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ABSTRACT

The quality of cotton and cotton/elastane single jersey knitted fabrics before and after softening was evaluated through their mechanical properties, pilling, and volume electrical resistivity. Elastane-containing fabrics have higher bursting elongation and stiffness, lower bursting strength, the same or higher pilling grade, and 23–27% lower electrical resistivities compared to 100% cotton due to the increased compactness that enables better contact between the loops, and easier flow of charge through them. Softening does not affect or slightly improves the fabric pilling (up to 1000 cycles); it decreases fabrics' stiffness and increases their bursting strength and electrical resistivities. The last one was significantly decreased after the *in situ* synthesis of Cu-based nanoparticles on fabrics' surfaces. Namely, fabrics were first treated with sodium alginate whose carboxylate groups cross-linked Cu^{2+}-ions (from $CuSO_4$ solution) that were further reduced with ascorbic acid. *In situ* synthesis of Cu-based nanoparticles (detected by FESEM) improves the fabrics' quality and enables obtaining multifunctional fabrics having 3.4–9.6 times lower resistivities, which are in line with the content of Cu after reduction (determined using ICP-OES), up to 2.5 times higher antioxidant activity and provided maximum microbial reduction for *E. Coli, S. aureus*, and *C. albicans*.

抽象的

通过力学性能、起球性能和体积电阻率，对柔软前后棉和棉/弹性纤维针织物的质量进行了评价. 与100%棉相比，含弹性纤维的织物具有更高的断裂伸长率和刚度，更低的断裂强度，相同或更高的起球等级，以及更低的23-27%的电阻率，这是因为增加了紧密度，使得线圈之间能够更好地接触，并且更容易通过线圈进行电荷流动. 柔软不会影响或略微改善织物起球(最多1000次)；它降低了织物的刚度，增加了织物的耐破强度和电阻率. 在织物表面原位合成铜基纳米颗粒后，最后一个显著降低. 也就是说，首先用海藻酸钠对织物进行处理，海藻酸钠的羧基交联了Cu2+离子(来自CuSO4溶液)，然后用抗坏血酸进一步还原. 原位合成铜基纳米颗粒(通过FESEM检测) 提高了织物的质量，并能够获得电阻率降低3.4-9.6倍的多功能织物，其与还原后的铜含量(使用ICP-OES测定)一致，抗氧化活性高达2.5倍，并为大肠杆菌、金黄色葡萄球菌和白色念珠菌提供了最大限度的微生物还原.

KEYWORDS

Cotton; elastane; softener; Cu-based nanoparticles; mechanical properties; antioxidant and antimicrobial activity

关键词

棉；弹性纤维；柔软剂；铜基纳米颗粒；力学性能；抗氧化和抗菌活性

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Introduction

Single jersey knitted fabrics made of cotton fibers are widely used for the production of underwear, whose quality is under constant consumer scrutiny. Among many consumers' demands, including durability, the underwear should also have satisfactory mechanical properties. Moreover, special attention is paid to fabric good elasticity, dimensional stability, ability to recover, and fit the body. In addition to these properties, the fabrics intended for underwear should be comfortable, with good air and water vapor permeability. Furthermore, pilling resistance is not essential but one of the desired fabric properties that strongly affects its appearance since pills formation is an unwanted effect observed on the fabric surface (Hassan et al. 2020).

Some of the mentioned fabric properties, such as mechanical properties and volume electrical resistivity are not important only for the consumers, but also for garment manufacturers and designers. Namely, the knitting process is very complex, and wary fabric construction should be performed in order to minimize the static electricity and changes in fabric shape during wearing and washing. All above could be achieved by introducing elastane (a man-made fiber characterized by extension-at-break higher than 200% and rapid recovery after the tension is released, Ivanovska et al. 2021) which is possible to perform in two ways: by using it as a core in the core-spun yarns with cotton fibers or as additional yarn (full and half plated) during circular knitting. From the literature (Herath 2021; Sitotaw and Gedion 2020), it is well known that the elastane introduction had an outstanding impact on knitted fabric mechanical properties; it increases their breaking strength and elongation and decreases the stiffness. On the other hand, Hassan et al. (2020) reported that many fabric surface and mechanical properties could be also altered by different functional finishes such as softening, where the cationic softener is widely used.

