IMPROVE THE ANTIBACTERIAL PROPERTIES OF COTTON BANDAGES COATED WITH SILVER PARTICLES AND FINISHED WITH A NATURALLY EXTRACTED DYE

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ABSTRACT

We created antibacterial stretchable medicated textiles. Initially, we used a versatile one-pot green synthesis method to produce a concentrated and stable colloidal solution of silver nanoparticles (Ag-NPs) by self-assembling tannic acid, avoiding any harmful chemicals. The silver particles were later deposited on the cotton fabrics. The surface morphologies were analyzed by SEM and the presence of metals was inspected by dynamic light scattering and XRD. In second step, the natural antibacterial dye from the pomegranate peel was prepared and the fabrics of silver coated cotton were treated by the exhaust dyeing method. We assessed the CILAB (L*, a*, b*, C, h, and K/S) and color fastness properties of the dyed fabric samples. Additionally, we evaluated the antipathogenic properties (antibacterial, antiviral, and antifungal) of all coated fabrics.

KEYWORDS

Silver nanoparticles; Antibacterial bandages; Natural dyes; Green synthesis; Aesthetic properties; *S. Aureous*; *E. Coli*.

INTRODUCTION

Silver nanoparticles (AgNPs) are identified as nanomaterials with sizes ranging from 1 to 100 nm. They have a higher surface area (area-to-volume ratio) and a greater volume capacity than bulk silver. Due to the distinct electrical, optical, and catalytic characteristics of AgNPs at the nanoscale, research and development has been directed toward uses in targeted drug delivery, imaging, diagnosis and detection [1] [2]. The impressive antibacterial properties of AgNPs have garnered significant attention from both researchers and industries. They have demonstrated effectiveness against multidrug-resistant bacterial populations and various infectious and pathogenic microorganisms, showcasing their antimicrobial activity. The enhanced antibacterial action of silver at the nanoscale is beneficial in the medical and healthcare fields. AgNPs have been integrated into numerous products, including food contact materials, cosmetics, surgical instruments, wound dressings, catheters, textiles and dental products [3]. Research has shown that AgNPs can function as antibiotics through multiple mechanisms of action that impact various microbial structures simultaneously, allowing them to effectively target different bacterial strains [4]. Because of their potent antibacterial qualities, AgNPs are frequently utilized in a variety of commercial products, especially in the textile industry, to avoid microbial contamination. Many researchers have identified AgNPs as ideal antibacterials, ensuring that fabrics remain free from microorganisms such as viruses, bacteria and fungi. The incorporation of AgNPs significantly enhances the antimicrobial effectiveness of wound dressings when sprayed onto fabrics. Most antimicrobial composites containing AgNPs have shown high efficacy against nearly 650 different bacterial strains. The methods used to prepare these nanoparticles can lead to variations in their physical and chemical properties [5]. Traditional synthesis methods often involve toxic substances, which can endanger both the environment and human health. Currently, fabrics are coated with nanoparticles using various techniques such as screen spraying, painting, padding, dip coating, and sonochemical methods. These coating techniques aim to improve the nanoparticles' stability and adsorption on the fabric. It is crucial that the resulting nanoparticles maintain a stable structure, whether in colloidal or metallic form. These factors are important considerations for the coating process to ensure optimal performance [6]. Researchers have concentrated on producing stable Ag NPs while controlling their size and minimizing the

