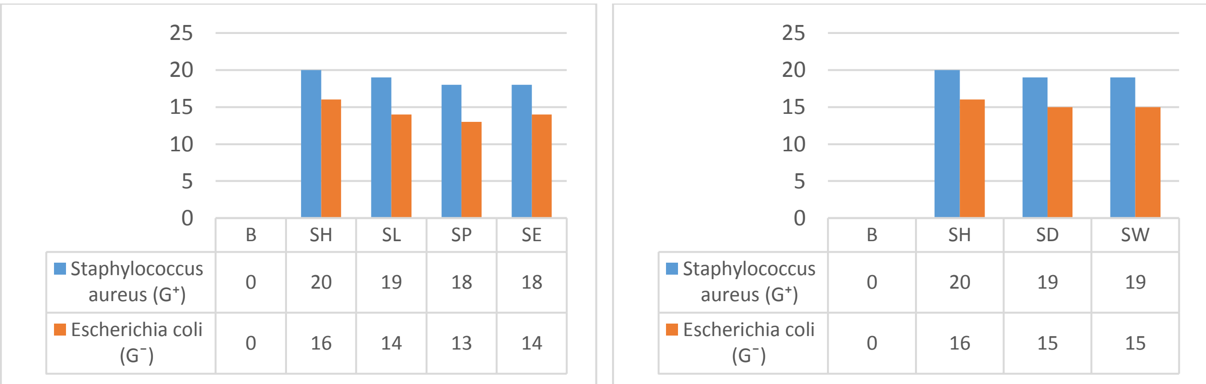


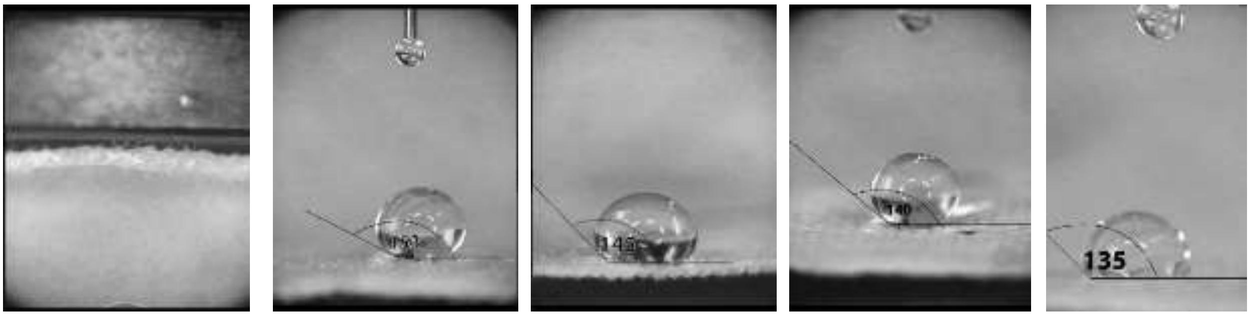
Figure 16 Effect of The Different Treatment Applications on Anti-bacterial for Knitted Cotton Fabric (Indian Cotton)

There was improvement in the treated samples compared to blank samples in all fabrics tested, and this can be noticed through the improvement happened in the inhibition zone as the blank samples was zero and treated samples have a range from 12 to 29 mm.

While the best result was for SiO_2 high concentration treatment samples where inhibition zone ranging from 22 to 16 mm; and this because of SiO_2 effect on anti-bacterial resistant.

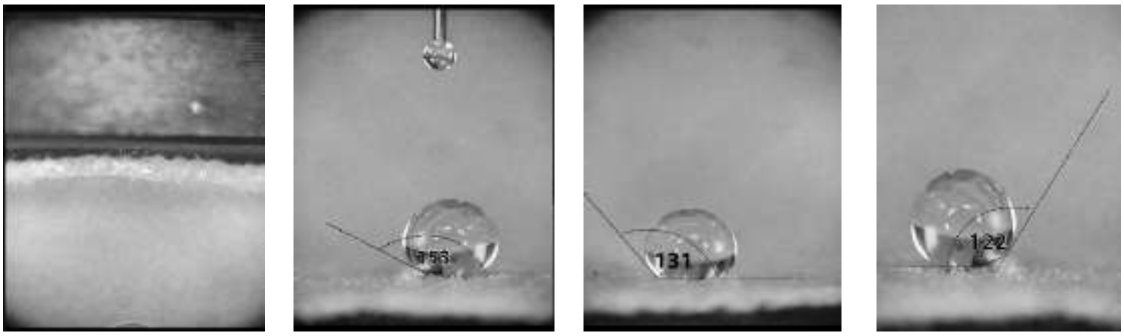
The results of dyeing and washing compared to the blank sample have also improved, and the positive effect of anti-bacterial occurred due to treatment was still present in the dyed and washed samples.