Keeping in mind the negative effect of different microorganisms and oxidative stress on people's lives, in the twenty-first century, many research groups are focused on the development of multifunctional textile materials. In most of the published papers, different metal nanoparticles (NPs) were *in situ* synthesized on the fabrics' surfaces by using eco-friendly reducing agents such as ascorbic acid (Hasan et al. 2020), or natural extracts (Shahid-ul-Islam et al. 2019; Yu et al. 2021). Among different metal NPs, the synthesis of Cu-based NPs is of great interest for fabric functionalization since the process is low cost (the copper precursor salts are much cheaper than those of silver) and nontoxic, while the Cu-based NPs show catalytic, antimicrobial (cause the disassembly of the bacterial membrane, Ermini and Voliani 2021), anticancer, and antioxidant activity, or cytotoxicity (Din et al. 2017).

Although it seems impossible to merge all the above discussed in one study, the results presented in this paper prove the opposite. Namely, one part of this investigation is focused on the elastane incorporation, cationic softening as well as their synergistic effect on the mechanical properties, appearance (*i.e.*, pilling resistance), and volume electrical resistivity of cotton and cotton/elastane knitted fabrics. The unexpected slight increase in a fabrics' volume electrical resistivities after softening gives us an idea to use the environmental approach for *in situ* synthesis of Cu-based NPs on their surfaces in order to decrease the tendency to produce static electricity. For that purpose, in the second part of the manuscript, the knitted fabrics were treated with sodium alginate, whose carboxylate groups were used to crosslink with Cu^{2+}-ions (from $CuSO_4$ solution), and were further reduced with ascorbic acid. Surprisingly, all the above mentioned resulted in obtaining multifunctional underwear, which at the same time is comfortable, antimicrobial, and with a higher ability for trapping the free radial of oxygen species and preventing cell deterioration. To the best of our knowledge, this is the first study focused on producing comfortable, antioxidant, and antimicrobial cotton and cotton/elastane softened and unsoftened knitted fabrics *via* a facile, rapid, and green *in situ* synthesis of Cu-based NPs.

Experimental

Material

The cotton ring-spun yarn of 20 tex and elastane yarn of 22 dtex were used for the production of 100% cotton – CoR and half plated cotton/elastane – Co2ELR (98.5% cotton and 1.5% elastane) single jersey knitted fabrics based on the already published procedure (Ivanovska et al. 2021). The raw fabrics were bleached with H_2O_2 and optically brightened. Half of the bleached fabrics were subjected to softening with cationic softener, while the other half were not softened. All used fabrics (Figure 1) were prepared in industrial conditions (Zona-Triko from Vinica, Republic of North Macedonia) according to the standard recipes used for finishing the commercial knitted fabrics.

Methods

Characterization of knitted fabrics

The studied fabrics were characterized in terms of their thickness, weight, and stitch density. The fabric thickness was measured on a SiroFAST apparatus under the pressure of 10 kPa (ASTM D 1777–96 (2011)). The fabric weight and stitch density were determined according to the standards ISO 3801:1977, and BS 5441:1988, respectively. The reported results are the average of ten measurements per sample, whereby the coefficients of variations were below 1.8%.

Mechanical properties, pilling, and volume electrical resistivity of the fabrics

The fabric stiffness was determined on a Digital Pneumatic Stiffness Tester M003F (SDLATLAS, USA) (ASTM D 4032–94). The bursting strength and bursting elongation were measured on the H5KT dynamometer (Tinius Olsen, USA) (ASTM D 6797–02). The knitted fabric pilling propensity (after 125, 500, 1000, 2000, 5000, and 7000 cycles) was determined by using Martindale Abrasion and Pilling Tester (ISO 12945–2:2020). The measurement of fabric volume electrical resistivity (in course direction) through decreasing the humidity in the chamber from 65 down to 55% was performed using the voltage method that has been presented by Kramar et al. (2018).

In situ synthesis of Cu-based NPs on the fabrics' surfaces

In order to obtain fabrics with *in situ* synthesized Cu-based NPs, they were first immersed in a 2% sodium alginate aqueous solution for 1 h at room temperature to improve the Cu^{2+}-ions uptake. After squeezing and drying at 100°C for 10 min, the *in situ* synthesis of Cu-based NPs was performed in two steps. Each fabric (CoB, CoBC, Co2ELB, and Co2ELBC) was immersed in 10 mM of $CuSO_4$ solution for 2 h, 1:100 liquid ratio. After rinsing with distilled water, the samples were immediately dipped into the 0.2 M ascorbic acid solution adjusted to pH 6.50 and the reduction process took place in the following 2 h at 80°C. The fabrics were thoroughly rinsed with deionized water and dried at room

