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Application of MCT-βCD to Modify Cellulose/Wool Blended Fabrics for Upgrading Their Reactive Printability and Antibacterial Functionality

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Abstract: Pre-loading of monochlorotriazinyl β-Cyclodextrin (MCT-βCD) onto/within viscose/wool (V/W) and cotton/wool (C/W) blended fabrics provide hosting cavities that can form host-guest inclusion complexes with reactive dyes in post-printing as well as with triclosan derivative or silver nanoparticles/hyperbranched polyamide-amine (AgNPs/HBPAA) composite in subsequent final antibacterial finishing step. Coloration properties, antibacterial activity against (*S. aureus*) and (*E. coli*) pathogenic bacteria, durability of the obtained products, according to the above mentioned route, to wash, surface morphology and composition of selected samples were investigated. Results obtained signify that premodification of the nominated substrates with MCT- βCD (10 g/*l*), followed by reactive printing with mono-or bifunctional reactive dye (20 g/*l*), and subsequent post-finishing with triclosan derivative or AgNPs/HBPAA composite (15 g/*l* each) is an efficient treatments sequence for attaining reactive prints with significant antibacterial efficacy and noticeable durability to wash. Surface depositions of selected active ingredients were also confirmed using SEM and EDX analysis.

Keywords: Cellulose/wool blended fabrics, MCT-βCD, Pre-modification, Reactive printing, Post-antibacterial finishing, High quality colored/functionalized products

Introduction

Textile fabrics based on cotton/wool and viscose/wool blends have found expanded utilizations such as for apparel, sportswear, leisure activities, fashion, home textiles, etc. due to their enhanced characteristics like eco-friendly, hydrophilicity, comfortability, biodegradability, etc. [1]. However, natural fibers provide proper surface and environment for hosting and growing of pathogenic microorganisms such as bacteria, fungi, etc. thereby facilitating cross-infection, developing of offensive odors along with fabric deterioration and discoloration [2,3]. Hence, antibacterial functionalization of textile materials based on natural fibers has gained growing attention to reduce/prevent infections, to inhibit odor development as well as to protect the textile material itself from microbial attack using proper antimicrobial agents having the ability to kill (biocidal) or inhibit (biostatic) the growth of pathogenic microorganisms [4-9].

Moreover, permanent fixation of β-Cyclodextrin derivatives onto textile substrates to form inclusion complexes with a variety of dyestuffs and/or active ingredients within their hydrophobic cavities for the development of high quality colored and/or functionalized textile products has received increasing attention in the textile finishing domain [3,10-15].

Herein, a new facile approach was developed in which MCT-βCD (monochloro-triazinyl β-Cyclodextrin) was pre-loaded onto cellulose/wool blended fabrics for enhancing their post-reactive printing and imparting new functionalities using proper active ingredients namely Ruco®-BAC MED (nonionic triclosan derivative) and hyperbranched poly(amid-amine, HBPAA) loaded with Ag-nanoparticles (AgNPs) composite.

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Experimental

Materials

Plain woven mill-scoured and bleached cotton/wool (50/50, 220 g/m^2) and viscose/wool (50/50, 180 g/m^2) blended fabrics were used.

Cavasol® W7MCT (monochlorotriazinyl β-cyclodextrin, MCT- βCD, average molecular weight ~1560, degree of substitution (0.3-0.6 per anhydroglucose unit-Wacker, Germany), and Ruco®-BAC MED (nonionic antibacterial finishing agent-based on diphenyl alkane derivative of triclosan- Rudolf Chemie), Dialgin® LV-100 [Na-alginate of low viscosity, BF-Goodrich Diamalt, GmbH, Germany), Ludigol® (oxidizing agent based on m-nitrobenzene sulfonic acid sodium salt, BASF, Germany), and Leomin® W (nonionic wetting agent and detergent, BASF, Germany) were of commercial grade.

Reactive Red 198 (hetero-bifunctional) and Reactive Blue 19 (vinyl sulfone-VS-type), OH Young, Korea) were used for reactive printing of the nominated substrates.

