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Short communication

Synthesis of AgNPs and ZnONPs using tea leaves extract and their utilization to improve dyeability, printability and functionality of cotton and wool fabrics

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ABSTRACT

Finishing is to make textiles more appealing to consumers by attaining a number of objectives like as functionalization, increased quality, and improved performance. Polymers are increasingly being used instead of simple chemicals to improve multiple useful features in most natural and synthetic fibres, such as absorbency, antibacterial protection, and ultraviolet protection. The use of nanotechnology in textile finishing has helped to improve the quality and performance of textile materials by giving new and more sophisticated capabilities to textile substrates as well as boosting current functionality such as durability, antibacterial, and UV protection (UPF). The proclivity of metal nanoparticles, such as AgNPs and ZnONPs, to interact with microbes has affected desired results in textile materials. Tea leaf extract was used to create AgNPs. ZnONPs were calcined from the powder produced by reacting zinc acetate with tea leaf extract. The fabric is coated with polycation (PC) and metal nanoparticles that have been produced.

1. Introduction

Textile finishing is the process of treating textile materials to add new functional characteristics and improve its appearance, texture, or performance [8,26,34,35 40,41,46,47,64,73]. There are two definitions of textile finishing that are widely accepted and used. Textile finishing is defined by one of them as the final stage in the development of textile fabrics when the final attributes of the fabric are developed to complete the fabric's performance by inserting unique functional features. Montazer and Harifi [80] Finishing aims to make textiles more appealing to consumers by achieving a variety of objectives such as functionalization, increased quality, improved performance, and the attractiveness of textile materials. As a result, finishing completes the functionality of the cloth and adds unique features such as the finishing touch [6].

Polymers are increasingly commonly employed instead of basic chemicals to increase various useful qualities at the same time such as flame retardancy [34,39,68,71,76,97,99], water/oil repellence [48,58,79,100], antimicrobial [38,41,72,77,78,84], metal adsorption [22,23,32,86,92], gloss properties [44], rodent repellence [83], anti-Ultravielot protection [56,100], Stimuli-responsiveness temperature, and pH [67,77], heat storage [31,33,40,43] have occurred via a variety of methods, including polymeric material deposition and/or infiltration [4,5,40,74,75,98], shrinkage resistance [89] and nano-coating methods [22,24,30,32,37,40,42,76].

The use of polyethyleneimine for fiber pre-treatment highly encourages the adsorption of coloring dyes in fiber and may be especially beneficial to the textile sector because it significantly increases antibacterial activity. Chitosan, a polycationic amino polysaccharide, has received attention as a unique functional material for textile applications due to its biocompatibility, non-toxicity, and amazing biological capabilities [87].

Because of its favorable properties, it has been used in a range of processes, including textile softening, paper production, shampoo production, and water filtration. [19,30,42,60,61,85] PEI-metal nanoparticles, on the other hand, offer a wide range of applications due to their physicochemical characteristics.

Nanotechnology is the study of small objects having dimensions fewer than 100 nm. Scientists have discovered that minuscule particles and thin films, for example, may have dramatically different properties than larger-scale materials. This allows you to understand and monitor

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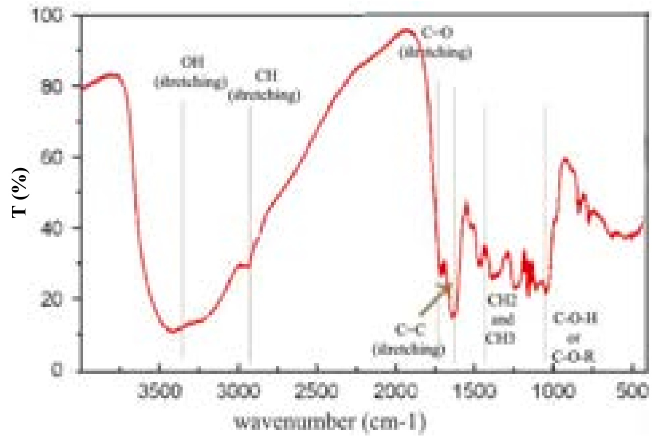

Fig. 1. FT-IR spectrum of tea leaves extract.

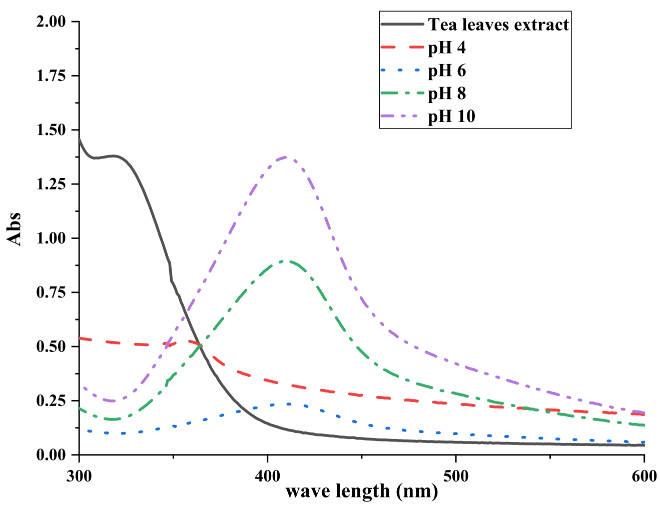

Fig. 2. UV spectra for synthesized AgNPs using tea leaves extracts at different pH.

small structure assemblies by exploiting the unlimited possibilities of building systems, structures, and materials [81].

Metal nanoparticles are employed in a range of applications. Metal nanoparticles in textiles are critical because, depending on the metal type, they impart a variety of beneficial properties to the treated fabric. Silver [18,38,61,77] zinc [68,76] and titanium [17,20,28,55,94] nanoparticles can increase the antibacterial characteristics of treated cloth. The fabric is Ultraviolet protected thanks to the last two metals. Nanoparticles of zinc, titanium and silicon increase the flame retardant qualities of textile textiles. [15,68,76,77,95].

The goal of this study is to create a metal nanoparticle using tea leaf extract and combine it with various polycation polymers to improve the ability of natural fabrics to be dyed and printed while also imparting new properties to these treated fabrics, such as antibacterial and UV protective properties.

2. Experimental

2.1. Materials

Cotton fabric (100%) was purchased from El-Nasr Spinning and Weaving Co., Egypt. Wool fabric (100%) was purchased from Golden-Tex Co., Egypt. Cotton/Wool fabric (30/70) was purchased from Ghazel El-Mahala for Textile Industry Co., Egypt.

Polycation materials namely polyethyleneimine (PEI, water-free Mw

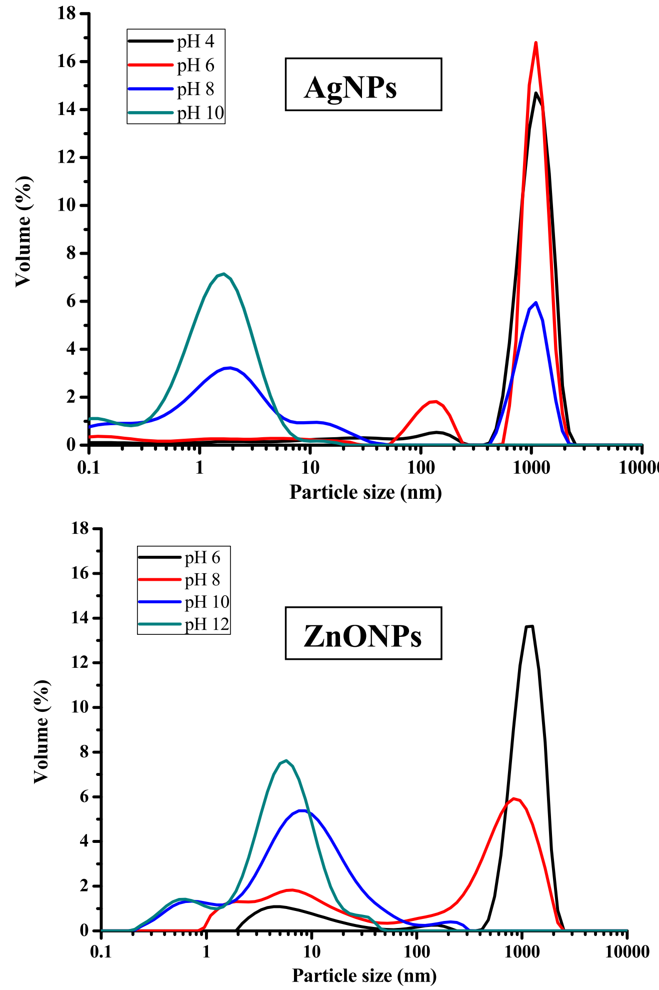

Fig. 3. particle size for synthesized AgNPs and ZnONPs using tea leaves extracts at different pH.

= 25000 g/mol, Aldrich) – chitosan (Ch, low molecular weight, deacetylation 82.9% Dalton, Vanson Inc. Co. USA) were purchased from ACROS Co. Reactive Dye (Syozol red k-3BS) and acid dye (Acid red 27) were supplied from the local market in Egypt.

Dried tea leaves were purchased from the Egyptian local market. Ethanol (95%), acetic acid, sodium carbonate, silver nitrate, and sodium carbonate were provided from Fluka. Zinc acetate was purchased from El Nasr pharmaceutical chemicals Co.

Folin ciocalteau reagent was purchased from Sigma Chemicals Co., and tannic acid, and methanol, were purchased from Merck. All the chemicals and reagents were used as received without purification.

2.2. Methods

2.2.1. Preparation of tea leaves extract

Bioactive chemicals were extracted from plant leaves in previous research [41]. 40 g of dried tea leaves were boiled for 24 h in 1 L of water using the Soxhlet technique. The extracted dyes and bioactive compounds were then collected in a filtrate, which was then used in fabric treatment and metal nanoparticle synthesis. Natural dye concentrations were as follows: 0.5 percent (extraction in double the amount of water), 1% (normal extraction as is), 2% (extraction in half the amount of water), and 3% (extraction in one-third the amount of water). A rotary evaporator was used to concentrate the water extract.

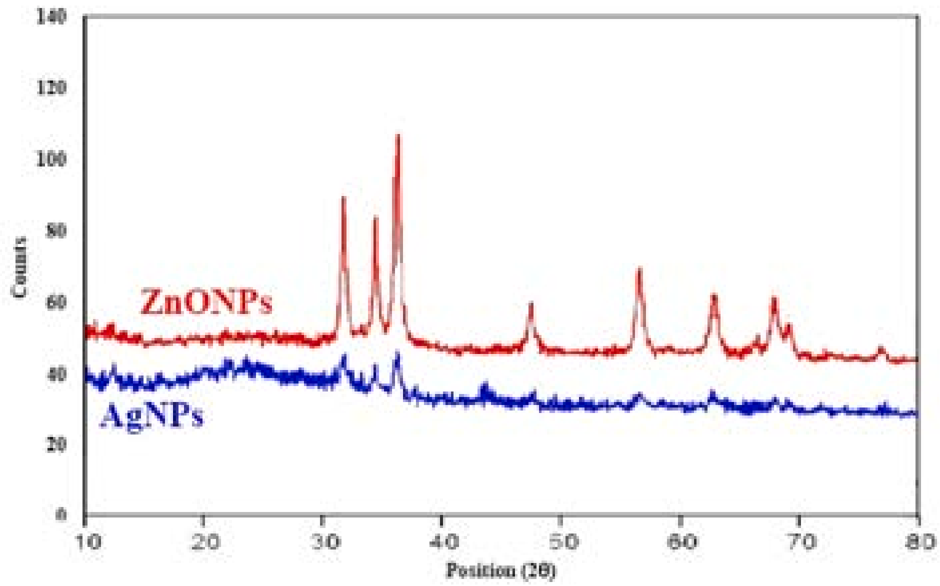

Fig. 4. XRD spectra for synthesized AgNPs and ZnONPs using tea leaves extracts at pH 10 and 12 respectively.