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use of harmful chemicals. In this context, green-synthesized nanoparticles were employed, which eliminates the need for cryogenically synthesized nanoparticles and their associated adverse effects. The green synthesis method ensures that the nanoparticles do not contain toxic substances, leading to formation of colloidal Ag NPs [7]. In this study, the synthesis of Ag NPs used *Peltophorum pterocarpum* flower extract as a non-toxic reducing and binding agent. Additionally, the dip and sonication methods did not require any adhesive, as the green-synthesized Ag NPs were directly applied directly to cotton textiles. Medical products that contain silver compounds are utilized for treating burns, wounds, and various infectious diseases. The growing issue of antibiotic resistance poses a significant challenge in treating certain infections, which raises concerns in the fight against contagious diseases. If not properly regulated, the excessive use of antibiotics could diminish the effectiveness of many bacterial pathogens. As a response to this, antimicrobial dressings have been increasingly developed using biological polymers that are integrated with antimicrobial components [8]. Each type of wound dressing aids in the healing process, but scientists are striving to deepen their understanding to create wound dressings that are free from toxins, have longer durability, offer stronger resistance, and gain clinical acceptance. Among the available materials, cotton is often considered a suitable candidate for modified dressings. Traditionally, cotton has been used in many countries for dressing wound sites to prevent contamination. Wounds such as cuts or grazes tend to heal faster when treated with cotton, and it is generally non-irritating to sensitive skin. However, using cotton pads for wound treatment presents several challenges. When immersed in wound fluids, cotton fibers can adhere strongly, similar to glue. As a result, when the cotton is pulled away, it can unintentionally remove healing cells from the wound site, leading to side effects such as prolonged healing times and pain during dressing changes, especially since the wound area is often sensitive [9]. This issue can be effectively addressed by using chitosan, a structural biopolymer known for its ability to form hydrogels and its anti-pathogenic properties, which facilitate easier wound management. Additionally, glycogen, a safe and nontoxic animal polysaccharide, can help mitigate these problems. It not only aids in healing but also prevents tissue scarring when the injury areas form albumin and are dressed, thereby promoting a more effective healing process [10]. Clinical textiles, often referred to as 'hospital textiles,' must meet specific standards, including being non-toxic, anti-allergic, antimicrobial, and anti-inflammatory. Various agents, such as metal particles and specific treatments, are applied to textile materials to impart antibacterial properties. Recently, the use of metallic compounds as nanoparticles has gained traction for integrating beneficial properties into fabrics, thereby reducing the spread of diseases and microbial growth. Commonly used compounds include Ag (silver), TiO_2 (titanium dioxide), Cu (copper), CuO (copper (II) oxide), Cu_2O (copper(I) oxide), ZnO (zinc oxide), and MgO (magnesium oxide) polycrystalline. Among these, silver and its compounds stand out due to their exceptional surface disinfectant properties, which include antiviral, antibacterial, and antifungal effects against various pathogens. Research by Ali et al. demonstrated that cotton fabric coated with silver nanoparticles exhibits significant effectiveness against harmful microbes, leading to the designation of this material as a multifunctional textile. In light of these findings, the article proposes a novel approach to producing antimicrobial cotton fabrics coated with silver, aiming to enhance both aesthetic and functional properties. The objective is to explore how these fabrics can benefit commercial and medical applications, particularly as they are expected to exhibit improved antibacterial activity post-dyeing. Beyond medical uses, these antimicrobial fabrics could find applications in pillow covers, bedsheets, and even clothing for patients, as well as in compression bandages [11]. The cotton fabric is indeed a remarkable achievement in textile engineering, known for its comfort, absorbance, and breathability. While it may not always match the strength of some synthetic materials, its unique characteristics keep it in high demand globally. Nowadays, consumers are increasingly focused on aesthetics, leading to a growing need for cotton fabrics that are not only stylish but also convenient and comfortable [12]. Nanotechnology has opened up exciting possibilities for modifying cotton textiles to fulfill these modern requirements. In textile manufacturing, there is now a greater emphasis on achieving multifunctional properties through specific finishes. These finishes, which have become standard, include antistatic, durability, antimicrobial, dirt repellent, flame resistance, water repellent, easy crease recovery, self-cleaning, and UV protection [13]. Enhancing the surface of textiles is a key method for augmenting these functional characteristics. The use of noble metal nanoparticles has emerged as an effective strategy for creating fabrics with multiple useful functions. Different types of nanoparticles offer distinct advantages for textile surfaces. For instance, zinc oxide nanoparticles are known for providing UV protection in garments, silver nanoparticles are recognized for their antibacterial properties, and titanium dioxide is utilized in self-cleaning fabrics. This innovative approach allows for the development of cotton fabrics that not only meet but exceed modern consumer expectations [14]. These nanoparticles are indeed applied to the surfaces of cotton fabrics, making them suitable for various applications, including casual clothing, sportswear, and medical settings such as bandages, absorbent pads, gowns, gauzes, and padding materials. The moisture-rich nature of cellulose-containing cotton fibers does make them vulnerable to microbial invasion, creating a conducive environment for bacterial and fungal growth [15]. Silver nanoparticles are particularly noteworthy due to their excellent antimicrobial properties when applied to textile materials. The effectiveness of these antibacterial characteristics increases as the particle size decreases. Anisotropic silver nanoparticles can also be used to dye cotton fabrics in a variety of colors while imparting those antibacterial properties [16]. Most research efforts have focused on assessing the antimicrobial properties of these nanoparticles, but there has been limited investigation into their wash durability. Factors such as shape, particle size, concentration, and surface treatment both before and after application can significantly influence the levels of antimicrobial activity observed. Interestingly, this research indicates that wash durability can be improved. However, to date, there has been no study specifically evaluating color uniformity in cotton materials coated with silver nanoparticles [17].

