Research Article

Enhancing Cotton Fabrics Properties by Coating with Zinc Oxide and Carbon Black Nanomaterials and Dyeing with *Terminalia catappa* Leaves Powder

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Abstract
This research focused on thermal stability, color fastness and UV protection properties enhancing cotton fabric coated with ZnO and carbon black nanoparticles and dyed with *Terminalia catappa* leaves powder. The XRD patterns of ZnO nanoparticles contained peaks associated with the hexagonal system, which can be attributed to the structure of ZnO wurtzite. The XRD pattern of carbon black showed a typical amorphous structure. SEM images of the coated cotton surface revealed a scattering of carbon and zinc oxide nanoparticles that increases in size in relation to the amount of carbon and zinc nanoparticles. The ATR-FT-IR spectra of cotton coated with ZnO and carbon revealed the presence of O-H bond, H-C-H bond, C-O-C bond, C-O bond and Zn-O bond. TGA analysis revealed that the cotton coated with zinc oxide and carbon exhibited a greater than 100 °C heat resistance. TGA analysis of cotton coated with CZ4 nanoparticles at 352 °C revealed a weight loss of 70.61%, whereas uncoated cotton lost 85.96 percent of its weight at 358 °C. Light fastness and washing fastness properties of cotton coated with zinc oxide and carbon nanoparticles were 4–5 (good to very good). The FE-SEM and EDS elemental analyses were used to confirm residual elements affected by the excellent UV protective functions of the coated cotton. Cotton fabrics coated with Zn3 and CZn4 are the optimal condition for enhancing the thermal stability, washability, and UV protection of dyed cotton. After 30 wash cycles, the EDS analysis revealed that the cotton fabrics coated with Zn3 and CZn4 retained their durability, with Zn element concentrations of 66.62 (%W) and 67.60 (%W), respectively. The coated cotton significantly outperforms uncoated cotton in terms of thermal stability, color fastness, UV blocking, tensile strength, and air permeability. As the results of this research established; the optimal dyeing protocol for cotton to obtain the desired textile properties.

Keywords: Cotton, Zinc oxide, Carbon black, *Terminalia catappa* leaves, UV protection, Color fastness

1 Introduction

Terminalia catappa is well known as tropical almond [1] and easily found in the local region of Thailand. The leaves of *Terminalia catappa* only become waste. The plant contains a variety of chemical constituents, such as triterpenoids, flavonoids, gallic acid, and hydrolyzed tannins as major components [2], [3]. The leaves contain several flavonoids (kaempferol or quercetin), several tannins (punicalin, punicalagin, or tercatin), saponins, and phytosterols [4]. Its leaf extract exhibits the following properties: antioxidant [5], antidiabetic [6], anticancer [7], anti-inflammatory [2], antimicrobial (flavones and flavanols) [8], anti-parasitic [9], and inhibitory effect on *Shewanella* spp. growth [10]. *Terminalia catappa* leaves could be effective in making folk medicinal cream used for skin protection and contain phytochemicals [1]. The yellow leaves of *Terminalia catappa* are rich in tannin components [11]. One of the benefits of natural tannins produced by the *Terminalia catappa* leaf in water is that they can be used as a source of natural dye on both silk and cotton. Because it is rich in tannic acid, the extracts exhibit good chelating properties. Natural dyes rich in tannin extracted from *Terminalia cattapa* leaves can be used for textile materials [12]. As reported, cotton was immersed in tannin solution and the color was raised using three different fixer solutions, such as alum $(Al_2(SO_4)_3$, CaO, and $FeSO_4$. They found that the alum fixer exhibited optimum result for color fastness with a rating of 4–5 (good). The chemical constituents of colorant from *Terminalia cattapa* leaves through characterization of the colorant extract which can lead to the formulation of structural formulas. Consequently, they also reported three types of dye compounds in the *Terminalia cattapa* leaf extract as anthraquinone, naphthaquinone, and indigoid dyes [13]. Natural dye from the waste leaves of *Terminalia cattapa* applied on silk and cotton yarns have achieved different color shades with isolated coloring materials using different mordants [14]. Various colors were obtained which varied from yellow to grey and black. These colors mainly depended on the mordant used. Different shades on silk fabrics with good to excellent fastness properties have also been obtained [4].