Table 1
metal nanoparticles size calculated from XRD analysis.

	θ°	FWHM	Calculated nanoparticles size (nm)
AgNPs	38.69	0.311	4.885
	44.11	0.402	4.539
ZnONPs	38.75	0.333	4.660
	48.14	0.305	5.336

2.2.2. Synthesis of silver nanoparticles (AgNPs) using tea leaves extract

Silver nanoparticles are created using tea leaf extract (AgNPs). As a reducing agent, tea leaf extract was used, and silver nitrate salt solution was used as an Ag source. Ten milliliters of tea leaf extract were added to a 95 mL aqueous silver nitrate solution (0.002 M) and incubated at 80 °C for ten minutes. The pH medium was varied from 4 to 10 to determine the best conditions for AgNPs synthesis. The visual shift from a transparent yellow solution to a dark brown solution indicated AgNPs production. The produced nanoparticle was validated using a UV–vis spectrophotometer [82].

2.2.3. Synthesis of zinc oxide nanoparticles (ZnONPs) using tea leaves extract

As previously reported, zinc oxide nanoparticles have been manufactured [100]. In a nutshell, 70 mL of tea leaves extract were poured into a beaker, and the pH medium was adjusted with sodium carbonate to (8, 10, or 12). The temperature was then raised to 70 °C, and 30 mL of 1 N zinc acetate in distilled water was added drop by drop to the tea leaves extract for 30 min while constantly stirring. After that, the solution was kept at this temperature for another 30 min while being stirred. The powder was filtered and dried at 90 °C for 24 h. The powder produced was a combination of $Zn(OH)_2$ and $Zn(CO_3)_2$, or a superposition of the two as $Zn_5(OH)_6(CO_3)_2$. As the calcination step is critical to the formation of ZnONPs, it was carried out at 400 °C for 4 h. The calcined ZnONPs were then put to use.

2.2.4. Fabric application

2.2.4.1. Fabric pretreatment. The cotton and wool fabrics' exterior surfaces were cleaned to remove waxy components and contaminants. Cotton and cotton/wool textiles were washed in a 2 g/L (Na_2CO_3) solution for 15 min at 40 °C, while wool fabrics were washed in CH_2Cl_2 for 15 min before drying at room temperature.

2.2.4.2. Fabrics treatment with synthesized AgNPs. Fabric treatments were carried out using synthesized AgNPs in tea leaves extract (at optimal conditions) as follows [101]: 10 g polycation compound (PEI or chitosan) was dissolved in 900 mL distilled water while stirring. To ensure optimal nanoparticle dispersion inside the polycation network, 100 mL of manufactured AgNPs in tea leaves extract was added at 80 °C with stirring for 30 min. The finished emulsion was immersed in pre-treated fabrics for 10 min before being squeezed with 100% wet pickup and dried at 100 °C for 5 min.

2.2.4.3. Fabrics treatment with synthesized ZnONPs. According to the protocol, a ZnONPs emulsion for fabric treatments was produced in distilled water to achieve 10% in the presence of a polycation component (PEI or chitosan) of 10 g/l [100]: 10 g polycation compound (PEI or chitosan) was dissolved in 1 L distilled water while stirring. 10 g calcinated ZnONPs were added at 80 °C for one hour with vigorous stirring to ensure that the nanoparticles were evenly distributed throughout the polycation network. The solution was then homogenised in a homogenizer for 3 min at 10000 rpm to ensure homogeneous dispersion. The finished emulsion was submerged in pre-treated fabrics for 10 min before being squeezed with 100% wet pickup and dried at 100 °C for 5 min.

2.3. Analysis and measurements

2.3.1. Characterization of tea leaves extract and synthesized metal nanoparticles

The extract of tea leaves is monitored using JASCO UV–visible absorption spectrophotometers between 300 and 800 nm to monitor the reduction of silver nitrate to silver nanoparticles. The FT-IR of the tea leaves extract was evaluated using the JASCO spectrometer tester. Images of tea leaf extracts and manufactured metal nanoparticles were examined using a JEOL JEM-1200 EX transmission electron microscope.

According to standard test procedures, the size of the produced metal nanoparticles was determined using the MasterSizer/2000 laser particle size analyzer (MALVERN Instruments, UK) [54], ASTM E11:61, [53,13,23,53,54].

The total phenolic content of tea leaf extract was determined using the Folin-Ciocalteau method, with minor modifications as previously indicated [91,93,101].

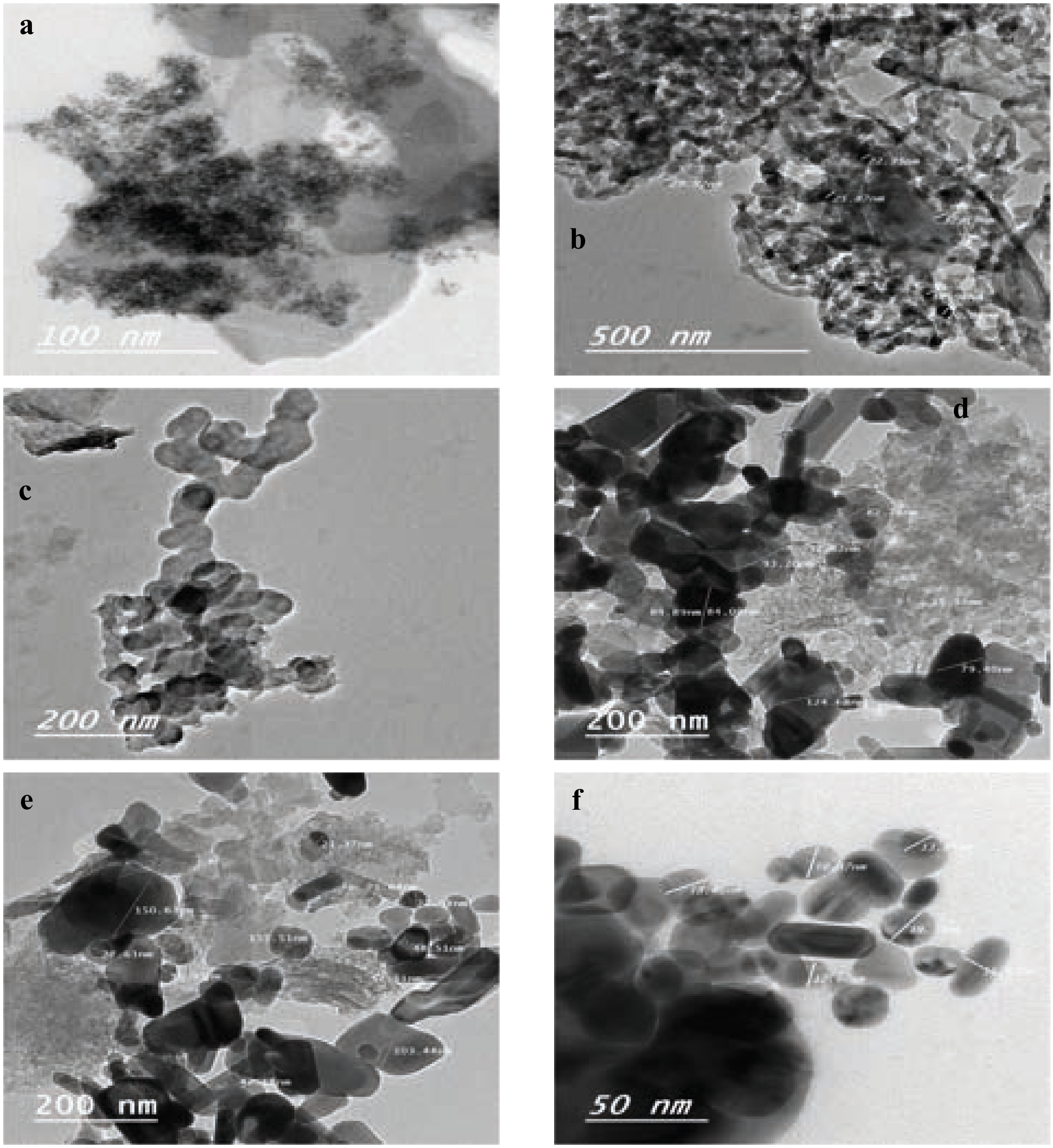

Fig. 5. TEM image for synthesized AgNPs and ZnONPs using using tea leaves extracts at different pH. a) AgNPs at pH 6, b) ZnONPs at pH 6, c) AgNPs at pH 8, d) ZnONPs at pH 8, e) AgNPs at pH 10 and f) ZnONPs at pH 10.

The antioxidant capacity of bioactive tea leaves extract and treated textiles was tested using the radical scavenging ability of 2,2-diphenyl-2-picrylhydrazyl (DPPH) [9,27,88].

2.3.2. Characterization of treated fabric

The treated textiles were studied using a Scanning Electron Microscope - JSM 5400 instrument (Joal, Japan). The ultraviolet protective factor was determined for untreated and treated textile fabrics using an absorption spectrophotometer (JASCO) and an Australian/New Zealand standard test technique [14].

The self-cleaning activity was determined by measuring the degradation of methylene blue (MB) under UV irradiation [100].

The Hunter Lab Ultra-Scan Pro was used to assess the colour strength of treated coloured textile materials at Egypt's National Research Centre. The K/S values were calculated using the Kubelka-Munk equation [29–30,59,63,72,96,97].

$$\frac{(1-\boldsymbol{R})^2}{2\boldsymbol{R}} - \frac{(1-\boldsymbol{R_o})^2}{2\boldsymbol{R_o}}$$

where K is the absorption coefficient, S is the dispersion coefficient, and R_{kmax} is the cloth's reflectance at its maximum wavelength.