EXPERIMENTAL

Materials and Methodes

In this Method, silver nanoparticles are synthesized and deposited onto cotton stretch fabric. The chemicals used for this process were of 99.99% purity and sourced from Sigma-Aldrich. The pretreated fibers were first treated with a 12 wt% aqueous sodium hydroxide solution at room temperature for 10 minutes, followed by rinsing with distilled water. This treatment likely aimed to enhance the surface properties of the fibers for better nanoparticle adhesion. Three different concentrations of silver nitrate ($AgNO_3$) solution were prepared: 1M, 0.5M, and 0.25M. Aqua ammonia (28 wt%) was gradually added to these solutions and stirred continuously until a clear $[Ag(NH_3)_2]^+$ solution formed. The alkali-treated textiles were then immersed in each solution for 10 minutes and dried at 90°C for another 10 minutes. This immersion and drying process was repeated for a total of 10 cycles to maximize the deposition of $[Ag(NH_3)_2]^+$ and Ag+ ions onto the textiles. Finally, the treated fabrics were immersed in a 0.3M glucose stock solution, along with any remaining $[Ag(NH_3)_2]^+$ solution [18].

Application of dye on fabric

The fabric was dyed using a material-to-liquid (M: L) ratio of 1:40. This means that for every1 part of fabric, there are 40 parts of the dyeing liquid. The dyeing process began with the addition of alkali sodium hydroxide (NaOH) at a concentration of 1 g/L. This helps to increase the pH of dye bath, which can improve the dye uptake by the fabric. Next, 40 g/L of sodium sulfate (Na_2SO_4) was added to the dye bath. Sodium sulfate acts as an electrolyte, helping to maintain the ionic strength of the dye bath and improving the leveling of the dye on the fabric. After that, the fabric was soaked in the dye bath to allow it to absorb the color. The exhaust dyeing method typically involves heating the dye bath to help the dye penetrate the fabric more effectively. After the desired dyeing time, the stained fabric was taken out of the dye bath and washed with tap water. This washing step is crucial to remove any excess dye that did not bond to the fabric, ensuring that the final product has a clean and even color.