Cotton is a natural fiber that consists of cellulose. It is highly popular because of its absorbing nature, its ability to quickly wick away moisture, and is comfortable to wear. Recently, modification of cotton fabrics with nanomaterials as TiO_2, ZnO, chitosan, and carbon was studied in depth to enhance its physical properties, such as antibacterial, UV-blocking, self-cleaning, photocatalytic activity, and flame retardant properties. ZnO is one of the nanomaterials with excellent UV absorption, photocatalytic activity, antimicrobial, self-cleaning properties, and photo-oxidizing ability against chemical and biological species [15]–[17]. Carbon nanomaterials such as multi-walled carbon nanotube, nanographite, single-walled carbon nanotube, fullerene, and single-walled carbon nanohorn are extensively investigated due to their potential applications for improving textiles properties [16], [18]. Bharath *et al.* have coated multi-walled carbon nanotube (MWCNT) on rough surfaces of cotton fabrics by simple dip and dry technique [19]. The coated MWCNT formed interconnecting network on cotton fibers and enhanced its electronic properties. The ZnO-BTCA-CNT-coated cotton fabric improved antibacterial activity as reported by Yazhini *et al.* [18]. The carbon nanotube made the cotton fabric flame-retardant, water-repellent, ultraviolet-resistant, and conductive multifunctional fabric with a UV resistance represented by the UPF value of 121 [20], [21].

Carbon black consists of amorphous partial materials that form spherical particles or similar spherical particles that combine to form tight or loose clumping of particles and often merge into larger cubes. Particles have an average diameter of 80–500 nm and an average primary particle diameter of 11–95 nm with three nonmetric dimensions. Carbon black is now widely used in industrial applications such as pigments and reinforcement for the tire industry [22]. Carbon black is also used as black color pigments in plastics, paints, and inks, as ultraviolet (UV) stabilizers in polymers to avoid their degradation under the influence of visible and UV light [23]. These properties could be the result of the particle's size and its interaction with light. Additionally, carbon black has a high absorption capacity for ultraviolet light. Thus, incorporating carbon black into other materials protects them from ultraviolet degradation. Graphene oxide (GO) nanostructures modified cotton surface showed that GO-loaded cotton fabrics have enhanced thermal stability, antibacterial activity, and photocatalytic activity [24]–[27] compared to the bare cotton fabrics [28]. The proposed mechanism for the cotton fabric coated ZnO and carbon black nanoparticles dyed with *Terminalia catappa* leaf powder is shown in Figure 1. Succinic acid was used as a cross-link so that its carboxylic group (-COOH) could be bonded with a hydroxyl group (-OH) of cellulose and the other carboxylic group forms an ionic bond with ZnO. Cotton fibers are cellulose with a dihydroxyl group at the surface; therefore, they are hydrophilic materials that can form strong hydrogen bonds between fibers and cross-linked substances. The carboxylic group forms a three-dimensional structure in the presence of hydrophilic cellulose. This creation of nanocomposite material corresponds with antibacterial properties and UV resistance [15], [29]. The carboxylic group of

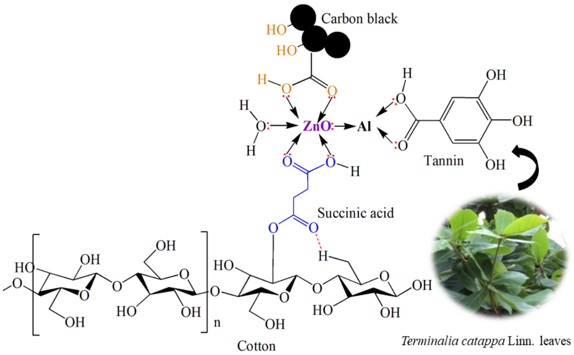

Figure 1: Proposed mechanism for the cotton fabric coated with ZnO and carbon black nanoparticles dyed with *Terminalia catappa* leaves powder.