The mechanical and physical properties were assessed using a variety of established test techniques. A tensile strength apparatus type FMCW

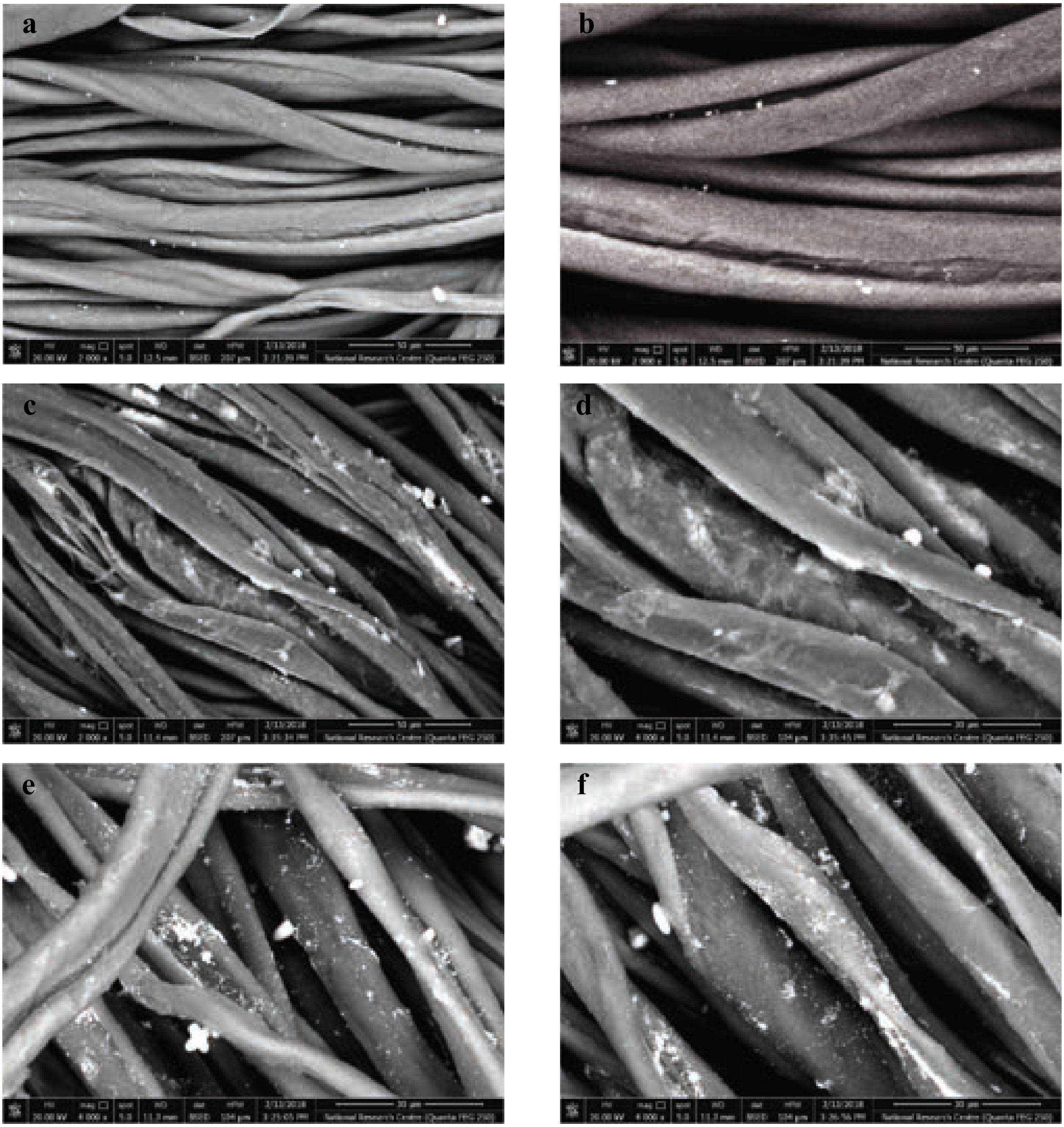

Fig. 6. SEM image for treated cotton fabric with polycations in the presence and absence of synthesized metal nanoparticles. a) treated cotton fabric with PEI, b) treated cotton fabric with chitosan. c) treated cotton fabric with PEI/AgNPs, d) treated cotton fabric with chitosan/AgNPs. e) treated cotton fabric with PEI/ZnONPs, f) treated cotton fabric with chitosan/ZnONPs.

500 (Veb Thuringer Industrie Werk Rauenstein 11/2612 Germany) is used to test tensile strength and elongation at break [11]. For treated textiles, the dry crease recovery angle (CRA) was measured and assessed [1]. Surface Roughness measurement equipment SE 1700 was used to determine fabric roughness [12]. The cantilever instrument was used to test stiffness [10].

2.3.2.1. Antimicrobial activity. The antibacterial activity was quantified against Staphylococcus aureus (ATCC 29213), a gram-positive bacterium, Escherichia coli (ATCC 25922), a gram-negative bacterium, and Candida Albicans (ATCC 10231), a fungus, according to the AATCC 100–2004. (bacterial reduction method) [2,34,36,49,58,70,100].

2.3.2.2. Durability. After being washed in 2 g/L non-ionic detergents (Hostapal) for 10 min at 40 °C and dried for 3 min at 100 °C, the coloured textiles were tested for durability.

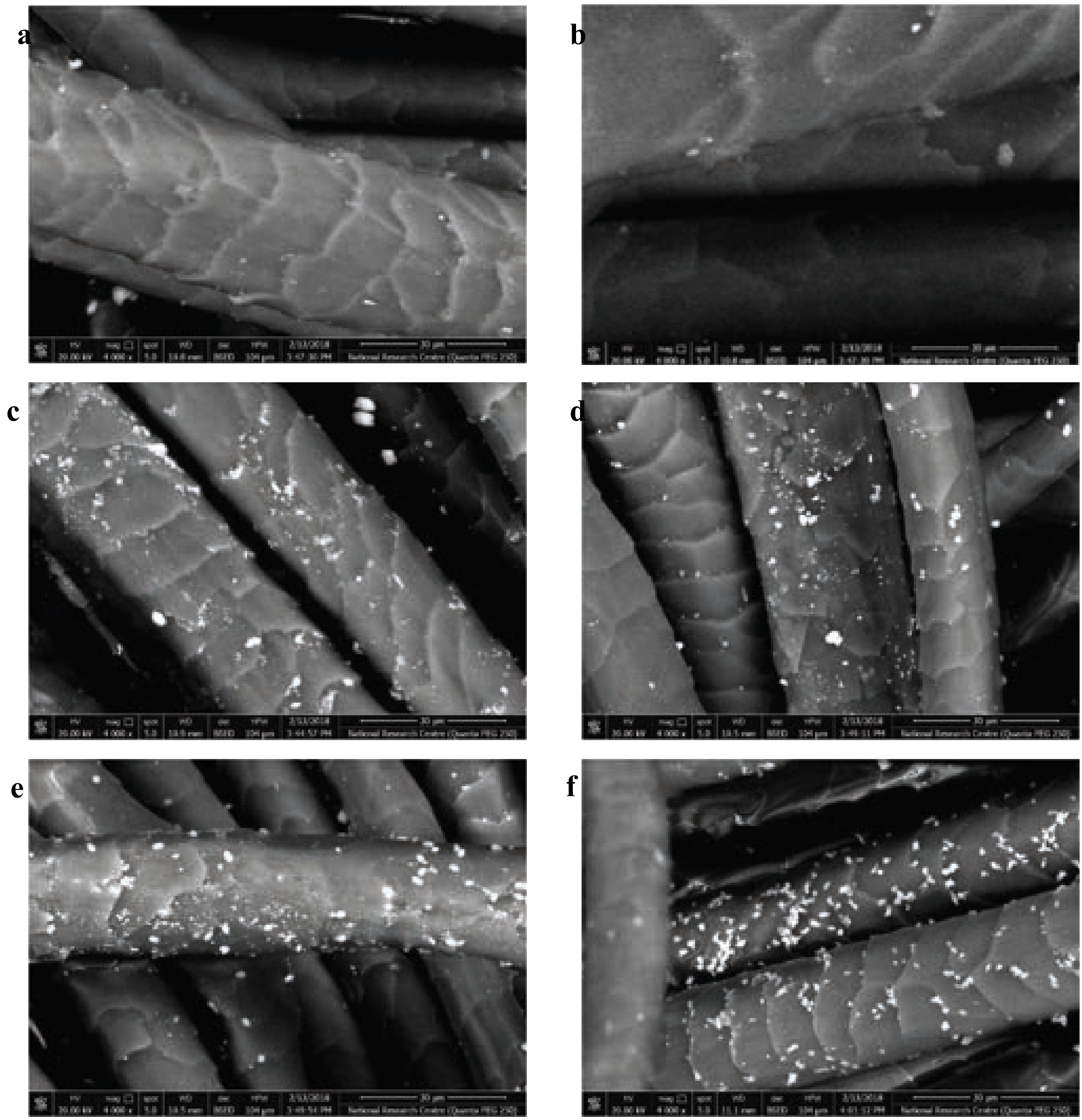

Fig. 7. SEM image for treated wool fabric with polycations in the presence and absence of synthesized metal nanoparticles. a) treated wool fabric with PEI, b) treated wool fabric with chitosan. c) treated wool fabric with PEI/AgNPs, d) treated wool fabric with chitosan/AgNPs. e) treated wool fabric with PEI/ZnONPs, f) treated wool fabric with chitosan/ZnONPs.

3. Results and discussion

3.1. Characterization of tea leaves extract and synthesized AgNPs and ZnONPs

Because of the presence of a hydroxyl group in its molecular structure, phenolic is more soluble in polar liquids. Polar solvents, such as ethanol and water, outperformed non-polar solvents in extractors. The polar solvent's hydrogen bond can interact with the phenolic groups of hydroxyls [3,9].

The spectrum of tea leaves extract studied by FT-IR is shown in Fig. 1. The O–H stretching and N–H of the fatty acids and carbohydrates units contained in tea leaves extract induce the bandwidth in the FT-IR spectrum of tea leaves extract, with a peak in the area of 3390–3470 cm^{-1} [62]. For asymmetric and symmetric stretching, the C–H bond in the CH_2 group has peaks at 2955 and 2860 cm^{-1}, respectively.

Because of C=O stretching between 1740 and 1620 cm^{-1}, there is significant overlapping of alternative bands. A carbonyl group may appear at (1730 and 1710 cm^{-1}) and (1650 cm^{-1}) in fatty acids or amides, respectively. There is also a stretching peak at 1583 cm^{-1} due to

Table 2
Physical and mechanical properties for treated fabrics with polycations with synthesized AgNPs and ZnONPs.

Fabric	Polycation (1 %)	Metal NPs	R (μm)	Tensile strength	Elongation at a break (%)	CRA (W + F°)
Cotton	Blank		20.90	154.00	36.10	221.60
	PEI	—	18.60	163.10	38.80	236.30
		AgNPs	19.75	158.54	38.29	228.78
		ZnONPs	19.18	158.36	38.05	223.22
	Chitosan	—	19.80	165.10	38.60	238.11
		AgNPs	19.49	157.48	36.85	229.26
		ZnONPs	19.64	152.30	35.57	223.42
Wool	Blank		21.40	158.00	37.00	227.40
	PEI	—	19.10	116.00	26.40	211.70
		AgNPs	20.28	112.75	26.05	204.96
		ZnONPs	19.69	112.63	25.89	199.98
	Chitosan	—	20.40	118.10	29.30	192.90
		AgNPs	20.08	112.65	27.97	185.73
		ZnONPs	20.24	108.94	27.00	181.00
Cotton/Wool	Blank		22.00	162.10	38.00	233.30
	PEI	—	19.50	119.00	27.10	217.10
		AgNPs	20.71	115.67	26.74	210.19
		ZnONPs	20.10	115.54	26.58	205.08
	Chitosan	—	20.90	121.20	30.10	197.80
		AgNPs	20.57	115.61	28.74	190.45
		ZnONPs	20.74	111.80	27.74	185.59

Fabrics were treated with polycations in the presence and absence of metal nanoparticles at 70 °C for 15 min.