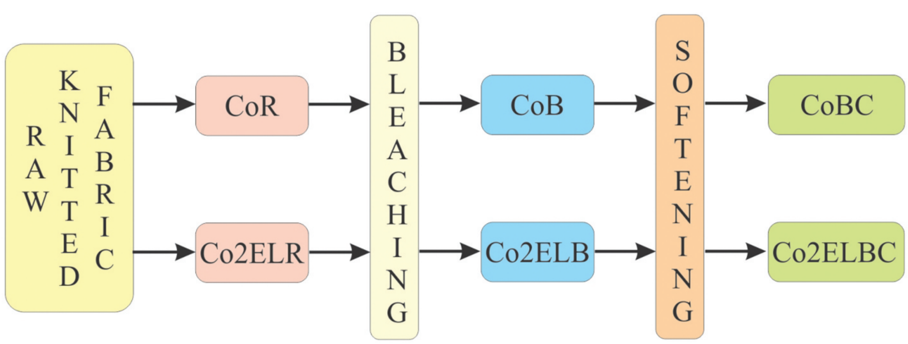

Figure 1. Knitted fabric codes.

temperature; the obtained fabrics were marked as CoBNPs, CoBCNPs, Co2ELBNPs, and Co2ELBCNPs. The content of Cu in these fabrics was determined following the procedure given by Kramar et al. (2018). FESEM microscopy (Tescan MIRA 3 XMU) was used to prove the existence of Cu-based NPs on the knitted fabrics' surfaces.

Antimicrobial and antioxidant activity assay

The fabrics' antimicrobial activity was determined against Gram-negative bacteria *E. coli* ATCC 25922 and Gram-positive bacteria *S. aureus* ATCC 25923, and yeast *C. albicans* ATCC 2443 according to ASTM E 2149–01 (2001) standard, while their antioxidant activity was determined following the procedure described in the literature (Shabbir, Rather, and Mohammad 2018).

Results and discussion

Knitted fabric mechanical properties

Knitting is a very complex process that requires careful fabric construction in order to minimize unwanted changes in its shape during wearing and washing. Additionally, to ensure the knitted fabrics' durability, they should be constructed in such a way as to have satisfactory mechanical properties such as stiffness, bursting strength, and bursting elongation. Fabric stiffness is also one of the factors affecting its softness; low stiffness indicates a softer fabric, while the bursting strength refers to the perpendicular force required to break or rupture the fabric (Hassan et al. 2020). The incorporation of elastane yarn in the cotton knitted fabric and the cationic softening contributed to some changes in the mentioned fabric mechanical properties, Table 1.

The elastane belongs to the group of highly elastic fibers; it is comprised of soft segments providing stretching and hard segments holding the chains together (Ivanovska et al. 2021). Compared to elastane, cotton fibers have very low breaking elongation (400–700% *vs*. 5.6–7.1%), and therefore, it was expected that the introduction of elastane will improve the fabric bursting elongation. The cotton fibers' higher tenacity (27–44 cN/tex *vs*. 5.4–7.2 cN/tex) resulted in about 11% higher bursting strength of CoB compared to Co2ELB fabric. Khandaker et al. (2014) reported that the bursting strength of the knitted fabrics decreases after the heat setting. This also applies to Co2ELR (Figure 1) which is heat-set at 193°C, while the CoR was kept on a flat surface under standard atmospheric conditions and dry relaxed after knitting (Ivanovska et al. 2021). Furthermore, Herath (2021) and Sitotaw and Gedion (2020) reported that single jersey knitted fabric made of 100% cotton yarns possessed higher bursting strength than cotton/spandex fabric, even though, it has shown higher structural parameter values. Besides the fact that the elastane soft segments affect the fabric bursting elongation, the elastane hard segments increased fabric compactness (Table 2) and have a dominant influence on fabric stiffness. The fabric stiffness increases by about 8% after the incorporation of elastane, which is in line with the results published by Salopek, Skenderi, and Geršak (2007).

After softening, both CoBC and Co2ELBC fabrics have about 18% and 6% lower stiffness than before softening, Table 1. These results were expected since the fabric softener acts as a lubricant; it reduces the coefficient of friction between yarns within the fabric and facilitates their slipping. All mentioned phenomena along with the slightly increased bursting elongation are the main reasons for the improvement in fabric bursting strength after softening, which was also observed for differently softened cotton (Safdar et al. 2014), and polyester (Hassan et al. 2020) knitted fabrics. Based on the

Table 1. Mechanical properties of knitted fabrics.

