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Using Some Nanomaterials in Life Applications: Green Synthesis of Silver Nanoparticles for Antimicrobial Textile

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Abstract

An environmentally friendly synthesis of silver nanoparticle was developed using green tea extract. Further silver nanoparticles AgNPs were deposited and firmly adhered onto pure cotton, polycotton, and polyester textiles using dip coating method. The effect of ZnO and SiO_2 on the adsorption ability of AgNPs on textile were studied. Characterization of AgNPs was carried out using UV-Visible/ reflectance spectroscopy and XRD. The average particle size was 16 nm, and synthesized AgNPs with a face cubic crystalline nature were observed by XRD. The reflectance spectra of the textile confirmed that ZnO and SiO_2 increase the adhesion ability of AgNPs on different textiles. The antimicrobial activity of AgNPs coated fabrics were evaluated against E. coli and Aspergillus niger. Most fabrics showed good antimicrobial activity. Moreover, AgNPs/SiO_2 coated polycotton and polyester show the highest antibacterial activity against E. coli. In addition, AgNPs/SiO_2 coated polyester and AgNPs/ZnO coated cotton revealed high antifungal activity against Aspergillus niger.

Key Words:

Silver nanoparticles, Textile, ZnO, SiO_2, Antimicrobial activity.

1. Introduction:

Textile industry plays an important role in human's life (Li et al., 2017, 351-357).

Recently, fabrication of multifunctional textiles has been increasingly considered in the world (Lu et al., 2015, 8-14; Wang et al., 2017, 1840-1848). Nanoparticles (NPs) can be synthesized via chemical, physical or biological processes. Chemical and physical techniques are harmful to the environment. Further, toxic chemicals which used may reduce its biomedical applications (Gundikandula & Maringanti, 2016, 714-721). Biosynthesis methods of NPs involve the utilization of microorganisms, algae, plant, plant tissues, fruits, and plant extracts (Kumar & Y. Chisti, 2013, 346-356). The use of plant to synthesize NPs has advantages over the other methods that are economical, time saving, energy efficient, cost-effective, eco-friendly, and free from hazardous by-products. Plants contain biomolecules which able to reduce metal salts into NPs. On the other hand, the rate of reduction of metal ion to NPs with plant extracts is faster than that by microorganisms (Shah et al., 2015, 7278-7308). In addition, green synthesis is more stable and easier to scale up for the production of large amounts of nanoparticles (Shah et al., 2015, 7278-7308).

Silver nanoparticles AgNPs have been widely used in medical devices and healthcare products due to their antimicrobial activities (Xiang et al., 2021, 128291; Jin et al., 2023, 139268). AgNPs display other different properties such as electrical, thermal conductivity, and photocatalytic activity depending on their size and morphology (Haji et al., 2013, 315-318; Haji et al., 2013, 8-12; Li et al., 2017, 351-357; Os´orio et al., 2012, 200-203).

Recently, plant extracts method has been widely used for synthesis of AgNPs and coating on textile (Alhaji & Sujatha, 2022, 5684-5689; Deeksha et al., 2021, 75-81; Sivaranjana et al., 2021, 1111-1126; Gollapudi et al., 2020, 508; Seetha et al., 2020, 828-835; Siengchin et al., 2020). The plant extract AgNPs provide additional antimicrobial properties to NPs which increase the performance and efficiency of NPs on fabric (Makarov et al., 2014, 35-44; Sintubin et al., 2012, 2422-2436; Mukherjee et al., 2012, 455103).

Studies have been made to graft a binder on the fiber to improve the adhesion of AgNPs to the surface of fabric using radiation, hydrothermal and plasma processes (Xu et al., 2018, 796-803; *Ye* et al., 2022, 1163-1174; Liu et al., 2022, 963-971).

In the present study we focused on:

- AgNPs synthesis using green tea extract.
- Coating AgNPs on cotton, polycotton and polyester fabrics using ZnO/ SiO_2 as a binder.
- Screening the antimicrobial activity of AgNPs coated textiles.