AgNPs/Hyperbranched poly(amide-amine-HBPAA) composite was synthesized using Ibrahim *et al*., method [2]. To prepare Hyperbranched poly(amide-amine-HBPAA), 30.95 gm of diethylene triamine was added in 50 m*l* methanol then 30.99 gm of methyl acrylate was added dropwise with continuous stirring and kept for 48 hours, the reaction mixture was transferred to rotary evaporator where vacuum

was applied for 2 hours at 60 °C. The temperature was raised to 100, 120, 140 °C for 2, 2, 10 hours respectively and viscous reddish yellow polymer was obtained. To synthesize AgNPs/HBPAA composite, 3 g of HBPAA with 100 m*l* distilled water was taken in a round bottle flask with continuous stirring and 5 m*l* solution of 0.1 g $AgNO_3$ in water and 5 m*l* solution of 0.1 g $NaBH_4$ in water was simultaneously added drop wise into the polymer solution with vigorous stirring at 25 °C until the color of the resultant solution turn light to dark yellow indicating the formation of Ag-colloid nano-particles. The obtained solution was kept in a brown glass bottle for further studies.

All other chemicals used in this study were supplied by Sigma-Aldrich.

Methods

Pre-loading of MCT-βCD

Aqueous solution of MCT-βCD (0-15 g/*l*) along with sodium bi-carbonate (0-20 g/*l*) and nonionic wetting agent (2 g/*l*) were prepared with constant stirring. Fabric samples were padded twice in the prepared solutions to wet-pick up 80 % owf, followed by direct fixation at 125 °C for 10 min. The treated fabric samples were then rinsed for 10 min to remove the unfixed and/or partially hydrolyzed MCT-βCD and finally dried at 100 °C for 5 min.

Reactive Printing

The pre-modified fabric samples and un-modified ones were post-printed using the nominated reactive dyes using the flat screen technique according the following conditions:

Printing paste components	g/kg paste
Reactive dye	20
Na-alginate (10 %)	500
Na-bicarbonate ($NaHCO_3$)	20
Urea	100
Ludigol®	10
Water	350
Total	1000

The Printed fabric samples were then dried at 100 °C for 5 min and steam fixed at 110 °C for 15 min using Ariolt® CSL-steamer, Italy. A portion of reactive printed fabric samples were rinsed thoroughly, soaped at 60 °C for 15 min in the presence of 2 g/*l* Na_2CO_3 and 2 g/*l* nonionic /detergent agent, then thoroughly rinsed and finally dried at 100 °C for 5 min.

Post-treatment with Ruco®-BAC MED (triclosan derivative)

Part of printed fabric samples were post-treated with triclosan derivative aqueous solution (10 g/*l*) using a sample dyeing machine according to the following conditions: pH (5) using acetic acid, LR (1/20); agitation rate (40 rpm), at 50 °C for 30 min followed by squeezing to give a wet pick-up of 80 %, thermofixed at 150 °C for 3 min, thoroughly rinsed to remove excess and unfixed active ingredients and finally dried at 100 °C for 5 min.

Post-finishing with AgNPs/HBPAA Hybrid

Another part of active prints were padded twice in a finishing formulation containing AgNP's/HBPAA (10 g/*l*), along with a nonionic wetting agent (2 g/*l*) at pH 5, using acetic acid, to give a wet pick-up of 80 %, followed by direct thermofixation at 150 °C for 3 min, rinsed thoroughly, washed at 50 °C for 10 min in the presence of a nonionic wetting agent to remove unreactant and unfixed hybrid, rinsed and finally dried at 100 °C/5 min.

Tests

Nitrogen content %N was determined according to the micro-Kjeldahl method [16].

The depth of the obtained reactive prints before and after post-finishing, was determined at the wavelength of the maximum absorbance using an automatic filter spectro-photometer, and calculated using the Kubelka Munk equation [17]: $K/S=(1-R)^2/2R$, where K, S and R are the absorption coefficient, the scattering coefficient and the reflectance respectively.

Antibacterial activity of the treated and untreated fabric samples against Gram-positive (*S. aureus,* G+ve) and Gram-negative (*E. coli,* G-ve) pathogenic bacteria was evaluated qualitatively according to AATCC Test Method (147-1988), and expressed as zone of growth inhibition (ZI, mm) [18].

Color fastness properties to washing and crocking were evaluated according to AATCC Test Methods: (TM61-2013) and (TM8-2013) respectively [19,20].