carbon black also can chelate with Zn^{2+} ions from ZnO which is widely used in the field of adsorption [30]. The ionic radius of Zn^{2+} is 0.60 Å and has high groups that can cause nucleation and growth of inorganic substances as ZnO on an electronegative surface with enthalpy of hydration of –2044 kJ mol^{-1} [31]. ZnO is able to coordinate with lone pair electrons of O^{2-} from water molecules, which is helpful for ZnO stability of 6 coordination complexes after the fabric is dyed. Thus, the present work focuses on coated cotton fabric with ZnO and carbon black nanoparticles dyed with *Terminalia catappa* leaves powder to allow cotton fabrics to have high thermal stability and UV protective functions, and very good light fastness and washing fastness properties.

2 Materials and Methods

2.1 *Materials and cotton preparation*

Nano ZnO was provided from Infarmat Product Company #30N-0801 Nano ZnO Powder, 99.7%, 30 nm, m.p. 1980 °C, density 5.6 g/cm^3. Carbon black nanoparticles, with mean particle size 43 nm, iodine number (ASTM D1510) 43 mg/g, N2SA (ASTM D3037) 42 mg/g, absorption DBP (ASTM D2414) 121 mg/100 g and ASTM Classification (D1765) product code N550 was provided by Nanorabberchem company.

Sodium hypophosphate (NaH_2PO_4) as a catalyst and succinic acid $(CH_2COOH)_2$ as a cross-link agent were purchased from Ajax Finechem, Australia, (AR grade). Natural cotton handicraft fabrics were bought from the local market in Ubon Ratchathani province. Plain-weave cotton fabrics (from 100 cm weft length and 100 cm warp length) were cleaned by using nonionic detergent at room temperature for 24 h, then the cotton was rinsed and air-dried.

2.2 *Cross-link agent preparation*

Succinic acid $(CH_2COOH)_2$ as a cross-link agent (6% wt/wt) in the presence of sodium hypophosphate (NaH_2PO_4) as a catalyst (4% wt/wt) was prepared by weighing 40 g sodium hypophosphate and dissolved in 1,000 mL deionized water. Then, 60 g of succinic acid was mixed with 940 g sodium hypophosphate, stirred, and kept for further experiments.

2.3 *Coated cotton fabrics with cross-link agent*

Cotton fabrics were cut into 10 × 10 cm^2 and accurately weighed, then dipped into deionized water and heated at 80 °C for 1 h to remove wax and contaminants. Then, 100 mL cross-link agent solution was poured into a 250 mL beaker. Cotton samples were immersed in an aqueous solution of cross-link agent for 1 h. Cotton fabrics were dried in an oven at 85 °C for 3 min and then allowed for continuous curing at 180 °C for 2 min. Finally, they were allowed to air-dry at room temperature [32].

2.4 *Coated cotton fabrics with ZnO and carbon black nanoparticles*

Accurate weighing of 1 g (Z1), 2 g (Z2), 3 g (Z3), and 4 g (Z4) ZnO and 0.001 g carbon black (C) nanoparticles was done. Then, 100 mL deionized water was added and stirred with a glass rod. Afterward, the different ZnO and carbon black nanoparticles suspension was sonicated for 1 h. Cotton fabrics coated with cross-link agent were immersed into ZnO and carbon black nanoparticles suspension and were heated in a water bath at 80 °C for 1 h. The coated cotton was cured in an hot air oven at 100 °C for 30 min to fix ZnO and carbon black nanoparticles on the fabric. The cured fabric was sonicated for 10 min to remove the nonbonding reaction of ZnO and carbon black nanoparticles on the cotton fabric and allowed to air-dry at room temperature [32].