Table 3
Color strength (K/S) values and dye fixation (%) for dyed treated fabrics.

Fabric	Polycation	Metal NPs	Color performance					
			Reactive dye (λ = 540)		Acid dye (λ = 510)		Natural dye (Tea leaves, λ= 270)	
			K/S	dye fixation (%)	K/S	dye fixation (%)	K/S	dye fixation (%)
Cotton	Blank		0.5	67.5676	0.56	35.6688	3.14	40.9922
	PEI	—	11.95	92.4324	5.67	52.9907	13.05	90.374
		AgNPs	12.64	92.6752	6.43	59.5922	13.45	95.1875
		ZnONPs	12.67	94.6472	7.41	74.026	13.74	97.2399
	Chitosan	—	3.06	93.2927	1.26	50.3226	9.26	82.7525
		AgNPs	16.08	93.9252	5.15	68.5752	9.97	89.3369
		ZnONPs	16.93	96.3026	5.69	76.9959	10.14	89.2606
Wool	Blank		0.69	89.6104	4.05	89.7537	4.13	61.8263
	PEI	—	6.38	83.0729	6.68	89.1098	9.05	71.266
		AgNPs	7.49	95.1715	6.96	91.8206	9.52	78.5714
		ZnONPs	8.94	94.3038	6.88	89.5833	9.88	82.8164
	Chitosan	—	3.88	83.9827	2.6	56.6972	6.44	61.3918
		AgNPs	6.38	82.3226	4.15	67.1521	7.32	80.7056
		ZnONPs	6.81	80.1176	4.69	74.3265	8.16	83.3504
Cotton/Wool	Blank		0.54	71.0526	2.93	64.7015	4.59	60.7143
	PEI	—	10.45	85.3061	4.94	98.2107	8.88	63.4286
		AgNPs	13.81	93.1849	11.72	99.2379	9.32	91.8227
		ZnONPs	13.23	93.4322	11.81	97.4422	9.57	92.1078
	Chitosan	—	2.6	87.8378	2.32	61.4634	5.38	62.0531
		AgNPs	13.43	93.6541	5.77	76.9333	6.16	77.9747
		ZnONPs	13.06	92.6241	5.32	88.3721	6.22	77.75

C–N bonding.

A small shoulder band between 2750 and 2650 cm^{-1} is caused by carbonyl C=O in the form of aldehyde, as is a band between 1750 and 1620 cm^{-1} by aliphatic carbonyl bonds in the form of aliphatic ketones or esters. Furthermore, on the tea leaf extract, an asymmetric band at 1490–1385 cm^{-1} appears, indicating N–O stretching from aliphatic nitrogen [101]. An absorption peak at 1233 cm^{-1} is also caused by a C–O stretch from alcohol or phenol. A chemical interaction between the aromatic ring and oxygen results in another strong signal at 1165 cm^{-1} [101].

One of the most abundant chemicals in tea leaf extract is phenolic compounds. Total phenolic components in tea leaves extracted in water were determined using the colorimetric technique Folin-Ciocalteu. The total phenolic components of tea leaves extract were 76.32 ± 1.3. High antioxidant activity (88 ± 2.3) due to scavenging action was thought to be the cause of the high phenolic extracts, which may play a role in the bio-reduction of metal ions to metal nanoparticles [52].

The UV–Vis spectrum of produced silver nanoparticles using a tea leaves extract is shown in Fig. 2. The colloidal solution for silver nanoparticles has a peak absorption at 420 nm in the UV–Vis spectra (AgNPs). Furthermore, the pH medium influences AgNPs production.

After 10 min, the colour of the AgNPs production process changed from yellow to dark brown, indicating the formation of silver nanoparticles (AgNPs) 2017 [7]. Furthermore, increasing the pH medium causes the solution's colour to darken within 10 min. At low pH (pH 4), tea leaves extract had little affinity for AgNPs, but when the pH is raised to 6, AgNPs begin to form. Raising the pH medium increased the amount of AgNPs produced.

Fig. 3 depicts the particle size of AgNPs produced at various pH levels (4, 6, 8, and 10) when tea leaves extract was used as a reducing and stabilising agent. When the pH of the medium is increased, the size of the produced AgNPs particles decreases. The particle size of tea leaves is approximately 1000 nm. In aqueous media at pH 4, 6, 8, and 10, the particle size of produced AgNPs was 315, 266, 5, and 3 nm, respectively.

Table 4
Color strength (K/S) values and dye fixation (%) for printed treated fabrics.

Fabric	Polycation	Metal NPs	Color performance					
			Reactive dye (ƛ = 540)		Acid dye (ƛ = 510)		Natural dye (Tea leaves, ƛ= 270)	
			K/S	dye fixation (%)	K/S	dye fixation (%)	K/S	dye fixation (%)
Cotton	Blank		4.98	75.49	3.12	46.32	6.2	45.04
	PEI	—	10.91	83.66	6.43	83.1	15.15	84.26
		AgNPs	10.97	87.5499	6.89	91.6223	15.58	95.9951
		ZnONPs	10.98	88.835	6.5	91.0364	15.49	99.4223
	Chitosan	—	9.21	97.12	7.45	47.14	10.92	63.45
		AgNPs	6.9	98.991	8.36	85.0458	11.51	78.3526
		ZnONPs	6.81	98.31	8.43	90.4506	11.89	80.7196
Wool	Blank		5.4	74.08	4.31	50.55	5.94	59.83
	PEI	—	10.25	88.02	8.13	59.79	14.53	81.38
		AgNPs	10.02	88.7511	8.35	81.1467	14.86	90.7758
		ZnONPs	10.62	91.9481	8.25	81.3609	14.94	93.2002
	Chitosan	—	6.91	76.35	8.44	60.82	10.62	82.71
		AgNPs	7.7	87.7993	9.12	87.6081	12.83	84.5191
		ZnONPs	7.82	88.2619	9.74	93.2057	12.31	83.2319
Cotton/Wool	Blank		4.79	74.27	2.63	44.11	6.7	63.92
	PEI	—	13.29	86.66	7.73	76.27	14.23	91.11
		AgNPs	11.08	91.1184	8.28	84.0609	15.46	93.6402
		ZnONPs	13.82	91.2814	8.65	92.4145	14.95	93.613
	Chitosan	—	9.27	94.42	7.65	43.72	14	71.29
		AgNPs	9.84	95.4413	8.47	93.7984	15.01	86.513
		ZnONPs	10.16	95.9396	8.96	95.0159	15.75	92.2671

Table 5
Fastness properties for the dyed cotton fabrics with polycations in the presence and absence of metal nanoparticles using different dyes nature.

Fabric	Dye	Polycation (1 %)	Metal NPs	Fastness properties										
				Washing		Rubbing				Perspiration				Light
						Dry		Wet		Acidic		Alkaline		
				Alt	St	Alt	St	Alt	St	Alt	St	Alt	St	
Cotton	Reactive dye	without		3	2–3	3	2–3	3	2–3	3	2–3	3	2–3	4
		PEI	without	5	5	4–5	4–5	4–5	4–5	4	4–5	4–5	4–5	5
			AgNPs	5	5	4–5	4–5	4–5	4–5	4	4–5	4–5	4–5	5
			ZnONPs	4–5	4–5	4–5	4–5	4–5	4–5	4	4–5	4–5	4–5	5
		Chitosan	without	4–5	4	3–4	4	4	4	4	4	4	4	5
			AgNPs	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5
			ZnONPs	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	5
	Acid dye	without		2	2	2	2	2–3	2–3	2	2	2	2	3–4
		PEI	without	5	5	5	5	4–5	4–5	4–5	5	5	5	4–5
			AgNPs	5	5	5	5	5	5	5	5	5	5	5
			ZnONPs	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	5
		Chitosan	without	4–5	4	4	4–5	4–5	4	4	5	4	4	4
			AgNPs	4–5	5	3–4	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	5
	Natural dye	without		2	2	2	2	2	2	2	2	2	2	2–3
		PEI	without	4	4	3–4	4	4	3–4	4	4	4	4	4
			AgNPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
		Chitosan	without	3–4	4	3	3–4	3–4	3	4	4	4	4	4
			AgNPs	4–5	5	3–4	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5

Fig. 3 depicts and demonstrates the particle sizes of tea leaf extract at approximately 1000 nm. The particle sizes of ZnONPs generated at various pH levels were depicted and displayed in Fig. 3. (6, 8, 10, and 12). As the pH of the medium increases, the particle size of the produced ZnONPs appears to decrease. The deposited influence of tea leaf components on the ZnONPs surface could be responsible for the particle size reduction. Tea leaf extract was used to generate ZnONPs in the various pH media tested. It's worth noting that no ZnONPs form at pH 6, indicating a lower proclivity for ZnONP formation in acidic media [21,49,50]. When the pH medium is raised to 8, ZnONPs begin to form, but not in the same size, resulting in a low intensity range of 7 to 60 nm. Raising the pH medium to 10 and 12 produces ZnONPs with homogeneous particle size. Furthermore, pH 12 worked well for sculpting ZnONPs in both extracts.

Fig. 4 shows the X-ray diffraction patterns for produced AgNPs and ZnONPs at pH 10 and 12 correspondingly. Both materials exhibit the similar closer intensity and width series. d-Spacing values for synthesised AgNPs and ZnONPs are (2θ; 31.66, 36.11, 38.75, 48.14, 56.83, 63.21, 68.94, and 69.32) and (2θ; 31.63, 36.03, 38.69, 44.11, and 56.76), respectively [21,49,50,65,66,69]. The distinctive peaks of both metal nanoparticles were found to be significantly wider than expected, which suggests that smaller metal nanoparticles were formed. Peaks at 38 and 44 on the XRD pattern of metal nanoparticles are attributed to the crystalline structure of nanocrystals [38]. Using the Scherrer's formula and the full width at half maximum (FWHM) of the silver peak at 100 percent, the crystallite size of the metal nanoparticles was estimated.

Table 6
Fastness properties for the dyed wool fabrics with polycations in the presence and absence of metal nanoparticles using different dyes nature.