RESULTS AND DISCUSSION

Colorimetric data measurement

The CIELAB values of silver coated dyed and undyed fabrics differs considerably. The K/S values for dyed sample was relatively high (11.31) than for undyed fabric (7.47), indicating that dyeing has altered the light-colored silver coated fabric to a relatively dark-colored fabric. The variation in L* values among both fabrics confirmed the dark shade of the colored fabric. The L* value of the dyed fabric was relatively low (37.15) than the differences in color characteristics between silver-coated dyed and undyed fabrics, using CIELAB color space values. The K/S (absorbance/scattering) values indicate how much light is absorbed and scattered by the fabric. The dyed sample has a K/S value of 11.31, which is significantly higher than the undyed fabric's K/S value of 7.47. This suggests that dyeing has resulted in a darker appearance for the silver-coated fabrics. The L* value measures lightness, where lower values indicate darker shades. The dyed fabric has an L* value of 37.15, compared to 55.35 for the undyed fabric. This confirms that the dyed fabric is indeed darker than the undyed fabric. Chroma represents the intensity or saturation of the color. The dyed fabric has a C* value of 34.98, which is lower than the undyed fabric's C* value of 37.79. This indicates that the undyed fabric has a more vibrant and sharper shade, while the dyed fabric appears darker and duller. Both dyed and undyed fabrics have positive a* and b* values, indicating the presence of yellowish and reddish hues. This suggests that both fabrics share some color characteristics, but the differences in K/S, L*, and C* values highlight the impact of dyeing on the overall color perception. In summary, the dyeing process significantly alters the color properties of the silver-coated fabric, resulting in a darker, less vibrant appearance compared to the undyed fabric the L* value of the undyed fabric (55.35), indicating that the dyed sample is darker in color than the undyed sample. The chroma (C*) for the dyed fabric was relatively low (34.98) than for the undyed sample (37.79), indicating that the undyed samples had a sharper shade and the dyed sample had a darkened and duller shade. The a* and b* values were positive for both undyed and dyed fabric, representing a yellowish and reddish color.

Levelness of silver treated dyed and undyed fabric

The dye levelness provides valuable insights into the uniformity of dye application on silver-coated fabrics. Spectrophotometer Measurements: The use of a spectrophotometer to measure the reflectance at 12 different points on both dyed and undyed fabrics allowed for a comprehensive evaluation of dye levelness. K/S Values and Standard Error: The K/S values were accompanied by standard error measurements, which indicate the consistency of the dye application. The standard error was 0.12 which is quite low for dyed silver-coated fabric. This suggests that the dye is distributed evenly across the fabric, leading to excellent levelness. Comparison with Undyed Fabric: In contrast, the standard error for the silver-coated undyed fabric was significantly higher at 2.21. This indicates a highly uneven appearance, suggesting that the undyed fabric does not have a consistent look. Visual Assessment Ratings: The visual assessment further supports these findings, with dyed fabrics rated as grade 5 (excellent levelness) and undyed fabrics rated as grade 2 (poor levelness). This visual confirmation aligns with the quantitative measurements, reinforcing the conclusion that dyeing silver-treated fabrics results in a smoother and more even appearance.In summary, the dyed silver-coated fabrics demonstrate superior levelness and uniformity compared to their undyed counterparts, both in terms of statistical analysis and visual assessment [19].

Morphology of silver coated knitted dyed cotton fabrics

Visuals in Figure 1 (a) displayed nanometer-scale images of silver particles pre-application on fabric, showing spherical features without aggregations. The claim was supported by Zeta potential and polydispersity index (PDI) values of -51.63 ± 5.19 mV and approximately 0.292, respectively. These values indicated even particle distribution and high polydispersity. Scanning electron microscopy (SEM) revealed structural morphologies of silver particles on fabrics pre and post dyeing in Figures 1 (b,), showing a more consistent and denser silver coating. Moreover, Figures 1 (c) and Table 2 are showing the elemental composition of silver gained. Figures 1 (d) The average particle size distribution for silver nanoparticles was found to be approximately 13.23 ±1.6 nm. The phase composition of silver nanoparticles was determined by XRD. Figure 1 (e) presented XRD spectra in the range of 20 to 80 ° with a 0.02-degree step, showing ideal indexing to the silver structure, confirming the phase purity of the synthesized silver nanoparticles.

Antibacterial activity, antifungal and antiviral activity

The antibacterial efficacy of both undyed and dyed silver treated textile substrates was assessed through qualitative and quantitative standard testing protocols.