Fabric code	Stiffness, N	Bursting strength, N	Bursting elongation, mm
CoB	0.632	402.8	36.82
Co2ELB	0.680	359.6	42.82
CoBC	0.520	435.5	38.80
Co2ELBC	0.644	371.8	45.48

Table 2. Structural characteristics of bleached knitted fabrics.

Knitted fabric	Thickness, mm	Weight, gm^{-2}	Density, cm^{-2}
CoB	0.415	137	254.9
Co2ELB	0.462	150	253.1
CoBC	0.424	140	252.0
Co2ELBC	0.465	151	247.4

results presented in Table 1, it could be concluded that improved bursting strength and decreased stiffness will extend the life of products made of softened fabrics (CoBC or Co2ELBC). Among them, CoBC is characterized by lower stiffness and is considered more comfortable, it exerts lower pressure on the body due to its ease of shape adoption (Ali et al. 2018).

Knitted fabric appearance

The fabric pilling observed during garments' daily wearing or washing represents one of the essential factors contributing to its quality (Gun and Kuyucak 2021). Therefore, the formation of pills over the fabric surfaces was evaluated as a grade from 5 (no pilling) to 1 (dense surface fuzzing and/or severe pilling).

For all studied fabrics, it is evident that by increasing the number of pilling cycles from 125 up to 7000, pilling grades decreased from 4.5 down to 1 (Table 3) indicating pills formation. After the same pilling cycles, CoB has the same or a lower pilling grade as Co2ELB, which is due to its higher compactness (Table 2) and bursting elongation (Table 1). Elastane in fabric Co2ELB prevented the migration of fibers from its inside to the surface (Gun and Kuyucak 2021). Similarly, Sitotaw and Gedion (2020) indicated that the single jersey cotton/elastane fabric has higher pilling resistance compared to 100% cotton fabric, while Haji (2013) reported increased pilling resistance with an increase of lycra ratio in the cotton-based single jersey fabrics. On the other hand, according to (Abdel-Fattah and El-Khatib 2007), the improved pilling resistance could be a result of heat setting and stabilizing the fibers inside the yarn. This is also true for the elastane-containing fabric Co2ELB.

Up to 1000 pilling cycles, softening does not affect or slightly improves the fabric appearance. Furthermore, with increasing the cationic softener pick-up from 0.645 to 0.706 for CoBC and Co2ELBC (Ivanovska et al. 2021), the fabric pilling grade remains almost unchanged or increased slightly, Table 3.

Volume electrical resistivity of knitted fabrics

The volume electrical resistivity (in further text: resistivity) was examined to analyze the fabric's tendency to produce static electricity. Having in mind that the studied fabrics intended for underwear could be used in different humidities, the resistivity measurements were carried out at different relative air humidities (RHs), Figure 2. As was expected, by decreasing the RH from 65 down to 55%, the fabrics'

Table 3. Evaluation of the fabric pilling.

	Knitted fabrics			
	CoB	Co2ELB	CoBC	Co2ELBC
Number of pilling cycles	Pilling grade			
125	4	4	4.5	4.5
500	3	3.5	3	4
1000	2.5	3	2.5	3
2000	2	3	2	2
5000	1	2	1.5	1.5
7000	1	1	1	1

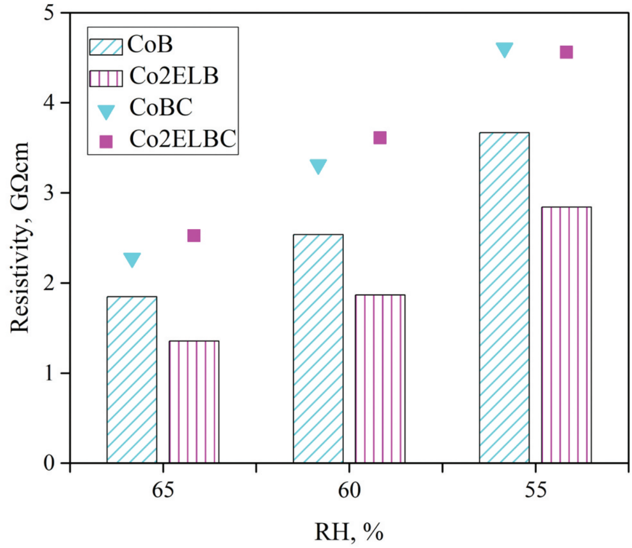

Figure 2. The influence of relative humidity (RH), elastane incorporation, and softening on the resistivity of knitted fabrics.

resistivities increased by about 1.8–2.1 times. Such behavior was previously observed by Asanovic et al. (2021) and Ivanovska et al. (2020) and could be ascribed to the fact that RH induced partly ionization of water molecules located around the fabrics, and neutralized the electric charges on the fabric surface.