1.1.1. Contact Angle



(a) Blank	(b) SiO_2 High Concentration	(c) SiO_2 Low Concentration	(d) SiO_2 without PEG	(e) SiO_2 with exhaust method
Angle = 0°	Angle = 153°	Angle = 145°	Angle = 140°	Angle = 135°

Figure 17 Effect of The Different Treatment Applications on Contact Angle for Mill-Scoured and Bleached Woven Cotton Fabric

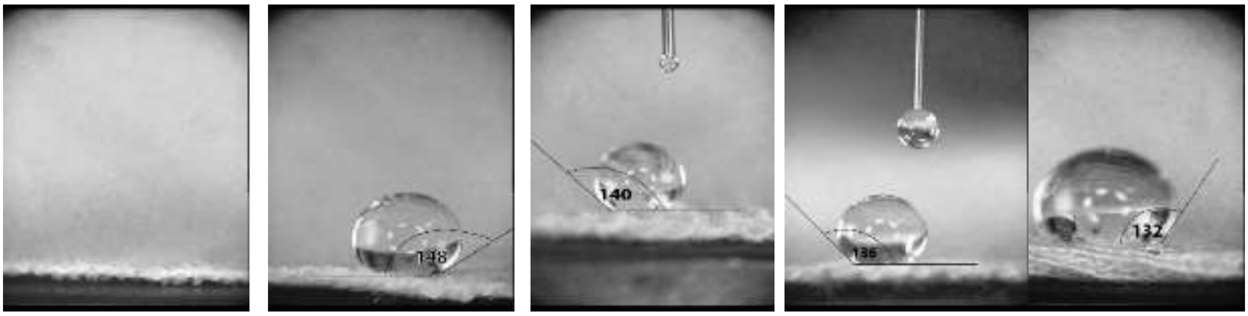


(a) Blank	(b) SiO_2 High Concentration	(c) Dyeing	(d) Washing
Angle = 0°	Angle = 153°	Angle = 131°	Angle = 122°

Figure 18 Effect of Dyeing and Washing on SiO2 High Concentration Treatment on Contact Angle for Mill-Scoured and Bleached Woven Cotton Fabric

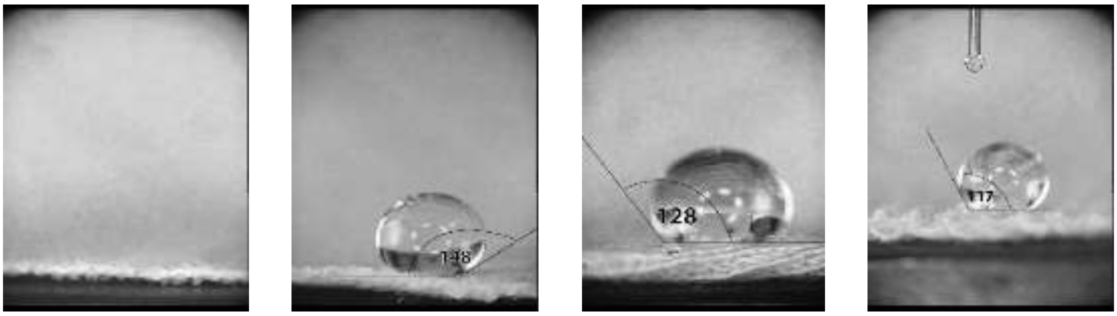
Drops of water form spherical shape on the fabric while cellulosic materials famously known by their super wettability characteristic that indicates hydrophobic effect modification of the fabric after treatment with SiO_2 NPs; that its crystal surface structure was responsible for the hydrophobic effect. Contact angle results recorded indicates that all of samples are above 90° and this proves that the treatment was effective. The highest result was angle 153° of treated sample with high concentration SiO_2 while the lowest result was for the exhaust method with angle 135°.