The qualitative evaluation of all treated samples was conducted using the AATCC-147 (disc-diffusion method) protocol, which tested the samples for antibacterial efficacy against both Gram-positive (*S. aureus*) and Gram-negative (*E. coli*) pathogens. The antibacterial efficacy of both undyed and dyed silver-treated textile substrates was assessed using the AATCC-147 (disc-diffusion method) protocol (Figure 3). The Zone of Inhibition (ZOI) for the dyed fabrics was found to be higher than that for the undyed fabrics. The higher ZOI values for the dyed fabrics indicate that the antibacterial qualities of the silver nanoparticles were unaffected by the antibacterial dye. Antibacterial dye did not negate the antibacterial properties of silver nanoparticles, as seen by the higher ZOI values for textiles colored with silver coatings. The antifungal activity of all treated fabric samples (both dyed and undyed) was evaluated using the AATCC-100 method against A. *niger* fungal species. In Figure 2(a), the results show the percentage reduction in fungal spore germination for all samples. All of the fabric samples that were treated showed strong antifungal activity against the A. *niger* fungus. The antifungal activity of the dyed samples was enhanced, indicating that the dye used has excellent antifungal properties. Among the undyed

Table 1. Reflectance measurement data for the dyed and undyed silver coated fabrics.

Number of Scans	K/S Values dyed sample	Standard deviation (S.D)	K/S Values undyed sample	Standard deviation (S.D)
Reading 1	11.32	0.12	13.75	2.21
Reading 2	11.56		16.56	
Reading 3	11.21		7.34	
Reading 4	11.98		12.56	
Reading 5	11.65		6.45	
Reading 6	11.45		11.35	
Reading 7	11.99		14.67	
Reading 8	11.56		7.65	
Reading 9	11.25		12.34	
Reading 10	11.42		8.45	