Besides the RH, the incorporation of elastane and softening agent also influenced the fabrics' resistivities. It is interesting to note that although elastane is a hydrophobic fiber, its incorporation in cotton fabric induced a decrease in the resistivity for 23–27%, Figure 2. By observing the results listed in Table 2 and those presented in Figure 2, it is clear that the increased fabric compactness (*i.e.*, increased weight and thickness) is the main reason for the lower resistivity of fabric Co2ELB compared to CoB. More precisely, better contact between the loops, and hence, the easier flow of charge through them occurred due to the increased fabric compactness.

The situation is different in the case of softened fabrics; they have a more compact structure than the non-softened ones (Table 2) and possessed about 23–93% higher resistivities (Figure 2) indicating that another factor affects their resistivities. The previously described mechanism of cationic softener pickup (Ivanovska et al. 2021) could be found as a possible explanation for such unexpected high resistivity values of softened fabrics. Namely, when the knitted fabrics were immersed in water, their surfaces get a negative charge and are capable of binding cationic softener positively charged ends. In such a way, hydrophobic carbon chains (Duru and Şahin 2020) repel each other contributing to a high volume of the yarns. In other words, hydrophobic carbon chains could disturb the electric flow through the fabric resulting in higher resistivity of softened fabrics. This assumption is additionally confirmed by the parallel influence of elastane incorporation and softening on the fabrics' resistivity since when the elastane was incorporated, a cationic softener pickup increases (Ivanovska et al. 2021), and the differences between the resistivities of non-softened and softened elastane-containing fabrics sharply increase (Figure 2).

Obtaining multifunctional knitted fabrics

Taking into account the increased demand for comfortable and multifunctional underwear as well as the metals' high conductivity, one of the protocols that could be used to decrease the fabrics' resistivity, and hence, to improve their overall quality is *in situ* synthesis of Cu-based NPs on their surfaces. Due to the lack of a sufficient number of functional groups as potential sites for binding Cu^{2+}-ions, the fabrics were first treated with sodium alginate solution. Owing to its anionic nature, sodium alginate carboxylate groups are crosslinked by Cu^{2+}-ions from copper(II) sulfate solution. Thereafter, the *in situ* reduction was performed using ascorbic acid as a green reducing agent. Such functionalized knitted fabrics were further characterized and the possibility for their utilization as multifunctional underwear was considered.

Table 4 compares the knitted fabrics' resistivities (at 55% RH) before and after *in situ* synthesis of Cu-based NPs. Interestingly, knitted fabrics with *in situ* synthesized Cu-based NPs have about 3.4–9.6 times lower resistivities, *i.e*., lower ability to produce static electricity, and therefore, they are more comfortable than before the treatment. It has to be emphasized that before *in situ* synthesis of NPs, non-softened fabrics possessed lower resistivities than softened ones, while after the *in situ* synthesis, this trend is opposite; the softened fabrics have about 25% lower resistivities compared to non-softened, Table 4.

This seems to be the right place to discuss the role of Cu content on the knitted fabrics' resistivities. The results listed in Table 4 indicates that the resistivities of knitted fabrics with NPs are in agreement with the Cu content after reduction. The reason why non-softened knitted fabrics have lower Cu content than softened undoubtedly lays in the putative adsorption mechanism and the intensity of the interaction between fabric surface and alginate. Namely, since both the alginate and cotton fibers are abundant in hydroxyl groups, it is reasonable to assume that the interactions between them are mainly achieved through the hydrogen bonds, Figure 3. On the other hand, alginate chains are stabilized and crosslinked by copper ions through chelate formation among themselves (Cao et al. 2020). After dipping in ascorbic acid, the reduction of copper ions takes place providing material bearing Cu-based NPs, Figure 3. Slightly higher content of Cu measured in the softened knitted fabrics (CoBNPs *vs*. CoBCNPs and Co2ELBNPs *vs*. Co2ELBCNPs) could be ascribed to cationic softener nature, Figure 4. Specifically, the cationic softener is oriented in such a way that its polar heads interact with the fabric surface (mainly with polarized hydroxyl groups), while the hydrophobic tail remains free creating a layer that restricts the formation of the intermolecular hydrogen bonds between hydroxyl groups of

Table 4. Comparison between the fabrics' resistivities (at 55% RH) before and after *in situ* synthesis of Cu-based NPs and the content of Cu after reduction.