2. The Theoretical Framework

In general, synthetic routes for producing nanosilver particles (NSP) can be classified into three broad categories: physical, chemical, and biological methods.

Physical methods:

Physical synthesis techniques for deriving nanosilver include evaporation/condensation and laser ablation. Evaporation/condensation involves using a furnace tube under atmospheric pressure, but this method has drawbacks such as high energy consumption and slow thermal stability. Jung et al. improved this technique by using a small ceramic heater with a local heating area, allowing for controlled cooling and resulting in a high concentration of nanosilver particles (NSPs) (Jung et al., 2006, 1662-1670)

Laser synthesis uses laser ablation of metals in solution without chemical reagents, producing pure nanosilver colloids. The size and concentration of these particles depend on laser fluence and the number of laser shots; higher fluence and longer exposure lead to larger particle size and higher concentration (Abid et al., 2002, 792-793).

Another method, reported by Tien et al., involves arc-discharge to produce silver suspension in pure water without surfactants or stabilizers. Silver wires serve as electrodes and are submerged in water, causing the surface layer to evaporate and condense into stable and well-dispersed NSPs measuring 20-30 nm in size (Tien et al., 2008, 752-758).

Chemical methods:

Chemical reduction is a commonly used method for synthesizing nanosilver, utilizing silver salt, reductants, and stabilizers or capping agents to control the growth of nanoparticles (NSPs). Silver nitrate is often employed due to its cost-effectiveness and stability. Reductants like borohydride are used for their strong reducing properties, resulting in small particles with rapid reduction rates; they -also act as stabilizers to prevent NSP aggregation during decomposition (Moore, 2006, 70; Tien et al., 2008, 752-758; Evanoff & Chumanov, 2005, 1221-1231; Pyatenko et al., 2007, 7910-7917; Blanco-Andujar & Thanh, 2010, 553-568).

Stabilizers such as surfactants, ligands, and polymers (e.g., polyvinylpyrrolidone, poly(ethylene glycol), poly(methacrylic acid)) are commonly used to enhance stability and prevent aggregation. Temperature-sensitive polymers like poly(*N*-isopropylacrylamide) and collagen can also serve as stabilizers, enabling unique thermal switching applications with capped nanosilver (Chen et al., 2013, 3108-3117).

Additionally, nanosilver can be synthesized in a two-phase water-organic system to achieve uniform and controllable nanoparticles. However, this method may introduce contaminants like surfactants and organic solvents on NSP surfaces, requiring time-consuming and costly removal processes (Ge et al., 2014, 2399-2407).

Biological synthesis

The biosynthesis (green synthesis) of nanosilver has gained significant attention due to the demand for environmentally friendly methods using eco-friendly reducing and capping agents such as proteins (Naik et al., 2002, 169-172), peptides (Nam, 2008, 1480-1486), carbohydrates (Anisha et al., 2013, 310-320), various bacteria (Sintubin et al., 2009, 741-749), fungi (Balaji, 2009, 88-92), yeast (Sintubin et al., 2012, 2422-2436), algae, and plants (Shankar et al., 2003, 1627-1631). Naik et al. synthesized nanosilver particles (NSPs) sized between 60–150 nm using silver-binding peptides identified from a phage-display peptide library. These peptides were exposed to a 0.1 mM silver nitrate solution for 24–48 hours at room temperature (Naik et al., 2002, 169-172).

Thomas et al. developed an economical approach using chitosan as a chelating and stabilizing agent to prepare large-scale chitosan-nanosilver films (400 nm) with potent antibacterial action against Escherichia coli and Bacillus (Thomas et al., 2009, 2129-2144).

Sintubin et al. reviewed various biological synthesis methods employing microorganisms or plants for nanosilver production (Sintubin et al., 2012, 2422-2436). In biological synthesis, organic solvents and toxic reagents are avoided since the reducing and stabilizing agents are derived from natural sources like proteins, carbohydrates, or microorganisms or plant. The mechanisms include enzymatic (e.g., nicotinamide adenine dinucleotide phosphate-dependent reductase) and non-enzymatic reduction processes. Non-enzymatic reduction, utilizing microorganisms or plants as agents, is rapid and can tolerate extreme conditions like high pH or temperature, accelerating synthesis (Sintubin et al., 2009, 741-749).