2.5 *Characterization of coated cotton*

The morphology of uncoated cotton and cotton coated with ZnO and carbon black nanoparticles was analyzed by using the Scanning electron microscope (SEM), model JSM-6010LV, JEOL, USA. The UV resistance was also confirmed by using the UV-visible spectrophotometer (UV), Lambda 35, Perkin Elmer Company, USA. The thermal property was carried out using a Thermogravimetric analysis (TGA) Mettler Toledo, Model TGA/DSC1, USA instrument with nitrogen as the purging gas in a temperature range of 25–1000 °C at a rate of 10 °C/min. The elemental analysis of ZnO and carbon black nanoparticles coated on cotton and washing fastness for 10, 20, and 30 washed cycles was confirmed by using Energy-dispersive X-ray Spectrometer (EDS) analysis, which is an attachment to the Field emission scanning electron microscope (FESEM-EDS), Carl Zeiss Model Auriga. Germany, Oxford.

2.6 *Dye preparation and cotton fabrics dyed*

50 g of *Terminalia catappa* leaves were weighed into 150 mL, 1 : 3 (M : L) liquor ratios. Then, the mixture was boiled at 100 °C until the water volume was reduced to the ratio of 1 to 3, filtered, dried, and ground as described in previous work [33]. Uncoated cotton and cotton coated with ZnO and carbon black (CZ) nanoparticles were soaked by deionized water for 1 h. 1 g of *Terminalia catappa* leaves dye powder was dissolved into 100 mL deionized water in 250 mL beaker, boiled at 80–100 °C in a static water bath, and added with 1 g of mordant as potassium aluminium sulphate (alum), ferrous sulfate, copper (II) sulfate, and tannic acid. Uncoated cotton and coated cotton with ZnO and carbon black nanoparticles were dyed for 15 min, washed until neutral pH is obtained, and air-dried at room temperature.

2.7 *Physical properties of cotton fabrics characterization*

The crystallinity of the ZnO and carbon black nanoparticles was determined using an X-ray diffractometer, Bruker, Model D8 advance, Germany with Cu Kα (λ = 1.54060 Å) radiation. The diffractograms were obtained in 2θ range from 10 to 80°, 40 kV, 40 mA. Attenuated total reflectance-Fourier transform infrared spectrophotometer (ATR-FT-IR) Model 45321 Spectrum 2000, Perkin Elmer Company, USA, was used to characterize the functional groups of coated cotton samples in the wavenumber range between 4000 and 400 cm^{-1}. The light fastness was performed according to ISO 105-BO2: 1994 (E), washing fastness was tested according to TISI 121, Volume 3: 2009 Method A (1) (40 °C, 30 min). The washing fastness of nanomaterials was tested and washing 10, 20, and 30 times was carried out. The UV resistance was also confirmed by using the UV-visible spectrophotometer, Lambda 35, Perkin Elmer Company, USA.

2.8 *The mechanical properties characterization*

The mechanical properties of cotton coated with ZnO and carbon black nanoparticles, such as tensile strength (N) were measured by a tensile testing machine (Instron model 5566), according to ISO 13934-2:1999(E) standard, condition testing: temperature 20 ± 2 °C, relative humidity 65 ± 4%. The air permeability was evaluated with a M021A air permeability tester. The standard method was used to measure the pressure difference between two surfaces (100 Pa), area testing of 20 cm^2 (ISO 9237: 1995 (E)). The vertical resistance was measured by a static lab tester (Mesdan Lab Code 291 B), air temperature 23 ± 1 °C, relative humidity 25 ± 5%, according to standard testing of BS EN 1149-1: 2006.

3 Results and Discussion

3.1 *Characterization of nanoparticles and coated cotton fabrics*

XRD patterns of ZnO and carbon nanoparticles were shown in Figure 2. The XRD patterns of ZnO nanoparticles exhibited the peaks attributed to the hexagonal system. The pattern of the characteristic peaks at 2θ diffraction angles of about 32°, 34°, 36°, 47°, 57°, 63°, 66°, 68°, 69°, 72°, and 77°, corresponding to the planes 100, 002, 101, 102, 110, 103, 200, 212, 201, 004, and 002, respectively, were clearly observed (JCPDS card no. 36-1451) [34]. All detectable peaks can be indicated to ZnO wurtzite structure. The XRD pattern of carbon black showed a typical amorphous structure with a broad low-intensity peak at around 26°. Figure 3 showed SEM images of