Knitted fabrics	Resistivity, GΩcm	Content of Cu after reduction, mg/g
CoB	3.67	/
CoBC	4.61	/
Co2ELB	2.84	/
Co2ELBC	4.56	/
CoBNPs	0.65	1.455
CoBCNPs	0.48	1.555
Co2ELBNPs	0.83	0.834
Co2ELBCNPs	0.62	0.963

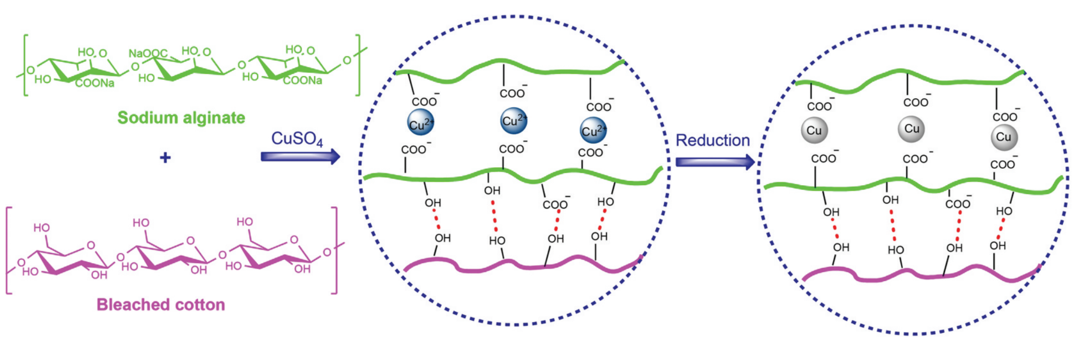

Figure 3. Sodium alginate adsorption mechanism onto cotton and cotton/elastane non-softened and softened knitted fabrics.

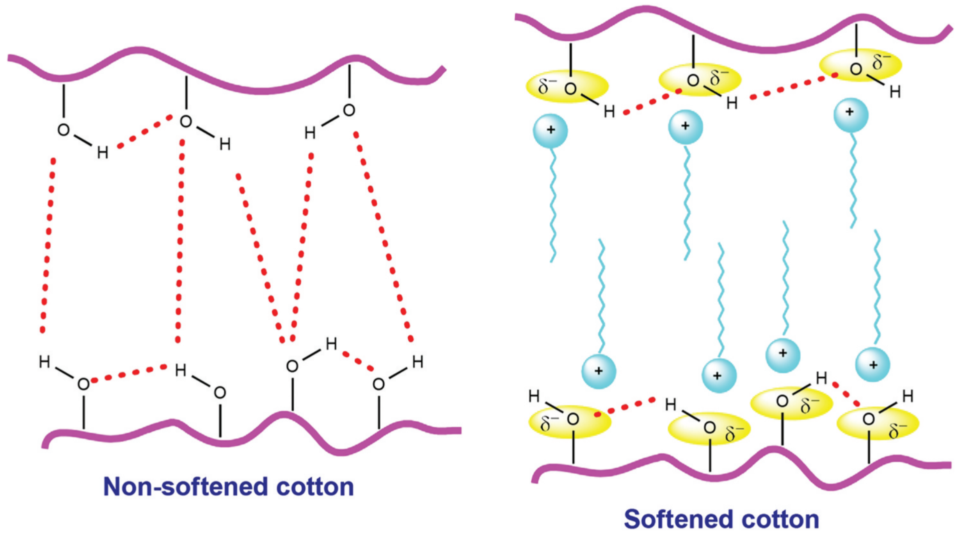

Figure 4. Inter- and intramolecular hydrogen bonds for softened and non-softened cotton knitted fabrics.

the adjacent cotton fibers (Igarashi et al. 2016). In such a way, these hydroxyl groups, whose intramolecular hydrogen bonds are mainly preserved, become more flexible and available for interaction with alginate resulting in higher content of Cu. It is good to mention that Co2ELBNPs and Co2ELBCNPs fabrics have a much lower Cu content when compared to corresponding fabrics without elastane (CoBNPs and CoBCNPs) which could be attributed to the more hydrophobic nature of elastane-containing fabrics having a lower affinity toward highly hydrophilic alginate chains.