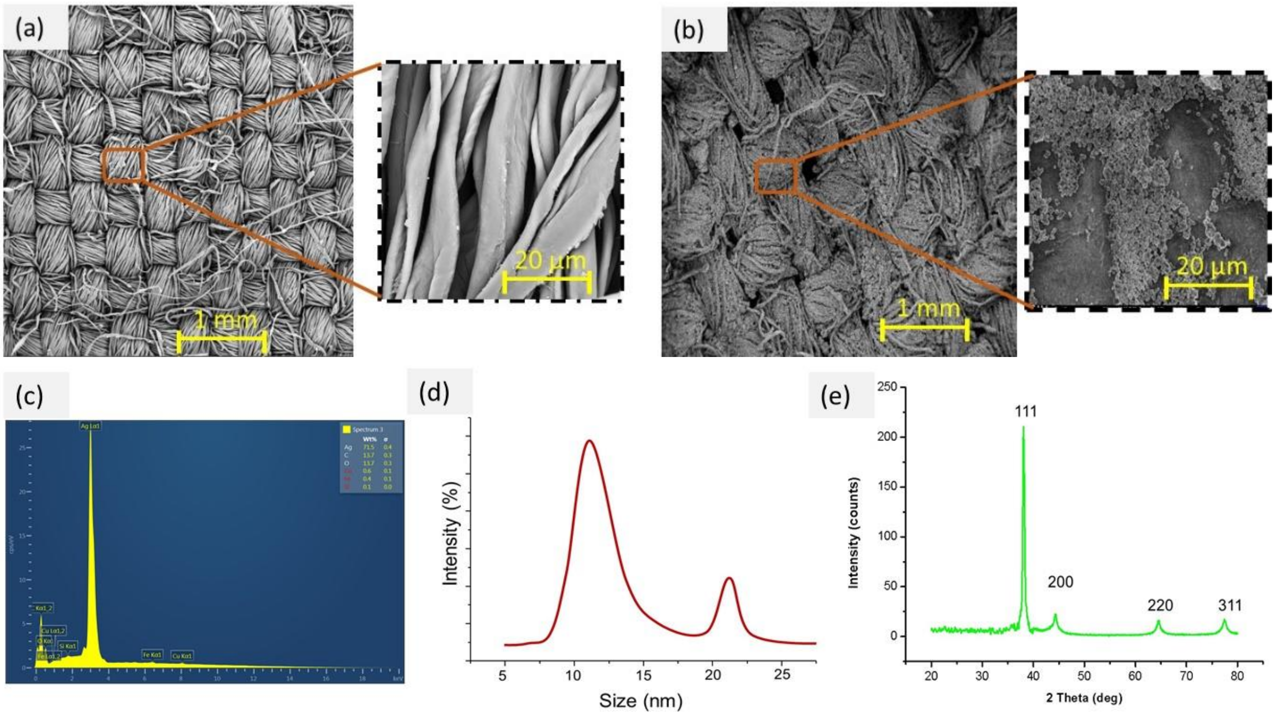

Figure 1. SEM images of (a) silver particles, (b) silver particles coated cotton fibers, (c) silver particles coated and dyed cotton fibers, (d) EDX analysis, (e) Size analysis and (f) XRD of silver particles.

Table 2. Elemental percentage of Silver.

Element	Line Type	Wt%	Wt% Sigma	Atomic %
C	K series	13.73	0.26	42.61
O	K series	13.71	0.31	31.94
Si	K series	0.12	0.03	0.15
Fe	K series	0.37	0.07	0.25
Cu	K series	0.60	0.10	0.35
Ag	L series	71.48	0.35	24.70
Total:		100.00		100.00

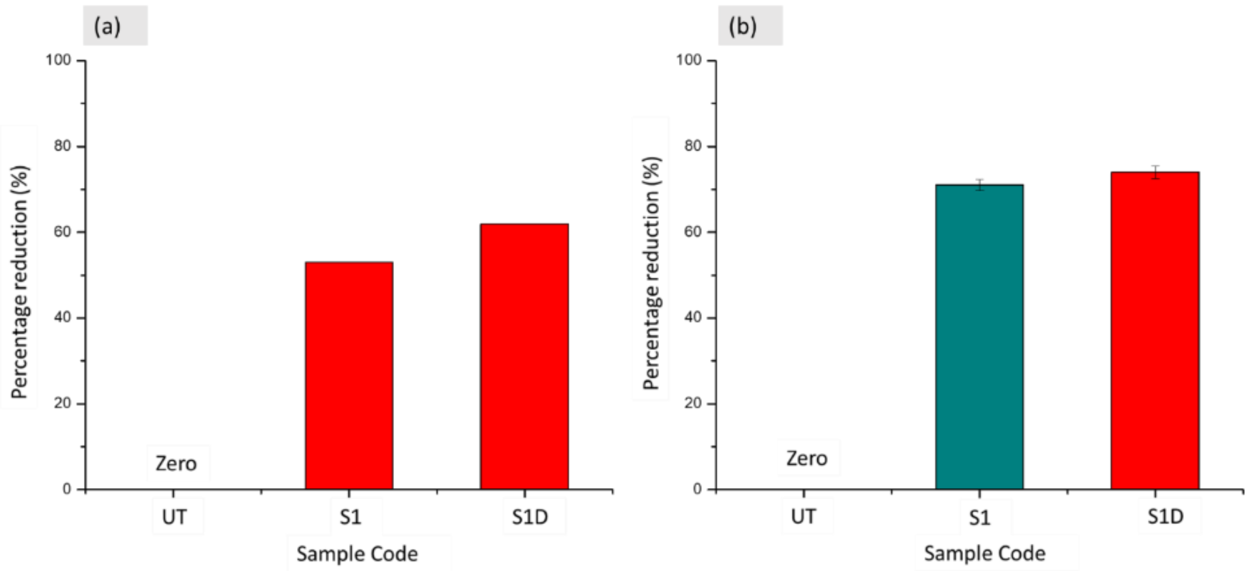

Figure 2. (a) antifungal activity (b) Antiviral reduction in percentage.