Fabric	Dye	Polycation (1 %)	Metal NPs	Fastness properties										
				Washing		Rubbing				Perspiration				Light
						Dry		Wet		Acidic		Alkaline		
				Alt	St	Alt	St	Alt	St	Alt	St	Alt	St	
Wool	Reactive dye	without		3–4	3	3	3–4	3–4	3	3	3	3	3	4
		PEI	without	4–5	5	3–4	4–5	4–5	4–5	4–5	5	5	5	4–5
			AgNPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
		Chitosan	without	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5
			AgNPs	4–5	5	3–4	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
	Acid dye	without		3	3	3	3	3	3	3	3	3	3	3–4
		PEI	without	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			AgNPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
		Chitosan	without	4	4	4	4–5	4	4–5	4	4–5	4	4	4–5
			AgNPs	4–5	5	3–4	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
	Natural dye	without		3	2–3	3	2–3	3	2–3	3	2–3	3	2–3	4
		PEI	without	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
			AgNPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
		Chitosan	without	4	3–4	4–5	5	4–5	4–5	4–4	4–5	4	4	5
			AgNPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5

Table 7
Fastness properties for the dyed cotton/wool fabrics with polycations in the presence and absence of metal nanoparticles using different dyes nature.

Fabric	Dye	Polycation (1 %)	Metal NPs	Fastness properties										
				Washing		Rubbing				Perspiration				Light
						Dry		Wet		Acidic		Alkaline		
				Alt	St	Alt	St	Alt	St	Alt	St	Alt	St	
Cotton / Wool	Reactive dye	without		3	3	4	3–4	3	3	3	3	3	3	3
		PEI	without	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			AgNPs	4–5	5	3–4	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
		Chitosan	without	4–5	4	4	4–5	4–5	4	4	4	4	4	4
			AgNPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
	Acid dye	without		2–3	2–3	3	2–3	3	2–3	3	2–3	3	2–3	4
		PEI	without	5	4–5	4–5	5	4–5	4–5	4–5	4–5	4	4	5
			AgNPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
		Chitosan	without	3–4	4	4	4–5	4–5	4	4	4	4	4	4
			AgNPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
	Natural dye	without		2–3	2–3	3	3	3	2–3	3	3	3	3	3
		PEI	without	4–5	4	4	4–5	4–5	4–5	4–5	5	5	4	4–5
			AgNPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
		Chitosan	without	3	3–4	3–4	3–4	4	3–4	4	4–5	4	3	4–5
			AgNPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5

$$d = \frac{K \times \lambda}{\beta \times \cos\theta}$$

where d is the metal nanoparticles' diameter (in nanometers), X-ray wavelength, FWHM of the diffraction line, diffraction angle, and K are constants; K is often taken to be 0.9. Table 1 shows the calculated average crystallite diameters, which for AgNPs varied from 4.885 to 4.539 nm and for ZnONPs from 4.660 to 5.336 nm, indicating that both synthetic metal nanoparticles are poly crystalline in nature.

Fig. 5 depicts TEM images of AgNPs made with tea leaf extract at various pH levels (6, 8, and 10). The TEM images have a spherical shape and a good dispersion. The particle distribution ranges for AgNPs at pH 8 are 135 to 60, according to the TEM analysis. When the pH medium was raised to pH 10, thin, spherical nanoparticles with diameters closer to 20 nm were detected for the AgNPs produced.

Fig. 5 also shows TEM images of ZnONPs generated at various pH levels (6, 8, 10, and 12). The TEM images show rod formations with a high degree of dispersion. At pH 8, the particles exhibited small-scale scattering in the 50–140 nm range. TEM images show that when the pH is raised to pH 12, thin rod nanoparticles form in a tiny cluster during the synthesis stages.

3.2. Characterization of treated fabric

The cotton fabric was treated with synthesised AgNPs and ZnONPs in both polycation compounds using tea leaf extract in water (chitosan and

Table 8
Fastness properties for the printed cotton fabrics with polycations in the presence and absence of metal nanoparticles using different dyes nature.

Fabric	dye	Polycation (1 %)	Metal NPs	Fastness properties										
				Washing		Rubbing				Perspiration				Light
						Dry		Wet		Acidic		Alkaline		
				Alt	St	Alt	St	Alt	St	Alt	St	Alt	St	
Cotton	reactive dye	without		3	2–3	2–3	2–3	2–3	2–3	3	2–3	3	3	4
		PEI	without	4	4	4–5	4–5	4–5	4–5	3	4–5	4–5	6–7	5
			AgNPs	4–5	5	3–4	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
		Chitosan	without	3–4	3	3–4	3	3	3	3	3	3	3	5
			AgNPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
	acid dye	without		2–3	2–3	2–3	2–3	2–3	2–3	2	2	2	2	4
		PEI	without	4	4	4	4	4	4	4	4	4	4	5
			AgNPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
		Chitosan	without	3–4	3–4	3–4	3–4	3–4	3–4	3–4	3–4	3–4	3–4	5
			AgNPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
	natural dye	without		2	2	2	2	2	2	2	2	2	2	4
		PEI	without	4	4	3	4	4	3	3	4	4	3	4
			AgNPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
		Chitosan	without	3–4	3–4	3	3–4	3–4	3	3–4	3–4	3	3	4
			AgNPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5

Table 9
Fastness properties for the printed wool fabrics with polycations in the presence and absence of metal nanoparticles using different dyes nature.

Fabric	dye	Polycation (1 %)	Metal NPs	Fastness properties										
				Washing		Rubbing				Perspiration				Light
						Dry		Wet		Acidic		Alkaline		
				Alt	St	Alt	St	Alt	St	Alt	St	Alt	St	
Wool	reactive dye	without		3–4	3	3	3–4	3–4	3	3–4	3–4	3	3	4
		PEI	without	4	4	4	4	4	4	4	4	4	4	5
			AgNPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
		Chitosan	without	3–4	3–4	3–4	3–4	3–4	3–4	3–4	3–4	3–4	3–4	5
			AgNPs	4–5	5	3–4	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
	acid dye	without		3	3	3	3	3	3	3	3	3	3	4
		PEI	without	4	4	3–4	3–4	3–4	3–4	3–4	4	4	4	5
			AgNPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
		Chitosan	without	3	3	4	4–5	3	3–4	3	3–4	3	3	5
			AgNPs	4–5	5	3–4	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
	natural dye	without		3	3	3	3	3	2–3	3	2–3	3	2–3	4
		PEI	without	4	4	4	4	3–4	4	3–4	3–4	3–4	3–4	5
			AgNPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
		Chitosan	without	4	3–4	3–4	4	3–4	3–4	3–4	3–4	3	3	5
			AgNPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5

PEI). The physical, mechanical, and functional properties of treated, treated dyed, and treated printed fabrics were investigated.

3.2.1. *Morphological behavior of treated fabric*

Fig. 6 and Fig. 7 depict the SEM images for cotton and wool fibers treated with synthesized AgNPs and ZnONPs in both polycation compounds (chitosan and PEI).

The surface of all treated fabrics with metal nanoparticles embedded in both polycations is highly rugged, and the holes on the fabric surface were filled with composites during treatment, resulting in roughness.

SEM images revealed AgNPs and ZnONPs surface deposition, which provides nanoparticles either alone or within the deposited thin layer of the chitosan or PEI network. The AgNPs and ZnONPs used were well deposited, as evidenced by SEM images.

According to the findings, fabrics treated with synthetic ZnONPs had rougher surfaces than those treated with AgNPs. This highlights the importance of polycation compounds in achieving uniform nanoparticle dispersion and penetration on treated fabric surfaces. According to the SEM images, AgNPs or ZnONPs are permanently attached to the surface of the treated fibres.

3.2.2. *Physical and mechanical properties*

Tensile strength, elongation at break, roughness, and crease recovery angle on textile fabrics were measured under optimal conditions before and after treatment with polycations and metal nanoparticles, and the results are shown in Table 2.

Table 10
Fastness properties for the printed cotton/wool fabrics with polycations in the presence and absence of metal nanoparticles using different dyes nature.

Fabric	dye	Polycation (1 %)	Metal NPs	Fastness properties										
				Washing		Rubbing				Perspiration				Light
						Dry		Wet		Acidic		Alkaline		
				Alt	St	Alt	St	Alt	St	Alt	St	Alt	St	
Cotton / Wool	reactive dye	without		3	3	3	3	3	3	3	3	3	3	4
		PEI	without	4	4	3–4	3–4	3–4	3–4	3–4	4	4	4	5
			AgNPs	5e	5	4–5	4–5	4–5	4–5	4	4–5	4–5	4–5	5
			ZnONPs	4–5	4–5	4–5	4–5	4–5	4–5	4	4–5	4–5	4–5	5
		Chitosan	without	3	3	4	4–5	3	3–4	3	3–4	3	3	5
			AgNPs	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5
			ZnONPs	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	5
	acid dye	without		3	3	3	3	3	2–3	3	2–3	3	2–3	4
		PEI	without	4	4	4	4	3–4	4	3–4	3–4	3–4	3–4	5
			AgNPs	5	5	5	5	5	5	5	5	5	5	5
			ZnONPs	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	5
		Chitosan	without	4	3–4	3–4	4	3–4	3–4	3–4	3–4	3	3	5
			AgNPs	4–5	5	3–4	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	4–5	5
	natural dye	without		3	3	3	3	3	2–3	3	2–3	3	2–3	4
		PEI	without	4	4	4	4	3–4	4	3–4	3–4	3–4	3–4	5
			AgNPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5
			ZnONPs	5	5	4–5	4–5	4–5	4–5	4–5	5	5	5	4–5
		Chitosan	without	4	3–4	3–4	4	3–4	3–4	3–4	3–4	3	3	5
			AgNPs	4–5	5	3–4	4–5	4–5	4–5	4–5	5	5	5	4–5
			ZnONPs	4–5	4	4–5	3–5	4–5	5	4–5	4–5	4–5	4–5	5

Table 11
Metal content (%) and Ultraviolet Protection Factor (UPF) for dyed and printed fabrics treated with polycations in the presence and absence of metal nanoparticles.

Fabric	Polycation	Metal NPs	Metal content (%)/1 g fabric		UPF					
					Reactive dye (ƛ = 540)		Acid dye (ƛ = 510)		Natural dye (Tea leaves, ƛ= 270)	
			Ag	Zn	Dyeing	Printing	Dyeing	Printing	Dyeing	Printing
Cotton	Blank		0	0	0.17	0.17	0.17	0.17	0.17	0.17
	PEI	—	0	0	35.30	43.20	39.25	41.23	40.24	40.73
		AgNPs	0.43	0	55.69	64.53	60.11	62.32	61.22	61.77
		ZnONPs	0	0.64	90.84	99.68	95.26	97.47	96.37	96.92
	Chitosan	—	0	0	32.33	39.57	35.95	37.76	36.86	37.31
		AgNPs	0.41	0	52.36	60.47	56.42	58.44	57.43	57.94
		ZnONPs	0	0.61	87.51	95.62	91.57	93.59	92.58	93.09
Wool	Blank		0	0	4.30	4.30	4.30	4.30	4.30	4.30
	PEI	—	0	0	49.70	56.20	55.26	53.63	56.65	52.99
		AgNPs	0.46	0	71.81	79.09	78.04	76.22	79.60	75.50
		ZnONPs	0	0.69	106.96	114.24	113.19	111.37	114.75	110.65
	Chitosan	—	0	0	46.30	56.30	51.48	53.73	52.78	53.08
		AgNPs	0.44	0	68.01	79.21	73.81	76.32	75.26	75.60
		ZnONPs	0	0.66	103.16	114.36	108.96	111.47	110.41	110.75
Cotton/Wool	Blank		0	0	2.77	2.77	2.77	2.77	2.77	2.77
	PEI	—	0	0	52.70	61.63	58.60	58.81	60.07	58.11
		AgNPs	0.45	0	75.17	85.17	81.78	82.02	83.43	81.23
		ZnONPs	0	0.66	110.32	120.32	116.93	117.17	118.58	116.38
	Chitosan	—	0	0	48.75	59.44	54.21	56.72	55.57	56.04
		AgNPs	0.42	0	70.75	82.72	76.86	79.68	78.39	78.92
		ZnONPs	0	0.63	105.90	117.87	112.01	114.83	113.54	114.07

The physicomechanical properties of treated textile fabrics were crucial. CRA, tensile strength, and elongation at break were all significantly improved after treatment with polycations alone or with either AgNPs or ZnONPs, while surface roughness was reduced. This demonstrates that the polycations used were deeply embedded in the fabric's microstructure, forming a thin layer on the surface and resolving to bear responsibility for the changes [21,45,79,90].