Durability to washing was performed according to AATCC Test Method 61(2A)-1996 after 10 laundering: Colorfastness to Laundering, Home and Commercial: Accelerated (AATCC, 2002). Laundering conditions outlined in Test 2A: for fabric that are expected to withstand repeated low temperature machine washings [19].

The morphology and particle size of the prepared HBPAA/AgNPs hybrids were determined by transmission electron microscope (TEM) using JEOL, JEM 2100F electron microscope at 200 kV.

Scanning electron microscope (SEM) images of selected samples were evaluated using a JEOL, JXA-840A electron probe microanalyzer equipped with disperse X-ray spectroscopy (EDX) for the surface composition analysis.

Results and Discussion

This study was designed to demonstrate the positive impacts of pre-modification of cotton/wool (C/W) and viscose/wool (V/W) blended fabrics with MCT-βCD on subsequent reactive dyeing and antimicrobial functionalization of the obtained reactive prints using modified triclosan and AgNPs/HBPAA hybrid functional agents.

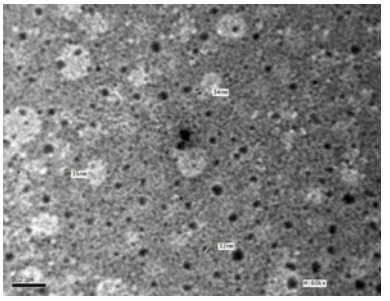

Figure 1. TEM images of HBPAA/Ag-NP's hybrid.

Charcterization of AgNPs/HBPAA Hybrid

Figure 1 illustrated the surface morphology of AgNPs. The TEM image showed homogeneous distribution of AgNPs inside HBPAA matrix, taking a spherical shape with particle size ranged between 32 and 35 nm.

SEM & EDX Analysis

SEM images of the surface of modified reactive printed V/W and C/W blank samples as well as post-treated fabric samples with AgNPs/HBPAA composite were shown in Figure 2. The SEM micrograph of the reactive prints showed