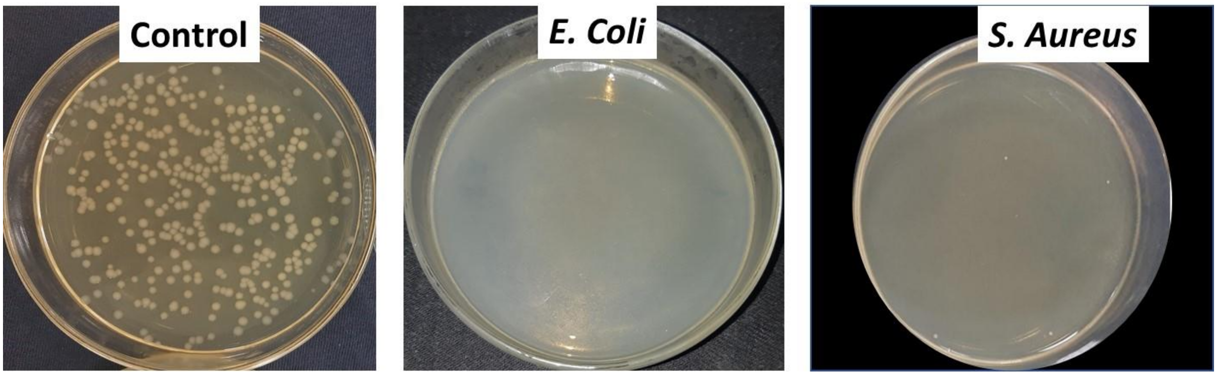

Figure 3. Antibacterial activity against gram positive and gram negative bacteria.

samples, with antifungal actions and 91%. The untreated fabric did not exhibit any inhibitory effect on the test microbe, confirming that the antifungal properties in all treated samples (dyed and undyed) were attributed to the presence of antimicrobial dye and silver nanoparticles. Overall, the study demonstrated superior antifungal properties of silver-coated dyed fabric. The reduction in the percentage of fungus seen in green-synthesized silver particles is consistent with this result and a previous study [20]. The present study showed better antifungal properties of silver-coated dyed fabric is justified by the results and comparison with related studies. The sample S3 (among all undyed fabrics) and S3D (among all dyed fabrics) showed the highest reduction in antiviral activity, with 80% and 84% effectiveness, respectively. The antiviral effect of silver-treated undyed and dyed fabrics can be explained by the binding of metallic nanoparticles and the phenolic part of the polyphenols to glycoproteins on the viral surface, which inhibits the viruses. In a recent study, fabric coated with silver particles using the photo deposition method exhibited a 97% reduction in the specific viral load of SARS-CoV-2. The antiviral activity of silver-treated undyed and dyed fabrics is due to the presence of silver nanoparticles and natural antimicrobial dye, which inhibit viruses by binding to glycoproteins on the viral surface [21].

CONCLUSION

Antibacterial properties of silver-coated fabrics are quite interesting and highlight the effectiveness of dyeing in enhancing antibacterial activity. A hygienic samples were created, consisting dyed and undyed fabrics, all treated with silver nanoparticles. This setup allows for a direct comparison of the antibacterial effects between dyed and undyed sample. X-Ray diffraction (XRD) and scanning electron microscopy (SEM) are used to determine the presence of silver nanoparticles on the fabric as well as their surface shape. These techniques are essential for understanding how the silver interacts with the fabric and how it might contribute to antibacterial properties The antibacterial efficacy against dyed silver-coated samples is higher than that of undyed samples, which indicates that the dyed materials are more effective at preventing the development of bacteria. This suggests that the dyeing process may enhance the antibacterial properties of the silver coating. Dyed fabric sample exhibited the strongest antibacterial effect, which is significant for applications where hygiene is critical. Overall, the findings suggest that dyeing silver-coated fabrics not only enhances their aesthetic appeal but also significantly improves their antibacterial properties, making them suitable for hygienic applications.

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