When compared to untreated fabrics or treated fabrics with ZnONPs/polycations composite, the physical and mechanical properties of the treated fabrics show that treated fabrics with AgNPs/polycations composite give good values. These findings lend credence to the notion that biopolymer materials can help improve mechanical and physical properties. It's possible that the key to improving the crease recovery angle was creating an extreme fabric structure network densely cross-linked by covalent chemical bonds between cellulose or protein chains and biopolymers.

3.2.3. *Color performance and fastness properties of dyed and printed fabrics*

In this study, three dyes were used to dye or print three pre-treated fabric samples (cotton, wool, and cotton/wool) with six different treatment formulas, as well as one untreated blank sample. Table 3 and Table 4 show the colour strength (K/S) and dye fixation (percent) values for dyed and printed pre-treated fabrics with PEI and chitosan (1 percent) using various dyes (acid, reactive, and natural extracted dyes from tea leaves).

When the fabrics were pretreated, the amine content increased, which increased the colour strength of the dyed or printed fabric with all

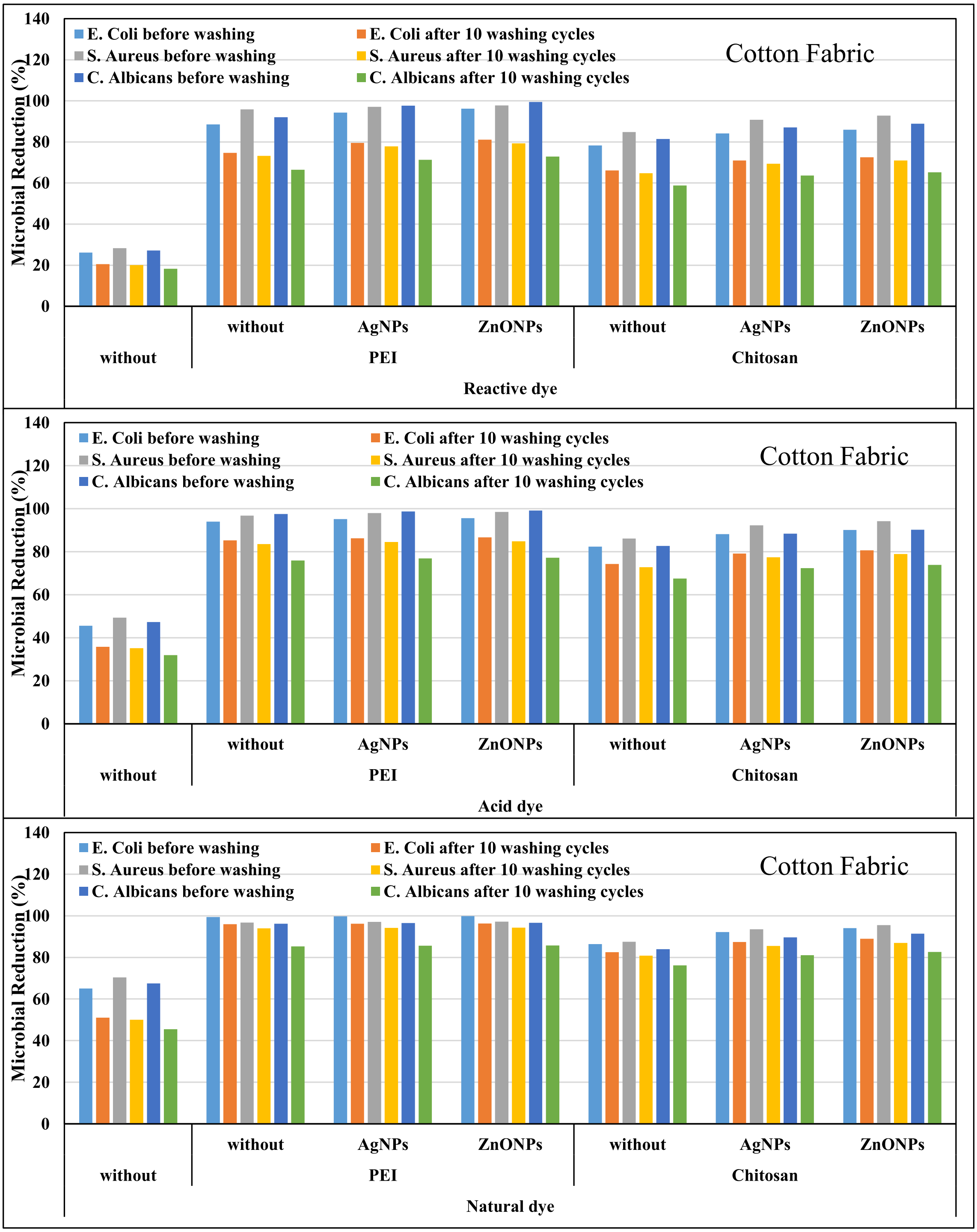

Fig. 8. Microbial reduction (R%) for dyed cotton fabrics with three different dyes treated with polycations in the presence and absence of metal nanoparticles.

examined dyes (synthetic or natural) on all fabric types compared to the untreated one. Furthermore, PEI-treated fabric had a higher amine content and higher K/S values than chitosan-treated fabric. When it comes to dye affinity, textiles made of cotton, wool, or their blends provide high colour strength and dye fixation when treated with polycation compounds.

The dye fixation of dyed or printed untreated and treated textiles was calculated using the equation presented in the experimental section. As demonstrated in Table 3 and Table 4, treatment with polycation compounds improved the dye-fixing of the utilized dyes (reactive, acid, and/or natural dye) on all substrates. PEI-treated textiles increased more than chitosan-treated textiles. Chemical interactions between I amino groups from polycation compounds, (ii) hydroxyl groups on the cotton surface or carboxyl groups from the wool surface or crosslinker, and (iii) dye molecules significantly increased dye-fixing when both polycations were used.

The presence of metal nanoparticles in polycation networks increases the K/S values of dyed or printed textiles, according to the key finding. Furthermore, treated fabrics containing both polycations in the presence of ZnONPs have higher K/S values than treated fabrics containing only one polycation or containing AgNPs.

Table 5, Table 6, Table 7, Table 8, Table 9, Table 10 shows the

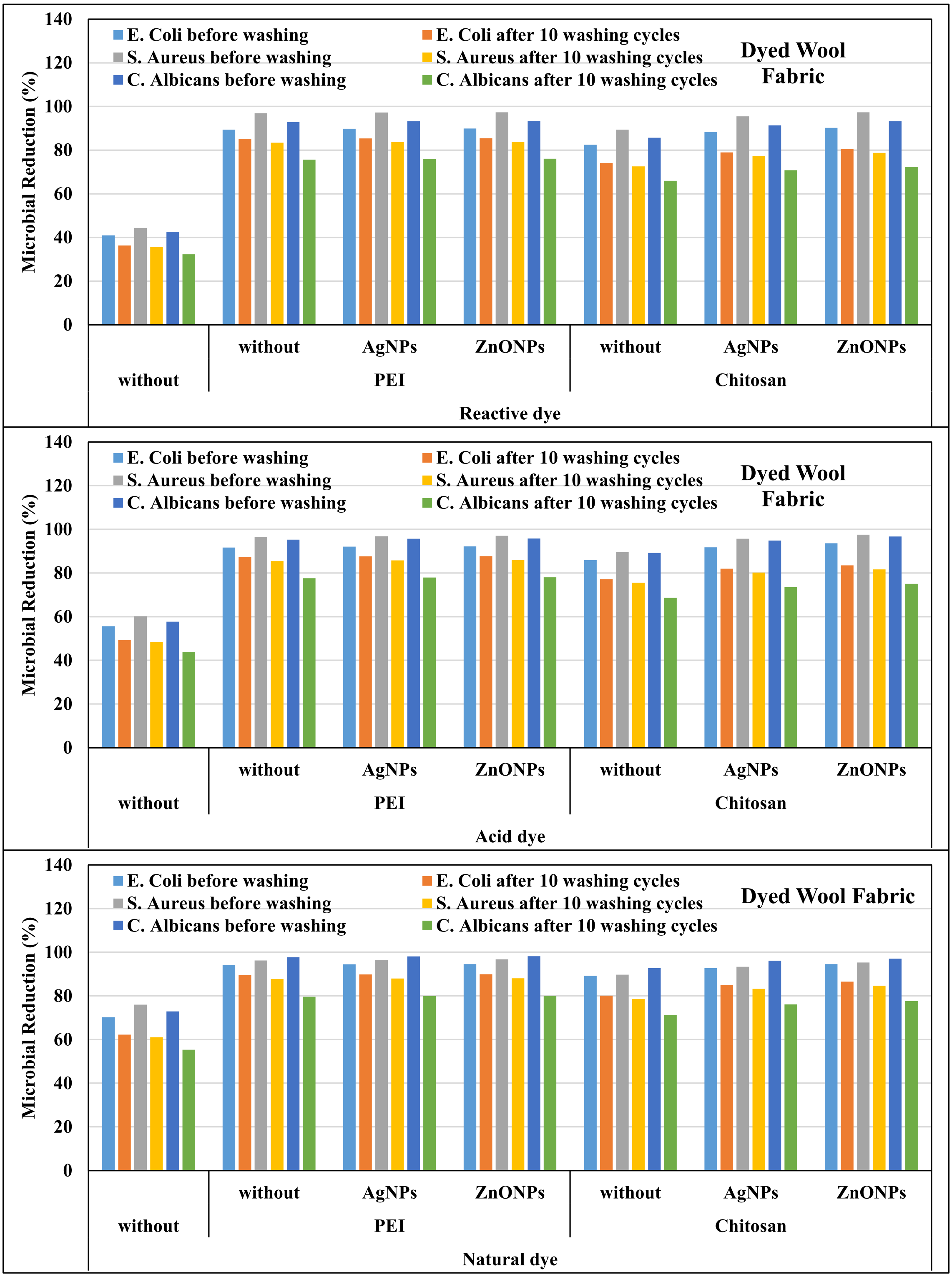

Fig. 9. Microbial reduction (R%) for dyed wool fabrics with three different dyes treated with polycations in the presence and absence of metal nanoparticles.

fastness properties of dyed and printed treated fabrics (cotton, wool, and cotton wool) with a polycation (PEI and chitosan; 1%) using three different dye natures (reactive, acid, and nature (tea extract)) in the presence and absence of metal nanoparticles (AgNPs and ZnONPs).