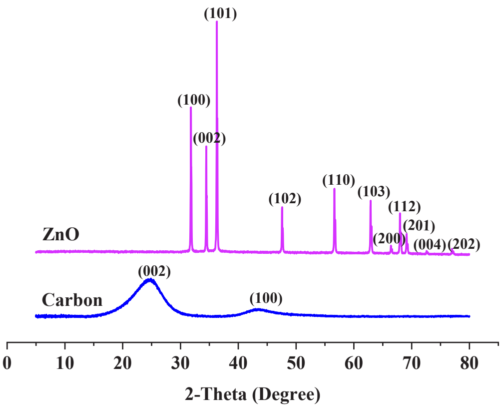

Figure 2: XRD patterns of ZnO and carbon nanoparticles.

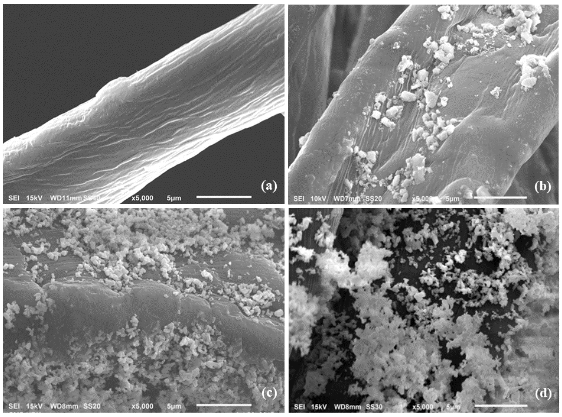

Figure 3: SEM images of (a) uncoated cotton, (b) cotton coated carbon, (c) cotton coated ZnO and (d) cotton coated CZn4 nanoparticles.

uncoated cotton (a), cotton coated carbon 0.001 g (b), cotton coated ZnO (4 g) (c) and cotton coated CZn4 (carbon 0.001g and ZnO 4 g) (d) nanoparticles. The morphology of uncoated cotton is a smooth surface with no nanoparticles adhering to the surface. The coated cotton surface is scattered with carbon and zinc oxide nanoparticles that increase with the increasing amount of the carbon and zinc nanoparticles.

Figure 4 showed ATR-FT-IR spectra vibration of uncoated cotton, cotton coated ZnO, cotton coated ZnO and carbon black nanoparticles. The ATR-FT-IR spectra of cotton coated with ZnO and carbon presented significant changes compared to uncoated cotton fabric. The cotton exhibited bands of 3338 cm^{-1} and 3332 cm^{-1} corresponding to OH stretching vibration, the band at 2896 cm^{-1} was due to CH_2

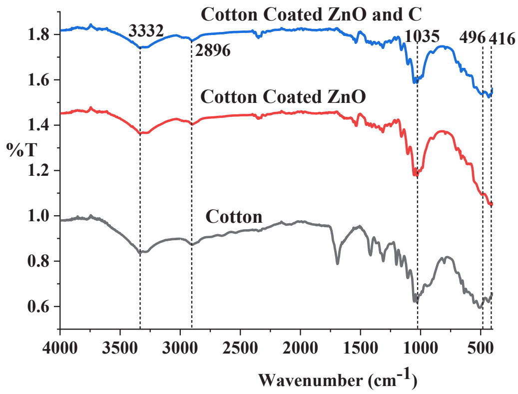

Figure 4: ATR-FT-IR spectra of uncoated cotton, cotton coated ZnO and carbon black nanoparticles.

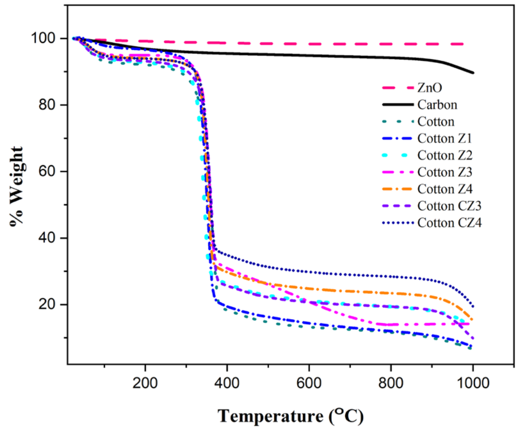

Figure 5: TGA curve of ZnO, carbon, uncoated cotton, cotton coated Z1, cotton coated Z2, cotton coated Z3, cotton coated Z4, cotton coated CZ3, and cotton coated CZ4.