Besides the change in fabric color (from white to pale yellow, Fig. S1, Supplementary material), FESEM microscopy was also used to prove the existence of Cu-based NPs on the fibers' surfaces. The first two SEM images (CoB, Figure 5) reveal a typical cotton fiber surface morphology with a pronounced convolution. In the case of the cotton fibers with *in situ* synthesized Cu-based NP-s, smaller and higher agglomerates of NPs were unevenly distributed over their surfaces (CoBNPs, Figure 5).

Apart from lowering the fabrics' resistivities for providing better comfort properties, and fabric quality, the *in situ* synthesis of Cu-based NPs also improved their antioxidant activity (Figure 6) known to be an important factor in biological damage caused by oxidative stress (Čuk, Šala, and Gorjanc 2021). Although cotton and cotton/elastane knitted fabrics contain hydroxyl groups originating from cellulose, they are characterized by a weak antioxidant activity ranging from 33 up to 41%. Knitted fabrics with *in situ* synthesized NPs have up to 2.5 times higher antioxidant activity compared

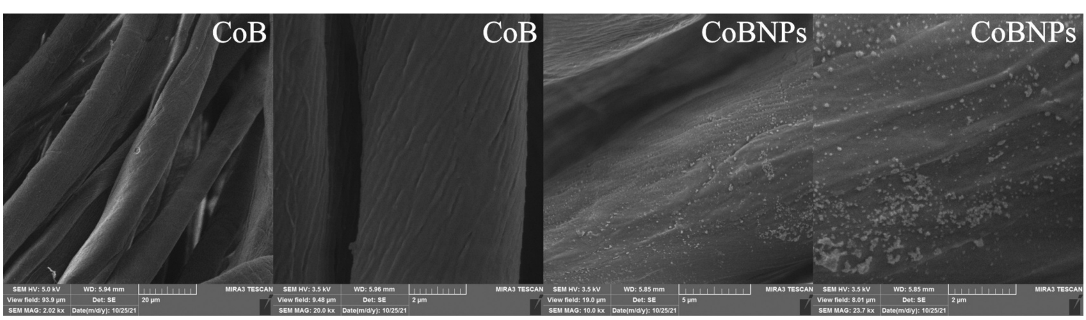

Figure 5. SEM images of cotton fibers before (CoB) and after (CoBNPs) *in situ* synthesis of Cu-based NPs.

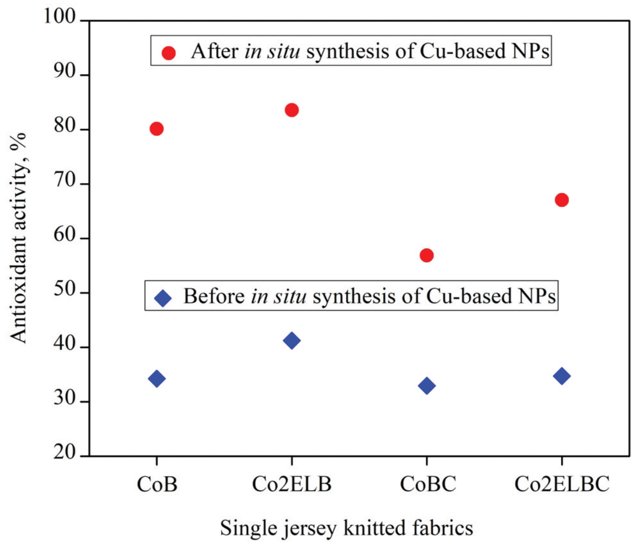

Figure 6. Comparison between the knitted fabric antioxidant activity before and after *in situ* synthesis of Cu-based NPs.

Table 5. Antimicrobial activity of knitted fabrics.

	Number of microbial colonies, CFU/ml, and microbial reduction, %					
Fabric codes	*E. coli*, CFU/ml	*E. coli*, %	*S. aureus*, CFU/ml	*S. aureus*, %	*C. albicans*, CFU/ml	*C. albicans*, %
CoB	$8.2 \cdot 10^6$	0	$1.1 \cdot 10^5$	0	$9.8 \cdot 10^5$	0
CoBC	$8.2 \cdot 10^6$	0	$1.1 \cdot 10^5$	0	$9.8 \cdot 10^5$	0
Co2ELB	$8.2 \cdot 10^6$	0	$1.1 \cdot 10^5$	0	$2.1 \cdot 10^4$	97.8
Co2ELBC	$8.2 \cdot 10^6$	0	$1.1 \cdot 10^5$	0	$9.8 \cdot 10^5$	0
CoBNPs	0	99.99	0	99.99	0	99.99
CoBCNPs	0	99.99	0	99.99	0	99.99
Co2ELBNPs	0	99.99	0	99.99	0	99.99
Co2ELBCNPs	0	99.99	0	99.99	0	99.99

to their counterparts before *in situ* synthesis of NPs. In other words, fabrics containing NPs have a higher ability for trapping the free radial of oxygen species, preventing cell deterioration and growing a new cell in the skin. Recent research conducted by Rajeshkumar et al. (2019) has shown that Cu-based NPs are rich in antioxidants and can be used for free radicals' elimination.