Treated textiles outperformed untreated materials in terms of washing, perspiration, lighting, and rubbing fastness. Chitosan and polyethyleneimine treatment significantly improved the washing and light fastness properties of coloured fabrics (dyed or printed) using all investigated dyes compared to untreated materials because polycation treated textiles absorb more colour molecules. This enhancement is due to the chemical bonds formed between polycations-treated materials and dye molecules.

Furthermore, enhanced hydrogen bonding between dye molecules, polycations, and the fabric surface binds the dye molecules within and on the textile surface. Furthermore, when the fabric is treated with a polycation, the dye molecules are absorbed better and more uniformly

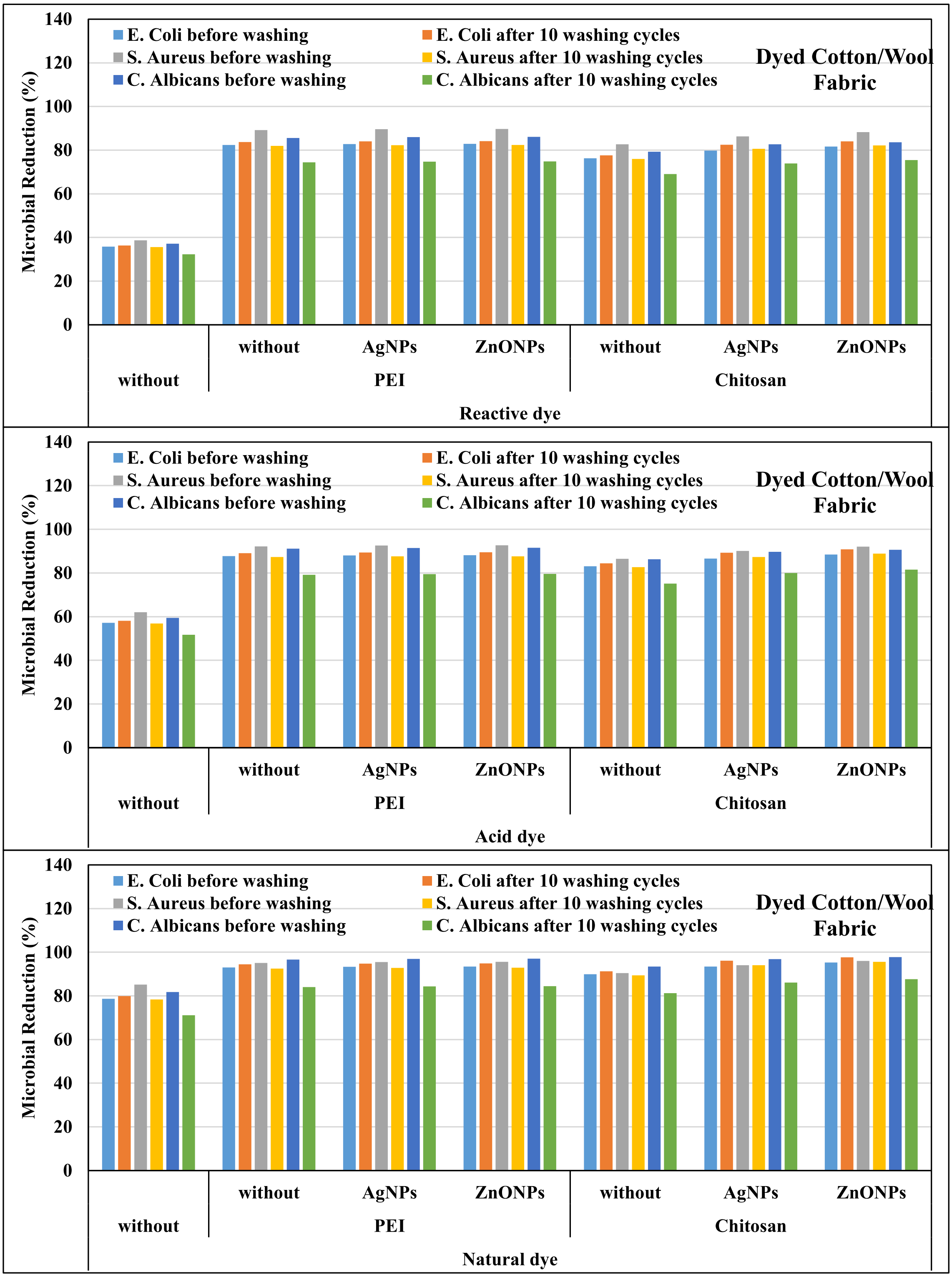

Fig. 10. Microbial reduction (R%) for dyed cotton/wool fabrics with three different dyes treated with polycations in the presence and absence of metal nanoparticles.

because the fibres have a uniform thin coating of polycations on the surface.

The presence of either metal nanoparticle (AgNPs or ZnONPs) in the polycation network had no effect on the fastness properties of all polycation-treated fabrics.

3.2.4. Metal content (%) and the ultraviolet protection factor (UPF)

The total content of silver and zinc metal % per 1 g fabric was determined quantitatively using a flame atomic absorption technique and the results were listed in Table 11. Table 11 also recorded the UPF for untreated and treated fabrics (dyed or printed with three different dyes of nature) in the presence and absence of AgNPs and ZnONPs, demonstrating that all treated fabrics have higher UPF values than

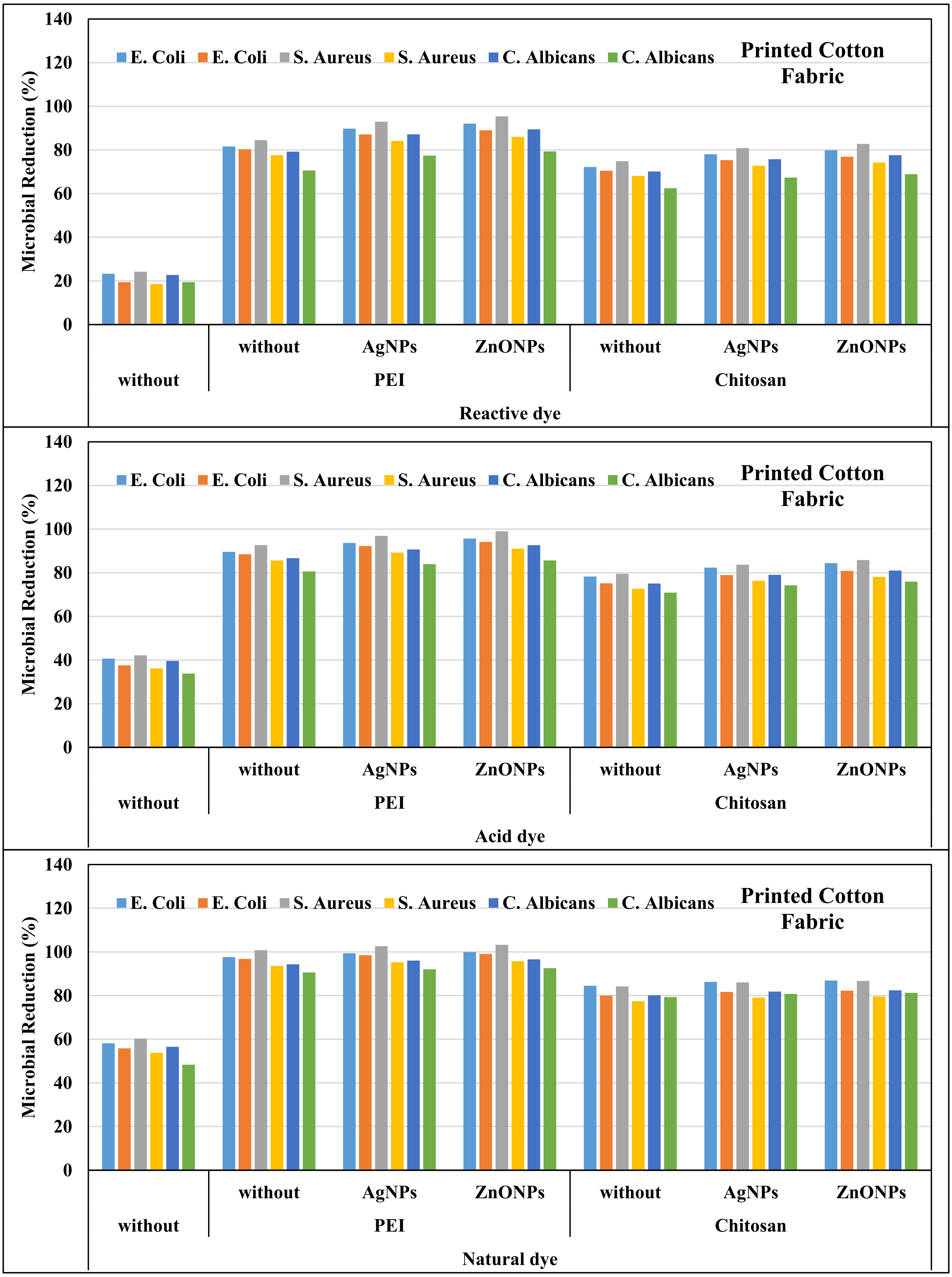

Fig. 11. Microbial reduction (R%) for printed cotton fabrics with three different dyes treated with polycations in the presence and absence of metal nanoparticles.

untreated. Furthermore, colored fabrics containing nature dye (tea extract) have higher UPF values than colored fabrics containing other dyes. This is due to the polyphenols and flavonoids chemicals' ability to absorb UV radiation, making it easier and more effective to protect the human skin from harmful UV rays. More research revealed that treated fabric with ZnONPs has higher UPF values than treated fabric with/without AgNPs.

3.2.5. Antimicrobial properties

The antibacterial activity of treated fabrics (dyed or printed) was tested quantitatively against three microbes: *Escherichia Coli* (*E. Coli*), *Staphylococcus Aureus* (*S. Aureus*), and *Candida Albicans* (*C. Albicans*). Fig. 8 to Fig. 13 shows the antibacterial results (Fig. 9, Fig. 10, Fig. 11, Fig. 12).