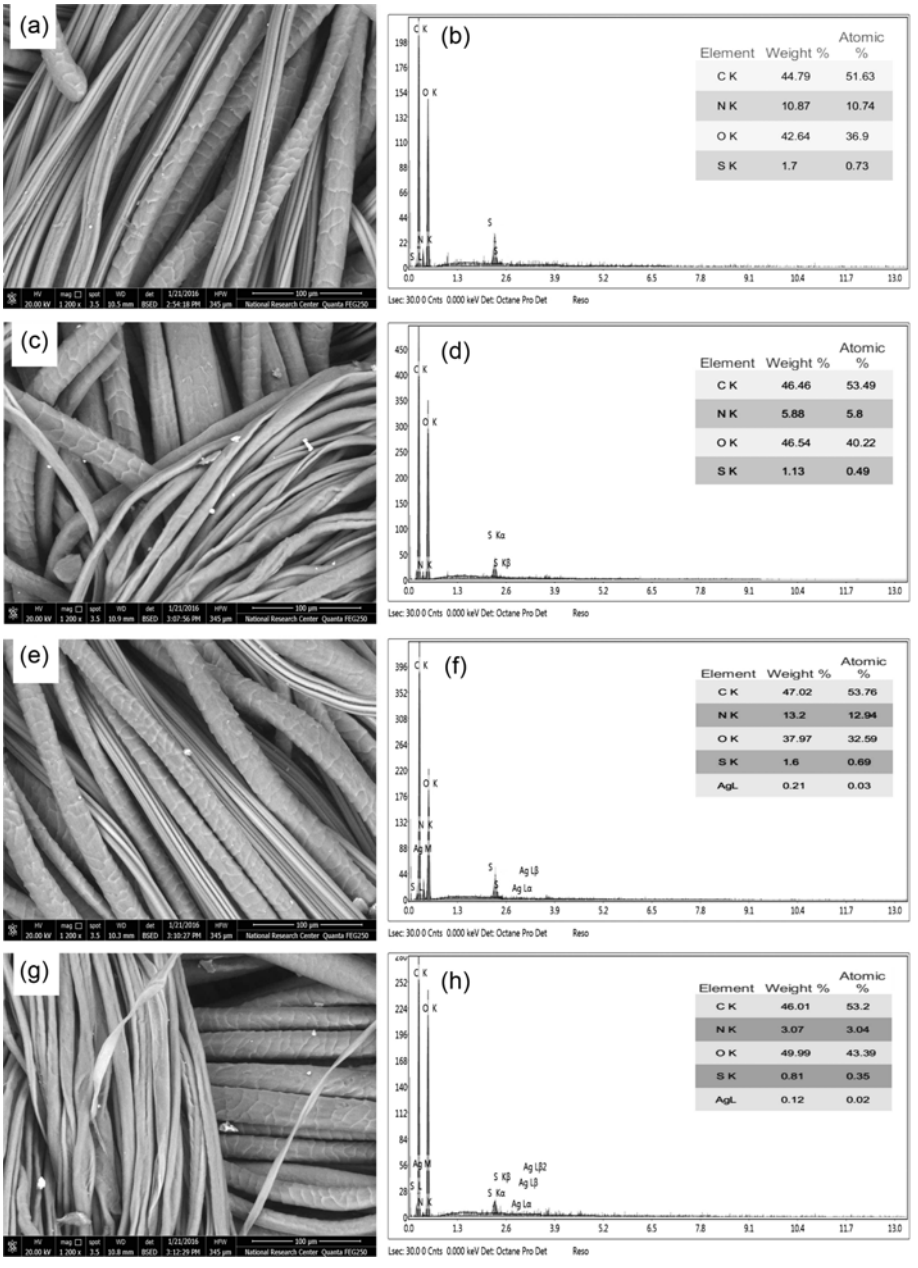

Figure 2. SEM and EDX of printed viscose/wool and cotton/wool fabrics (a,b) and (c,d) respectively. Printed viscose/wool and cotton/wool in presence of AgNPs (e,f) and (g,h) respectively.

a thin layer of printing paste distributed onto the fiber surface Figure 2 (a,c,d,e). All EDS (b,d,f,h) pattern showed peaks of carbon, oxygen and nitrogen as well as sulphur elements related to the cellulose/wool components and the used reactive dye. EDS spectra of reactive prints post treated with AgNPs/HBPAA composite, Figure 2(f&h) showed peaks of silver element in their patterns confirming the existence of AgNPs onto/into the treated fabric surface.

MCT-βCD-loading

Figure 3(a) shows the variation in %N, of the premodified samples as a function of MCT-βCD concentration (0-15 g/*l*) using Na-bicarbonate, as a catalyst. For a given pre-treatment conditions, it is clear that i) increasing MCT-βCD concentration up to 10 g/*l* results in an increase in the %N of the treated samples, regardless of the used substrate and ii) this increase in the %N is attributed to loading of MCT-βCD onto/within the fabric structure components as follows [10, 21-23]:

$$\underset{\text{Cell/W blend}}{HO-Cell/W-XH} + 2\,\underset{\text{MCT-}\beta\text{CD}}{Cl-T-\beta CD} \xrightarrow[\Delta]{OH^-} \underset{\text{MCT-}\beta\text{CD-loaded substrate (I)}}{\beta CD-T-O-Cell/W-X-T-\beta CD} + 2HCl \quad (1)$$

where Cell.OH = cotton or viscose, W-XH= W$\begin{cases} NH_2 \\ OH \\ SH \end{cases}$ wool

component active sites, Cl – T - βCD = MCT-βCD.

The extent of pre-modification of the nominated substrates is attributed to their differences in fabric construction, cellulose component, weight, availability of the two components reactive sites, and degree of penetration of the active ingredients into the fabric structure, which in turn affected the extent of loading of MCT-βCD on/into the fabric structure [17].

On the other hand, further increase in MCT-βCD up to 15 g/*l* has a marginal effect on the %N of pre-modified substrates, most probably due to the restricting effect of the loaded- MCT-βCD molecules onto the fabrics surface thereby minimizing the extent of further loading of MCT-βCD and/or partial hydrolysis of MCT-βCD under the given treatment conditions thereby losing its linking tool as follows [11]:

$$\underset{\text{MCT-}\beta\text{CD}}{H_2O + Cl-T-\beta CD} \xrightarrow[\Delta]{OH^-} \underset{\text{hydrolyzed form of MCT- }\beta\text{CD}}{HO-T-\beta CD} + HCl \quad (2)$$