When washing and dyeing was applied there was a slight decrease compared to treated sample while washing was more affected but still accounts for angle more than 90° that showed high chemical stability of treatment.



(a) Blank	(b) SiO_2 High Concentration	(c) SiO_2 Low Concentration	(d) SiO_2 without PEG	(e) SiO_2 with exhaust method
Angle = 0°	Angle = 148°	Angle = 140°	Angle = 136°	Angle = 132°

Figure 19 Effect of The Different Treatment Applications on Contact Angle for Knitted Cotton Fabric (Giza 86)

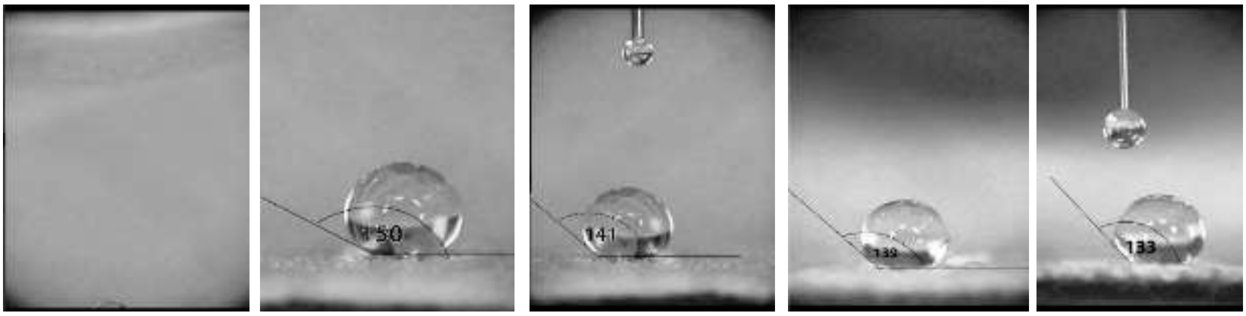


(a) Blank	(b) SiO_2 High Concentration	(c) Dyeing	(d) Washing
Angle = 0°	Angle = 148°	Angle = 128°	Angle = 117°

Figure 20 Effect of Dyeing and Washing on SiO2 High Concentration Treatment on Contact Angle for Knitted Cotton Fabric (Giza 86)

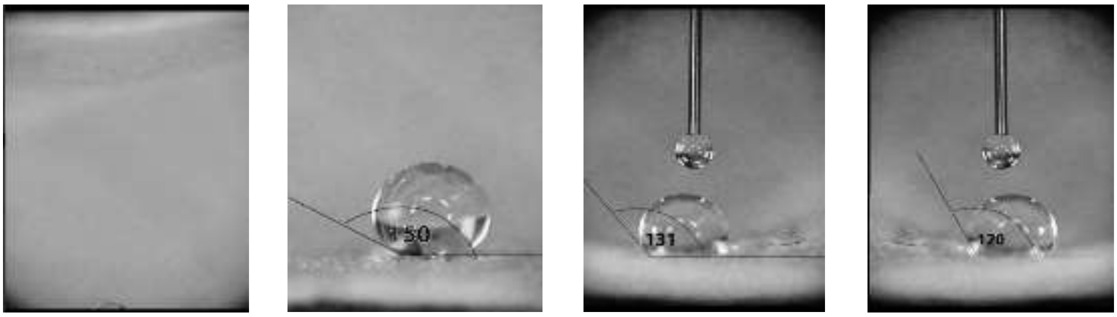
Drops of water form spherical shape on the fabric while cellulosic materials famously known by their super wettability characteristic that indicates hydrophobic effect modification of the fabric after treatment with SiO_2 NPs; that its crystal surface structure was responsible for the hydrophobic effect. Contact angle results recorded indicates that all of samples are above 90° and this proves that the treatment was effective. The highest result was angle 148° of treated sample with high concentration SiO_2 while the lowest result was for the exhaust method with angle 132°.

When washing and dyeing was applied there was a slight decrease compared to treated sample while washing was more affected but still accounts for angle more than 90° that showed high chemical stability of treatment.