Using the three microorganisms onto the treated cloth, the antibacterial efficacy of all dyed or printed fabrics is confirmed. All treated

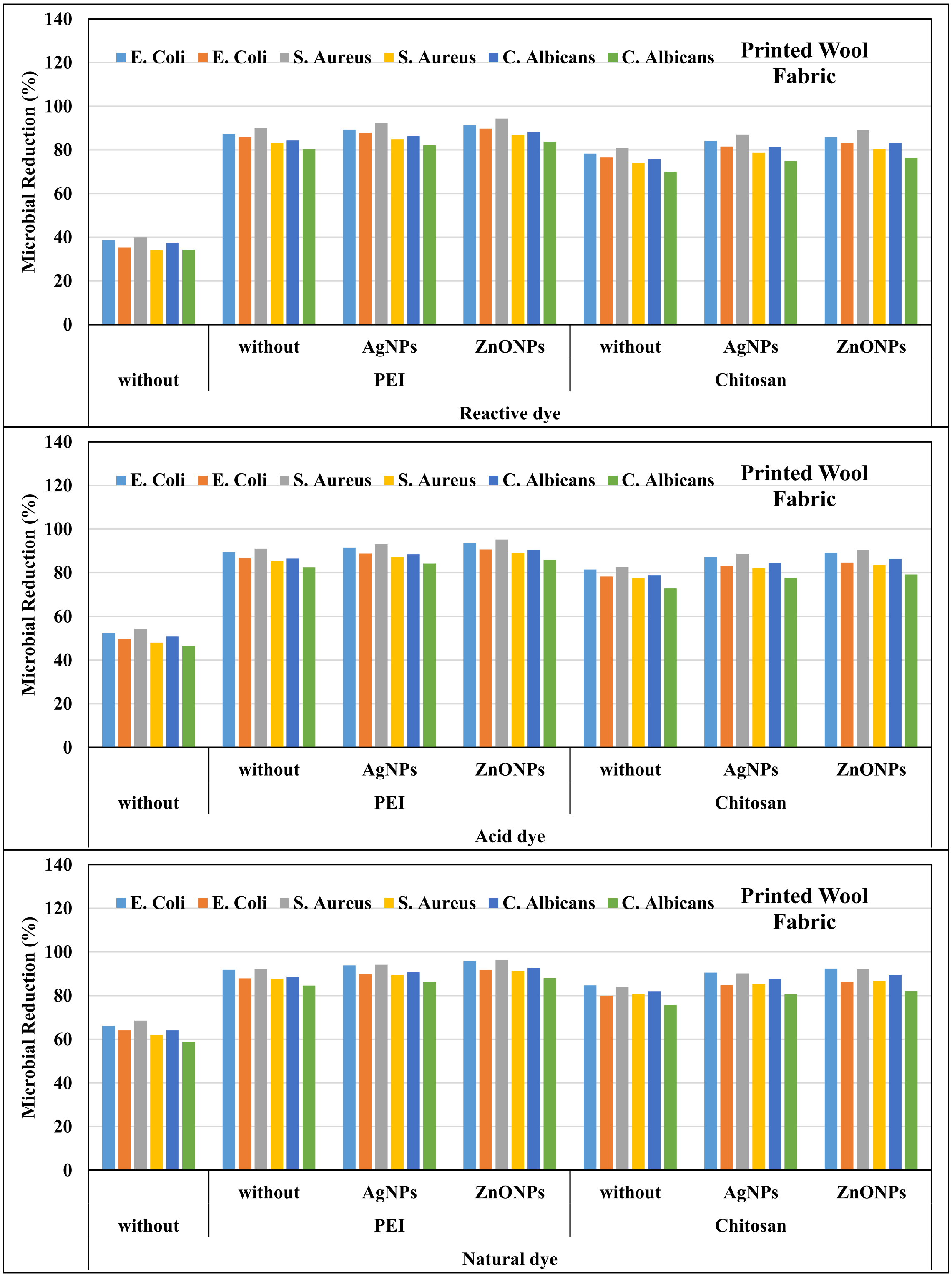

Fig. 12. Microbial reduction (R%) for printed wool fabrics with three different dyes treated with polycations in the presence and absence of metal nanoparticles.

fabrics provide good microbial reduction for the studied bacteria *E. Coli*, *S. Aureus*, and *C. Albicans*.

Because amine groups have a high bactericidal impact due to their positive charge, the addition of polycation as a composite has been shown to produce a better bacterial decrease, demonstrating the antimicrobial action of the treated textiles. This is due to the interaction of amines with more anionic gram-negative cell surface lipopolysaccharides, which impedes nutrition transfer into the cells [16].

Furthermore, this amino group boosts the compounds' lipophilic properties. The presence of metals and ZnONPs in the amino group of the metals and ZnONPs was thus hypothesised to have a greater impact on the antibacterial activity of the treated materials than the presence of AgNPs. As a result, the contact mechanism of the bacterial cytoplasmic membrane was disrupted [51].

Because of the high amine content in PEI compounds, treated fabric with PEI provides better microbial reduction than treated fabric with

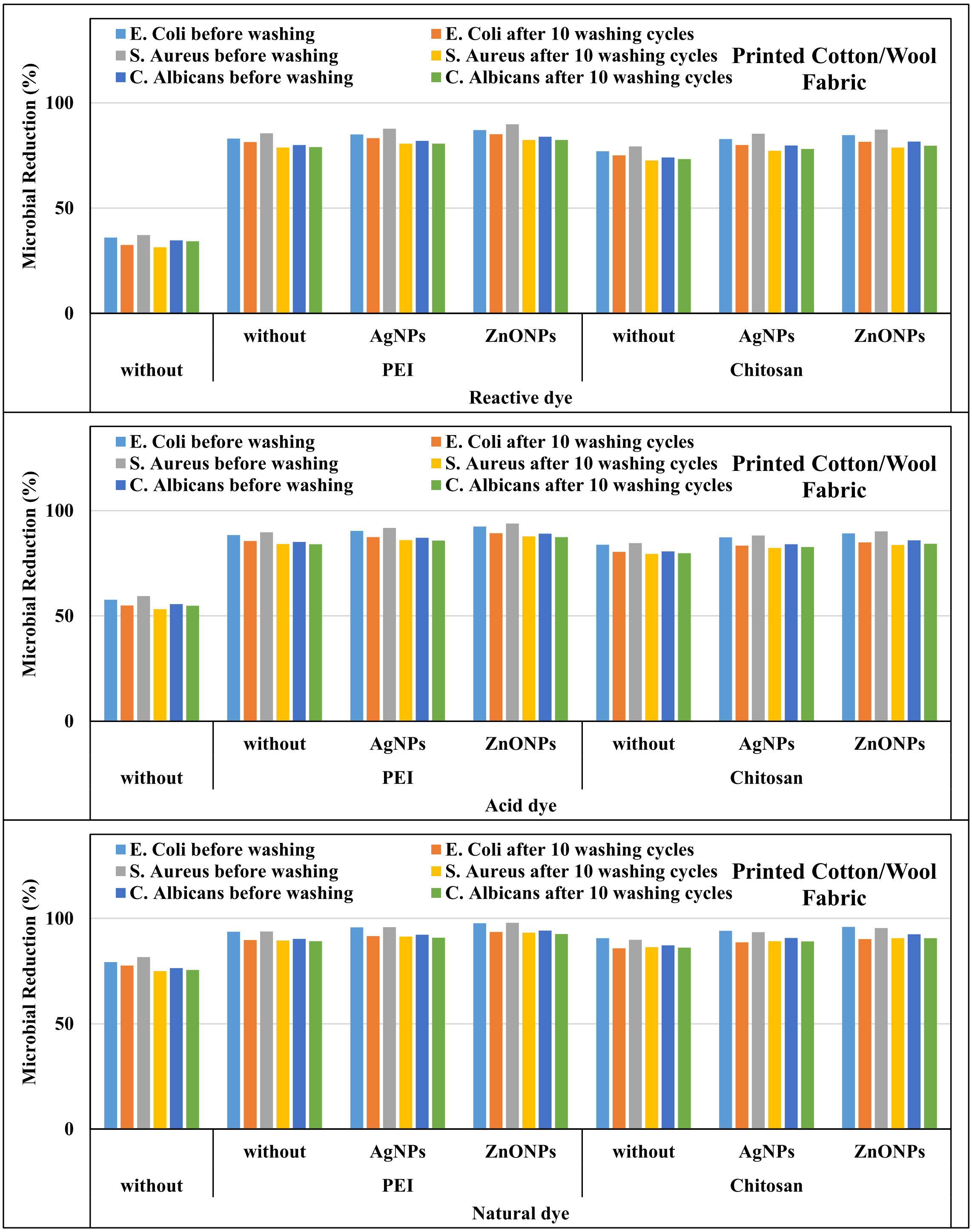

Fig. 13. Microbial reduction (R%) for printed cotton/wool fabrics with three different dyes treated with polycations in the presence and absence of metal nanoparticles.

chitosan. Furthermore, fabrics treated with polycation/ZnONPs exhibit higher levels of antimicrobial resistance than fabrics treated with polycation/AgNPs.

This beneficial effect is also attributed to the presence of phenolic and flavonoid chemicals in tea leaf extract. Furthermore, due to the fact that all of the bacteria studied had different cell wall structures, the treated textiles are more effective against Gram-positive bacteria than Gram-negative bacteria.

Polyphenolic chemicals' inhibitory activity in microbial RNA and DNA has been linked to antimicrobial activity. Depolarization of the cytoplasmic microbial membrane is also possible. Because ergosterol inhibits a key component of fungi's cell membrane, the chemicals are also antifungal [25,34,41,57,58]. In the coating process, polycation/ZnONPs or AgNPs successfully connect with bacterial cells [5,39,49,78].

The bacteria reduction percent of treated fabrics after various washing cycles was tested, and it was discovered that microbial resistance decreased up to 10 washing cycles. According to these findings, treated textiles have a high level of microbial resistance, which is reduced by washing but still inhibits bacteria growth. More evidence that these treated materials will produce positive results in the medical field.

4. Conclusion

Tea leaf extract was used to successfully synthesise AgNPs and ZnONPs. Metal nanoparticles (MNPs) were found to decrease as the pH of the medium increased. It has been discovered that treated fabric with MNPs in both polycations (PC) types is extremely rugged, resulting in a rough texture.

Following treatment with polycations alone or with either AgNPs or ZnONPs, the physical and mechanical properties of the treated fabric improved dramatically, while surface roughness decreased.

PEI-treated textiles increased dye fixation more than chitosan-treated textiles. Metal nanoparticles present in polycation networks raise the K/S values of dyed or printed textiles. Furthermore, treated fabrics containing both polycations in the presence of ZnONPs have higher K/S values than treated fabrics containing only one polycation or containing AgNPs. Treated textiles outperformed untreated textiles in terms of fastness.

The fastness properties were unaffected by the presence of either metal nanoparticle in the polycation network. Treated fabrics have higher UPF values than untreated fabrics, especially coloured fabrics using natural dyes, which is due to the polyphenols and flavonoids chemicals' ability to absorb UV radiation, making it easier to protect the human skin from harmful UV rays.

All pretreatment fabric (dyed or printed) frequently confers high to medium antibacterial power due to the use of two polycation compounds in the presence and absence of two different metal nanoparticles, treatment formula, and dyestuff, which are directly responsible for the suppression of bacterial growth. This strongly supported the inhibitory effectiveness of polycation and metal nanoparticles. Overall, the antibacterial assessment of all the fabrics tested (dyed or printed), whether pretreated or untreated, was extremely noticeable, promising, and motivating for further pharmaceutical research.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data are included in the text.

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