stretching, 1053 cm^{-1} peak was due to C-O-C bridge, and 557 cm^{-1} was attributed to the stretching vibration mode of C-O group. The absorption peaks at around 496 and 416 cm^{-1} were due to Zn-O bonding on coated cotton [15], [35]. The ATR- FT-IR study has shown that ZnO and carbon-coated on cotton fabrics successfully. Figure 5 illustrates the thermal properties of zinc oxide, carbon, uncoated cotton, and cotton coated with Z1, Z2, Z3, Z4, CZ3, and CZ4 nanoparticles. At 358 °C % uncoated cotton weight loss was 85.96% while the weight loss of coated cotton with Z1, Z2, Z3, and Z4 at a temperature range of 340–355 °C was found to be 85.64, 79.26, 77.67, and 74.71 (%), respectively.

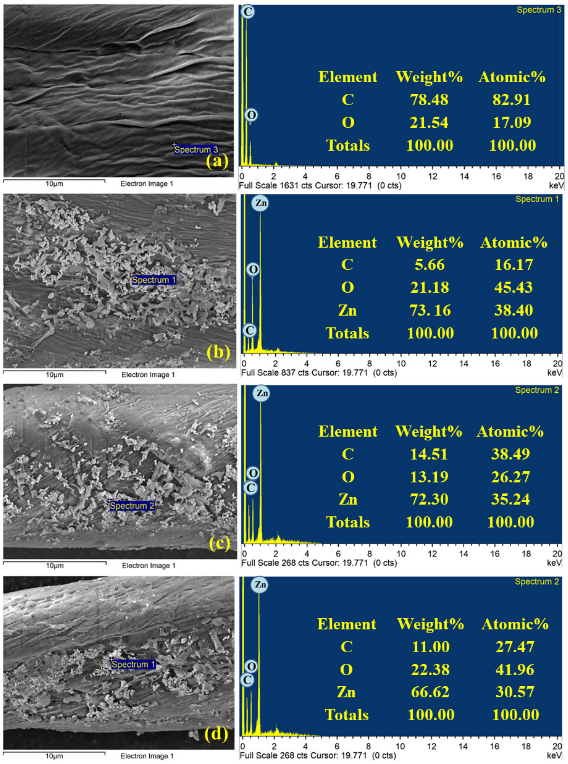

Figure 6: FE-SEM and EDS elemental analysis of (a) untreated cotton, coated cotton fabrics with Zn3 nanoparticles after repeated washing for various cycles (b) 10 washed, (c) 20 washed and (d) 30 washed.

TGA curve of cotton coated with CZ3 and CZ4 nanoparticles at temperatures of 358 and 352 °C showed weight loss of 80.03 and 70.61 (%), respectively. As a result, coated cotton with Z3 and CZ4 samples were chosen for further investigation. Figure 6 shows FE-SEM and EDS elemental composition of untreated cotton and coated cotton fabrics with Zn3 nanoparticles after repeated washing for 10, 20 and 30 washing cycles. The EDS analysis was indicated to highlight the percentage of elements in the sample, showing peaks for carbon, oxygen, and zinc residual elements. The cotton fabrics coated with Zn3 and CZn4 after 10, 20, and 30 washing cycles showed that the Zn content was 73.16, 72.30, and 66.62 (% W), 90.04, 71.43, and 67.60 (% W), respectively (Figure 7). Figure 8 shows the color shade of uncoated cotton (row 1) and cotton coated with CZn4 nanoparticles (row 2) and dyed with *Terminalia catappa* Linn. powder for various mordants as $FeSO_4$, Cu (II) SO_4, and tannin reflected