Reactive Printing

As far as the change in the color strength expressed as *K/S* values of the obtained reactive prints, ex, as a function of the variation in the MCT-βCD concentration in premodification step, Figure 3(b) shows that i) increasing MCT-βCD concentration from zero up to 10 g/*l* followed by direct reactive printing with Reactive Red 198 (20 g/kg printing paste) is accompanied by gradual improve in the *K/S* values of the pre-modified→reactive printed fabric samples, ii) beyond 10 g/*l*, there is a marginal increase in color strength values of the printed fabrics, iii) the increase in the *K/S* values is governed by type of substrate, as discussed before, as well as their extent of modification, and their ability to uptake, interact, and fix the reactive dye molecules onto/within the modified fabric structure via covalent and/or ionic bonding as well as the ability of the immobilized hydrophobic-inner cavities of the grafted MCT-βCD to form inclusion complex with the nominated reactive dye as follows [10,24-26]:

$$(I) + \text{Hetero-bifunctional reactive dye} \xrightarrow[\text{Steaming}]{OH^-} \underset{\text{Modified/reactive printed substrate}}{} \quad (3)$$

during the steam fixation step.

Figure 3(a,b) clearly demonstrates that, 10 g/*l* MCT-βCD seems to be the prober concentration for obtaining better

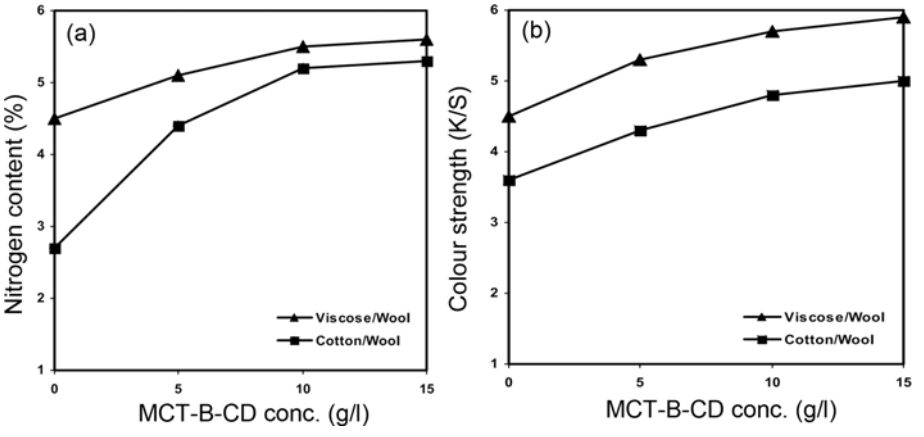

Figure 3. Effect of MCT-β-CD concentration on the nitrogen content (%) and extent of post reactive printing (*K/S*) of the treated cellulose/wool blended fabrics.

extent of premodification of the nominated substrates, i.e. better %N values, as well as extent of reactive printing, i.e. better *K/S* values.

Post-Finishing with Triclosan Derivative or AgNP's/ HBPAA Composite

Impact of post treatment of printed/unwashed samples with triclosan derivative (Ruco®-BAC) on the %N and *K/S* values of the printed-post-treated substrates is shown in Figure 4(a,b). For a given set of post-treatment, it is clear that: i) increasing the concentration of the functional agent up to 15 g/*l* is accompanied by a gradual increase in the %N as well as *K/S* of the treated fabric samples, ii) both the enhancement in %N and *K/S* values is governed by type of substrate, extent of interaction with triclosan derivative, degree of encapsulation of the active ingredients within the grafted MCT-βCD host cavities (equation (4)), extent of enhancing the reactive dye-fixation onto the treated substrates surface, in addition to the mode of interaction among the substrate component active sites, e.g. -NH_4, -OH, -COOH, etc., the grafted MCT-βCD and the dye structure for helping accommodation of more dye-particles onto/within the substrate [10,11,27], iii) the enhancement in both %N and *K/S* values follows the decreasing order V/W>C/W, keeping other parameters fixed, and iv) further increase in triclosan derivative concentration i.e. beyond 15 g/*l* has slight negative and positive impacts on %N, *K/S* values respectively

βCD-loaded substrate + Triclosan derivatives
(Host) (Guest)
⇌ Host-Gust inclusion complex (4)