It is well known that besides antioxidant activity, Cu-based NPs impart antimicrobial activity to different textile materials such as cotton (Sedighi and Montazer 2016), wool (Rezaie et al. 2017), *etc.* This gives us an idea to investigate and compare the antimicrobial activity of fabrics before and after *in situ* synthesis of Cu-based NPs against three microorganisms: *E. Coli, S. aureus*, and *C. albicans*, Table 5.

It was observed that fabrics with Cu-based NPs possessed maximum microbial reduction for *E. Coli, S. aureus*, and *C. albicans* which is ascribed to the existence of NPs. Din et al. (2017) proposed four possible mechanisms of Cu-based NPs antibacterial action which includes: (1) DNA helical structure damage due to the interaction with NPs, (2) entry of NPs inside the cell develop oxidative stress leading to cell death, (3) accumulation of the Cu-based NPs on the bacteria cell surface from pits in the membrane causing cell leakage, and (4) interaction of Cu-based NPs with bacteria cell membrane decreases the transmembrane electrochemical potential affecting membrane integrity.

The finding of this section showed that *in situ* synthesis of Cu-based NPs for lowering fabric electrical resistivity not only provide more comfortable but also multifunctional fabrics having higher antioxidant and antimicrobial activity.

Conclusion

The results of this study confirmed that knitted fabrics' of 100% cotton or half plated cotton/elastane along with cationic finishing significantly affect the fabrics' quality. Namely, the introduction of elastane increases fabrics' bursting elongation and stiffness and decreases bursting strength as a consequence of elastane's higher breaking elongation and lower tenacity compared to cotton fibers as well as the applied heat setting and higher compactness of elastane containing fabrics. Cationic softener decreases the fabric stiffness since it reduces the coefficient of friction between yarns within the fabric and facilitates their slipping. All mentioned phenomena in parallel with the slightly increased fabric bursting elongation are the main reasons for the improvement in fabric bursting strength after softening.

After the same pilling cycles, 100% cotton fabric has the same or a lower pilling grade compared to the fabric that contains elastane which could be ascribed to the parallel influence of higher compactness and breaking elongation of elastane-containing fabric that prevent the migration of fibers from the fabric interior to its surface. Up to 1000 cycles, softening does not affect or slightly improves the fabric's appearance.

The fabrics' quality was further evaluated based on their volume electrical resistivities. The elastane incorporation decreases the fabrics' resistivities by 23–27% due to their increased compactness which enables better contact between the loops, and hence, the easier flow of charge through them. Unexpectedly, cationic softening increases the fabrics' resistivities by 23–93% which could be explained by the softener pickup mechanism and the hydrophobic carbon chains on the yarns that disturb the electric flow through the fabrics. Such results were improved after the *in situ* synthesis of Cu-based nanoparticles over the fabrics' surfaces. Apart from lowering the fabrics' electrical resistivity (for 3.4–9.6 times) for providing better comfort properties, and therefore, fabric quality, the *in situ* synthesis of Cu-based NPs also contributed to obtaining multifunctional fabrics' having 2.5 times higher antioxidant activity, and maximum microbial reduction for *E. Coli, S. aureus* and *C. albicans*.

Highlights

1. Cotton/elastane knitted fabrics have higher bursting elongation and stiffness, lower bursting strength, the same or higher pilling grade, and 23–27% lower electrical resistivities compared to 100% cotton fabrics.

2. Softening with cationic softener does not affect or slightly improves the fabric pilling; it decreases fabrics' stiffness and increases their bursting strength and electrical resistivities.

3. Knitted fabrics' resistivity was significantly decreased after the *in situ* synthesis of Cu-based nanoparticles on their surfaces.

4. *In situ* synthesis of Cu-based nanoparticles improves the fabrics' quality and enables obtaining multifunctional fabrics having 3.4-9.6 times lower resistivities, up to 2.5 times higher antioxidant activity and provided maximum microbial reduction for *E. Coli, S. aureus*, and *C. albicans*.

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