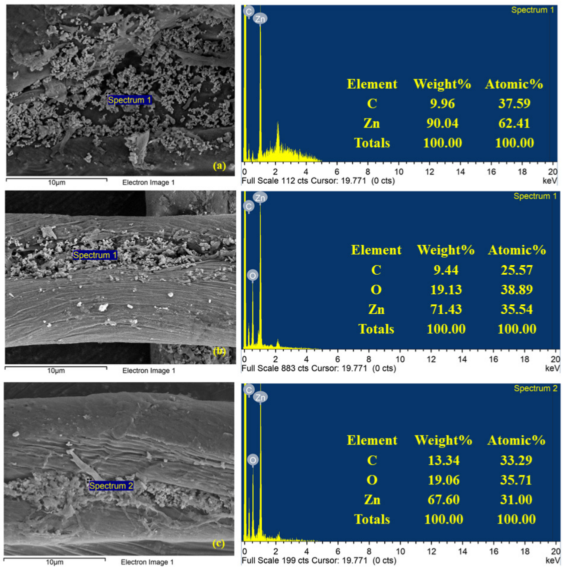

Figure 7: FE-SEM and EDS elemental analysis of CZn4 nanoparticles after repeated washing for various cycles (a) 10 washed, (b) 20 washed and (c) 30 washed.

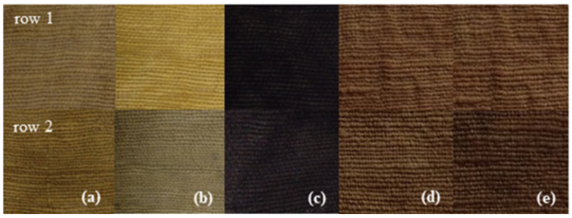

Figure 8: Color shade of uncoated cotton (row 1) and cotton coated with CZn4 nanoparticles (row 2) and dyed with *Terminalia catappa* Linn. powder for various mordants as (a) control, (b) Alum, (c) $FeSO_4$, (d) Cu (II) SO_4, and (e) Tannin.

color shades of dark yellow, light yellow, black, dark brown, and brown, respectively. Coated cotton with CZn4 reflected optimum color shade.

Table 1 showed tensile strength, air permeability, and ultraviolet protection factor (UPF) values of uncoated cotton and cotton fabrics coated with ZnO and carbon black nanoparticles. The result reflected that cotton coated with Zn3 and CZ4 nanoparticles had tensile strength, air permeability, and UPF protection values higher than uncoated cotton. The fabric treated with zinc oxide nanorods demonstrated an excellent UV protective factor (UPF) rating. ZnO nanoparticles were efficient at absorbing and scattering UV radiation

Table 1: Tensile strength, air permeability and UPF protection values of uncoated and cotton fabrics coated ZnO and carbon nanoparticles

Samples	Tensile Strength (N)		Air Permeability ($cm^3/s/cm^2$)	UPF	Protection Category
	Longitudinal Yarn	Streaking of Yarn			
Uncoated cotton	98.06	162.78	100.20	14.53	Low
Cotton coated Z3	112.33	189.13	108.08	44.83	Excellent
Cotton coated CZ4	113.89	165.44	100.74	43.87	Excellent

because they have larger surface areas per unit mass and volume than conventional materials, leading to the increase in the effectiveness of blocking UV radiation [30], [36]. The effectiveness of UV protection of ZnO is strongly depended on its concentration, particle size and shape. Higher ZnO nanoparticles concentration in the cotton substrate also enhances the UV protection properties [29].

Amorphous carbon black has a high surface area to volume ratio and it can absorb color well according to Karimi *et al.* [37]. Coating cotton fabrics with nano titanium dioxide and multi-wall carbon nanotubes (MWCNTs) effectively improve their abrasion resistance and UV blocking capability. Wang *et al.* reported that cotton fabric surface modified with carbon black nanoparticles was a suitable treatment for cotton fabrics to be dyed [38]. Nanoparticles have a greater surface area per unit mass and volume than conventional materials, which increases the effectiveness of UV radiation blocking [36]. Table 2 shows UPF rating and UV protection categories.