Figure 5(a, b) illustrate, the effect of post-treatment of the reactive printed fabric samples with AgNPs/HBPAA on the %N and *K/S* values of the obtained products. It can be seen that i) increasing the composite amount up to 15 g/*l* results in an enhancement in both the nitrogen content, %N, and depth of shade, *K/S*, values irrespective of the used substrate, ii) this improvement follows the descending order V/W>C/W, keeping other parameters fixed, iii) this enhancement is attributed to the ability of the used composite with the its active sites, e.g. -NH_4, -NH ...etc. [2,27] to interact with both the grafted MCT-βCD as well as the reactive dye solubilizing

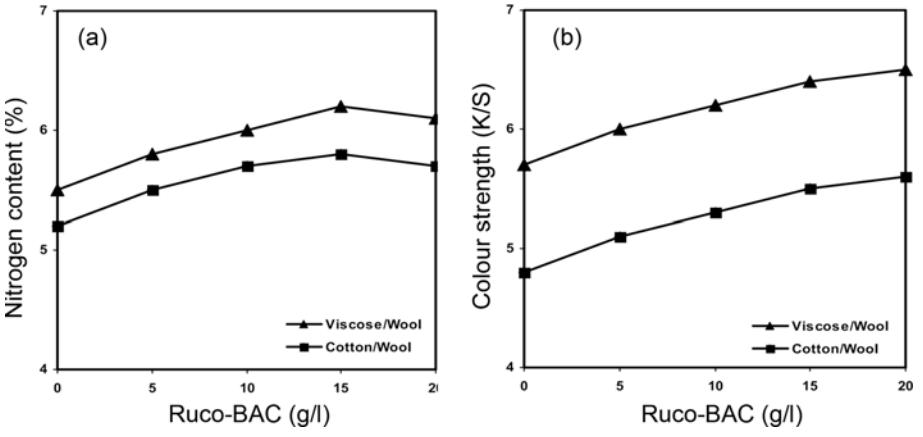

Figure 4. Effect of post-treatment of the printed fabric samples with Ruco®-BAC on nitrogen content (%) and colour strength (*K/S*) values.

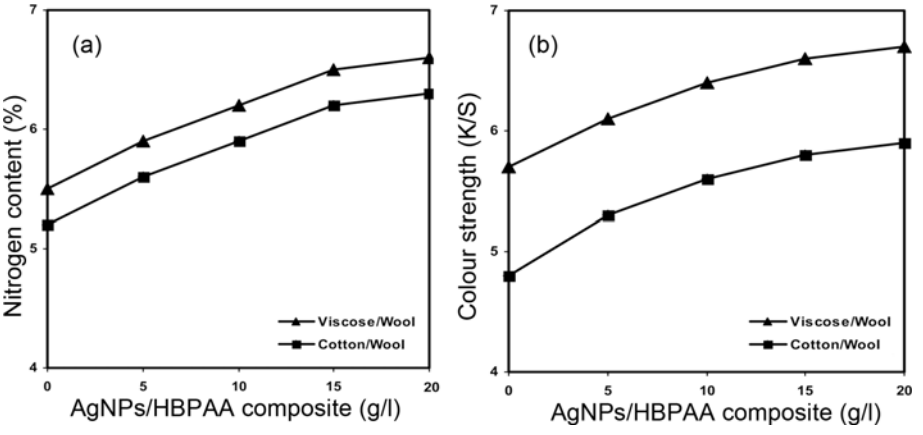

Figure 5. Effect of post-treatment of the printed fabric samples with AgNPs/HBPAA composite on nitrogen content (%) and colour strength (*K/S*) values.

groups thereby enhancing the extent of loading AgNPs/HBPAA composite (equation (5)), and iv) increasing the composite concentration up to 20 g/*l* results in a slight increase in the abovementioned properties.

$$\text{Reactive printed substrate} \sim SO_3^-Na^+ + H_2^+N \sim \xrightarrow[\text{Composite}]{\text{HBPAA/AgNPs}} \text{AgNPs/HBPAA-loaded substrate} \quad (5)$$

On the other hand, both Figures 4, 5 clearly demonstrate that the better %N and *K/S* values are obtained in case of using the functional agent at 15 g/*l* in the post-finishing step, and the change in %N and *K/S* values of the attained products reflects the differences between the triclosan derivative and the AgNPs/HBPAA composite in chemical structure, functional groups, molecular weight, extent of binding onto/into the fabric structure as well as the mode of interaction with MCT-βCD-loaded/reactive-printed substrates.