(a) Blank	(b) SiO_2 High Concentration	(c) SiO_2 Low Concentration	(d) SiO_2 without PEG	(e) SiO_2 with exhaust method
Angle = 0°	Angle = 150°	Angle = 141°	Angle = 139°	Angle = 133°

Figure 21 Effect of The Different Treatment Applications on Contact Angle for Knitted Cotton Fabric (Indian Cotton)



(a) Blank	(b) SiO_2 High Concentration	(c) Dyeing	(d) Washing
Angle = 0°	Angle = 150°	Angle = 131°	Angle = 120°

Figure 22s Effect of Dyeing and Washing on SiO2 High Concentration Treatment on Contact Angle for Knitted Cotton Fabric (Indian Cotton)

Drops of water form spherical shape on the fabric while cellulosic materials famously known by their super wettability characteristic that indicates hydrophobic effect modification of the fabric after treatment with SiO_2 NPs; that its crystal surface structure was responsible for the hydrophobic effect. Contact angle results recorded indicates that all of samples are above 90° and this proves that the treatment was effective. The highest result was angle 150° of treated sample with high concentration SiO_2 while the lowest result was for the exhaust method with angle 133°.

When washing and dyeing was applied there was a slight decrease compared to treated sample while washing was more affected but still accounts for angle more than 90° that showed high chemical stability of treatment.

1.2. Color Measurements

1.2.1. Effect of Treatment on Fastness Properties

Table 2 Effect of Different Treatment Applications on Fastness Properties for Different Fabrics

<table>
<tr><th rowspan="3">Sample</th><th colspan="3">Washing Fastness</th><th colspan="6">Perspiration Fastness</th><th rowspan="3">Light Fastness</th></tr>
<tr><th rowspan="2">Change</th><th rowspan="2">Cotton</th><th rowspan="2">Wool</th><th colspan="3">Acidic</th><th colspan="3">Alkaline</th></tr>
<tr><th>Change</th><th>Cotton</th><th>Wool</th><th>Change</th><th>Cotton</th><th>Wool</th></tr>
<tr><td>Woven cotton fabric</td><td>4-5</td><td>4-5</td><td>4-5</td><td>3</td><td>3</td><td>3</td><td>4</td><td>4</td><td>3-4</td><td>5</td></tr>
<tr><td>Egyptian Cotton Giza 86</td><td>3-4</td><td>3-4</td><td>3-4</td><td>3</td><td>3</td><td>3</td><td>3-4</td><td>3-4</td><td>3-4</td><td>4-5</td></tr>
<tr><td>Indian Cotton</td><td>3-4</td><td>3-4</td><td>3-4</td><td>3</td><td>3</td><td>3</td><td>3-4</td><td>3-4</td><td>3-4</td><td>4-5</td></tr>
</table>

The effect of using SiO_2 NPs gives better results on the fastness properties of dyed samples, and this means the different treatment applications were successfully applied on the different types of fabrics and it will be stable and durable.

It is noticeable that the washing fastness results for Mill-scoured and bleached woven cotton fabric was better than both knitted fabrics either Giza 86 or Indian cotton.

While in perspiration fastness the alkaline results was better than acidic, and results for Mill-scoured and bleached woven cotton fabric was better than both knitted fabrics either Giza 86 or Indian cotton.

Finally, for the light fastness the results was perfect and a slight fading occurred and results for Mill-scoured and bleached woven cotton fabric was better than both knitted fabrics either Giza 86 or Indian cotton.

2. Conclusion

This study shows that the performance of SiO_2 NPs treatment application on the surface of cotton fabrics. These have successfully achieved the UV-Blocking, hydrophobic, thermal stability, and antibacterial properties. The effect of these treatments were tested for mechanical, physical, thermo-comfort and functional properties of 100% cotton fabrics (Woven fabric, Indian Cotton, and Egyptian Cotton Giza 86), these properties either enhanced after the NPs treatment by the pad-dry-cure process or exhausting process.

After dyeing with direct dye and washing all results proved that, the pad-dry-cure method with high concentration SiO_2 NPs gave the best results especially with the woven fabric. The dyeing process with direct dye have a good impact on the fastness properties of the fabric (washing, perspiration, and light).

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