Uncoated cotton with longitudinal yarns and yarn streaking exhibited tensile strengths of 98.06 and 162.78 N, respectively. The tensile strength of coated cotton with CZ4 nanoparticles with longitudinal yarn and yarn streaking was 113.89 N and 165.44 N, respectively. The coated sample's tensile strength increased in accordance with previous work by Farouk *et al.* [39]. Tensile strength increased slightly when untreated cotton fabric was treated with ZnO sol/chitosan fabric, from 102.1 ± 0.75 daN to 107.2 ± 1.03 daN. The increase may be attributed to the chitosan molecule penetrating the treated fabrics, imparting a sizing effect and increasing the tensile strength. The air permeability of uncoated cotton was 100.20 $cm^3/s/cm^2$, whereas the air permeability of coated cotton with Zn3 and CZ4 nanoparticles was 108.08 $cm^3/s/cm^2$ and 100.74 $cm^3/s/cm^2$, respectively. Coated cotton improved its air permeability after being treated with ZnO and carbon nanoparticles. The air permeability of textile materials is a key element in determining the breathability of coated fabrics. The air permeability of uncoated cotton fabrics was 41.75 $cm^3/s/cm^2$, whereas cotton treated with zinc oxide in GPTMS-sol (10%) chitosan had a value of 43.08 $cm^3/s/cm^2$ [39].

Table 2: UPF rating and UV protection category [40]

% UV Blocked	UPF Rating	Protection Category
93.3–95.5	15–24	Good
96.0–97.4	25–39	Very good
97.5 to >98	40–50, >50	Excellent

Table 3: Fastness properties of uncoated cotton and coated cotton with ZnO and carbon nanoparticles in various concentrations and *Terminalia catappa* Linn. dyed

Samples	Mordants	Color Fastness	
		Light	Washing
Uncoated cotton	Control	4–5	3–4
	Alum	4–5	3–4
	$FeSO_4$	4–5	3
	Cu (II) SO_4	4–5	3
	Tannin	4–5	3
Cotton coated Z3	Control	4–5	4
	Alum	4–5	4
	$FeSO_4$	4–5	4
	Cu (II) SO_4	4–5	4–5
	Tannin	4–5	4–5
Cotton coated CZ3	Control	4–5	3
	Alum	4–5	4
	$FeSO_4$	4–5	3
	Cu (II) SO_4	4–5	4
	Tannin	4–5	4
Cotton coated CZ4	Control	4–5	4
	Alum	4–5	4
	$FeSO_4$	4–5	4
	Cu (II) SO_4	4–5	4
	Tannin	4–5	4

Table 3 showed color fastness properties of uncoated cotton and coated cotton with ZnO and carbon nanoparticles in various concentrations and *Terminalia catappa* Linn. dye. Light fastness and washing fastness properties of coated cotton were in the level of 4–5 (good to very good). The washing fastness of coated cotton with Z3 and *Terminalia catappa* Linn. dye mordanted with Cu (II) SO_4 and tannin was 4–5 (good to very good). The washing fastness of coated cotton with CZ4 and *Terminalia catappa* Linn. dyed with unmordanted and mordanted Alum, $FeSO_4$, Cu (II) SO_4, and Tannin was 4 (good). This suggests that the optimal condition is coated cotton with CZ4 and *Terminalia catappa* Linn. dyed. From the findings of this investigations, it is possible to deduce mechanically that the carboxylic group (-COOH) of succinic acid could be bonded with a hydroxyl group (-OH) of cellulose and the other carboxylic group forms an ionic bond with ZnO. The carboxylic group of carbon black also can chelate with Zn^{2+} ions from ZnO. ZnO is able to coordinate with lone pair electrons of Al from mordant and dye molecules on the cotton fiber surface, enhancing its durability. ZnO and carbon nanoparticles may be used to enhance the washability of dyed cotton.

4 Conclusions

ZnO and carbon black were successfully coated on cotton fabrics as confirmed by SEM image, ATR-FT-IR and FE-SEM, and EDS elemental analysis result. It was demonstrated that coated cotton with ZnO and carbon nanoparticles could improve thermal stability, washing fastness and UV protection of dyed cotton. Coated cotton with Zn3 and CZ4 nanoparticles had UV protection, tensile strength, and air permeability values higher than uncoated cotton.

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