Coloration and Antibacterial Functionalization

The coloration and antibacterial functionalization properties of the treated substrates are listed in Table 1. The data so obtained signify that i) post-treatment of the reactive prints with triclosan derivative (15 g/*l*) brings about an enhancement in %N, *K/S* and fastness properties of the post-treated samples, ii) the extent of improvement is governed by type of substrate, extent of loading MCT-βCD onto/within the substrate in the pre-treatment step, type of the reactive dye, mono or bifunctional, used in the printing step, and subsequent encapsulation and fixation of triclosan derivative in the final-step, iii) post treatment of pre-modified→ reactive printed substrates with triclosan derivative results in a signifcant improvement in the antibacterial activity of the treated substrates against both of (*S. aureus*) and (*E. coli*) pathogenic bacteria, iv) the imparted antibacterial functionality against the nominated pathogens follows the decreasing order: Gram-positive>Gram negative one, most probably due to their differences in their cell wall structure [28-30], v) the noticeable increase in the antibacterial activity of triclosan derivative-treated substrates is attributed to the ability of tricloasn to block lipid biosynthesis and inhibits pathogenic bacteria [22,29,31,32], and/or via interaction with amino acid residues of the enzyme-active site within the cell membrane, thus preventing the nominated bacteria from functioning and/or reproducing, vi) the colored/functionalized substrates exhibited a slight decrease in their coloration and antibacterial properties even after 10 consecutive washing cycles as a direct consequence of the removal of unfixed or physically entrapped color and unloaded triclosan derivative confirming the high extent of the nominated agents during the suggested treatment steps, and vii) pre-modification with MCT-βCD followed by reactive printing has no antibacterial effect against the nominated bacteria.

On the other hand, Table 2 demonstrates that change in coloration and antibacterial functionalization, expressed as *K/S*/fastness properties and ZI values respectively, as a function of type of substrate, treatment sequence as well

Table 1. Effect of post-treatment with Ruco-BAC on some coloration and antibacterial properties

Reactive dye (20 g/kg)	Substrate		N (%)	*K/S*	Fastness properties				ZI (mm)	
					WF		RF		Gram (−ve)	Gram (+ve)
					Alt	C	Dry	Wet		
Reactive Red 198	V/W	UT	5.501	5.71	4	4	4	4	0.0	0.0
		PT	6.202 (5.571)	6.34 (5.720)	4-5	5	4-5	5	30 (27)	27 (25)
	C/W	UT	5.801 (5.306)	5.41 (4.923)	4	4-5	4-5	4-5	26 (23)	24 (21)
		PT	5.801 (5.306)	5.41 (4.923)	4	4-5	4-5	4-5	26 (23)	24 (21)
Reactive Blue 19	V/W	UT	5.751	8.58	3-4	4	4	4	0.0	0.0
		PT	6.372 (5.804)	9.42 (8.512)	4-5	5	4-5	4-5	28 (25)	25 (22)
	C/W	UT	5.406	7.76	4	4	4	4	0.0	0.0
		PT	5.960 (5.401)	8.50 (7.703)	4-5	5	4-5	4-5	24 (21)	22 (19)

MCT-βCD concentration (10 g/*l*), reactive dye concentration (20 g/kg), Ruco-BAC (15 g/*l*).
Values in brackets represent durability to wash after 10 laundering cycles.
V/W: viscose/ wool blend, C/W: cotton/wool blend, UT: untreated reactive print, PT: post-treated reactive print with Ruco®-BAC (15 g/*l*), N%: nitrogen content, K/S: color strength, WF: washing fastness, RF: rubbing fastness, ZI: zone of inhibition, Gram +ve: *S. aureus*, Gram -ve: *E. coli.*

Table 2. Effect of post-treatment with AgNPs/HBPAA composite on some coloration and antibacterial properties

Reactive dye (20 g/kg)	Substrate		N (%)	*K/S*	Fastness properties				ZI (mm)	
					WF		RF		Gram (-ve)	Gram (+ve)
					Alt	C	Dry	Wet		
Reactive Red 198	V/W	UT	5.501	5.71	4	4	4	4	0.0	0.0
		PT	6.490 (5.846)	6.73 (6.14)	4-5	4-5	5	4-5	21 (18.5)	19 (17.0)
	C/W	UT	5.220	4.80	4	3-4	3-4	3	0.0	0.0
		PT	6.151 (5.516)	5.80 (5.31)	4-5	4-5	4-5	4	20.0 (17.0)	18.0 (15.5)
Reactive Blue 19	V/W	UT	5.662	9.58	4	4	4	3-4	0.0	0.0
		PT	6.662 (6.012)	11.08 (10.01)	4-5	4-5	4-5	4	23 (20.0)	21 (18.5)
	C/W	UT	5.453	6.76	4	4	4	4	0.0	0.0
		PT	6.391 (5.801)	8.01 (7.31)	4-5	4-5	4-5	4-5	22 (19.0)	20 (17.5)

MCT-βCD concentration (10 g/*l*), Reactive dye concentration (20 g/kg), AgNPs/HBPAA (15 g/*l*).
Values in brackets represent durability to wash after 10 laundering cycles.
V/W: viscose/wool, C/W: cotton/wool, UT: untreated reactive print, PT: post-treated reactive print with AgNPs/HBPAA composite (15 g/*l*), N%: nitrogen content, *K/S*: color strength, WF: washing fastness, RF: rubbing fastness, ZI: zone of inhibition, Gram + ve: *S. aureus*, Gram -ve: *E. coli.*

type of reactive dye. It is evident that i) pre-modified→ reactive printed substrates demonstrated non-antibacterial activity, irrespective of the type of substrate and kind of reactive dye, ii) post-treatment with AgNPs/HBPAA composite (15 g/*l*) brings about an enhancement in *K/S* values of the printed substrates along with a significant improvement in antibacterial efficacy of the treated reactive prints against Gram-positive (*S. aureus*) and Gram negative (*E. coli*) bacteria, iii) the extent of imparted activity is govrned by type of substrate, fixed reactive dye as well as extent of loading of the nominated composite onto the premodified-reactive printed substrate in addition to the kind of bacteria and follows the descending order: Gram-positive>Gram negative, iv) the imparted antibacterial activity to AgNPs/HBPAA-loaded substrates is attributed to damaging of the bacterial membrane, interaction with DNA, alteration of membrane properties, as well as catalyzing the production of reactive oxygen species that oxidize the molecular structure of bacteria as follows:

$$H_2O + 1/2\ O_2 \xrightarrow{AgNPs} H_2O_2 \longrightarrow H_2O + [O] \qquad (6)$$

thereby changing microorganism's metabolism, inhibiting its growth and finally causing the death of cell [2,28,33], v) the depth of the obtained reactive prints as well as the improvement in antibacterial functionality are varied with the kind of substrate and follows the decreasing order: V/W > C/W, keeping other parameters constant and, vi) there is no remarkable decrease in the depth and antibacterial activity of the treated substrates even after 10 consecutive washings, i.e. high durability to wash.

Conclusion

In conclusion, this research work introduces an effective treatment method to print both the cellulose and wool components of cellulose/wool blended fabrics with reactive dyes as well as to impart a remarkable antibacterial activity to the printed substrates via post-treatment with triclosan derivative and AgNPs/HBPAA composite individually.

The obtained results have signified that pre-modification of the nominated substrates with MCT-βCD, followed by reactive dyeing and finally post-finishing with the nominated antibacterial agents is an efficient route for attaining high quality reactive prints with remarkable antibacterial functionality against both the (*S. aureus*) and (*E. coli*) pathogenic bacteria.

The extent of enhancement in coloration and functionalization properties of the obtained products are determined by type of substrate, extent of premodification, type of reactive dye and extent of fixation, as well as type of post-finishing agent and its extent of loading and interaction with the modified→reactive printed substrate, in addition type of bacteria.

SEM images and EDX patterns for selected fabric samples confirmed the changes in fabric surface morphology as well as loading of Ag element compared with untreated ones.

In a word, this treatment sequence is an effective way to modify both the cellulose and wool components, enhance their printability with one class of dyes namely reactive, as well as to impart durable antibacterial functionalities to the

final reactive prints, i.e. high quality V/W and C/W reactive prints with remarkable antibacterial performance.

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