The main advantage of biosynthesis is its environmental friendliness, avoiding toxic reagents and producing stable NSPs over time. However, the purification process may introduce pathogenic bacteria, necessitating caution for medical applications (Sintubin et al., 2012, 2422-2436).

3. Methods of Research and the tools used

3.1. Materials

$AgNO_3$ and ZnO were purchased from Merck (Germany) with 99.9% purity. SiO_2 was provided from Fluka. Pure Egyptian cotton, poly cotton and polyester fabrics were also provided from local suppliers.

3.2. Methods

3.2.1. Fabric cleaning

The bleached cotton, polycotton, and polyester textiles were scoured in a bath containing sodium dodecyle sulphate (SDS) (1g/L) and NaOH (1g/L) to remove impurities. Then all fabrics were washed with distilled water and dried in oven at 40 °C (Khatabi et al., 2022, 126548).

3.2.2. ZnO/ SiO_2 treatment

Fabrics were cut 3×3 cm and firstly coated with ZnO binder compound (0.5 g/ 100 ml boiling distilled water). This step was repeated with SiO_2 binder compound (0.5 g/ 100 ml boiling distilled water). Binder compound is used to improve the adhesion and stability of AgNPs to fabrics. After that, the fabrics were washed with distilled water and dried in an oven at 40 °C.

3.2.3. Synthesis of green tea extract AgNPs

10 g of a green tea were dissolved in 100 ml distilled water, boiled for 30 min and filtered. By adding 1 ml of green tea extract to 50 ml of $AgNO_3$ solution (0.85 g/ 50 ml distilled water), AgNPs were observed, and the colour of solution changed from colourless to brown. The mixture was allowed to stand for 2 h.

3.2.4. Coating AgNPs onto textiles

ZnO treated fabrics were bleached in the solution containing AgNPs (0.1 g /20 mL) for 15 min. Then, the fabrics washed with distilled water and dried (80 °C). This process was also carried out with SiO_2 coated fabrics.

3.2.5. Characterization techniques

The UV-Visible/diffuse reflectance (UV-Vis/DR) spectra were measured by Jasco model V-550 UV-Vis spectrometer in the range 200-900 nm. This analysis was operated at the Laboratory of Inorganic Chemistry Research, Faculty of Education, Ain Shams University, Cairo, Egypt.
X-ray diffraction analysis was done using a XRD equipment model D2 phaser 2nd gen (Brucker, Germany).

3.2.6. Antimicrobial activity of textiles based AgNPs

Gram negative bacteria (E. coli) and Aspergillus niger were used. Antimicrobial activity of AgNPs coated textiles were evaluated by disk diffusion method.

4. Results of Research

4.1 Characterizations

Dip coat method was usually used for fabric coating (Haider et al., 2018, 455–461; Alhaji & Sujatha, 2022, 5684-5689; Qu et al., 2023, 146839-146847) (Fig. 1).
Formation of silver nanoparticles was confirmed by UV-Vis and XRD analysis.

Figure (1): Silver nano particles coated fabrics: uncoated cotton (1a), AgNPs coated cotton (1b), AgNPs-ZnO coated cotton (1c), AgNPs-SiO_2 coated cotton (1d); uncoated polycotton (2a), AgNPs coated polycotton (2b), AgNPs-ZnO coated polycotton (2c), AgNPs-SiO_2 coated polycotton (2d); uncoated polyester (3a), AgNPs coated polyester (3b), AgNPs-ZnO coated polyester (3c), AgNPs-SiO_2 coated polyester (3d)

After mixing the green tea extract with the colourless $AgNO_3$ solution, a gradual colour change was observed (colourless to brown) (Fig 2). The absorbance of solution was monitored by UV-Vis spectroscopy. It was observed that the absorbance of solution increases by time due to formation of AgNPs. In addition, the characteristic absorbance peak of AgNPs was observed at 460 nm (Ninsiima et al., 2023, e13922-e13931) (Fig. 2).

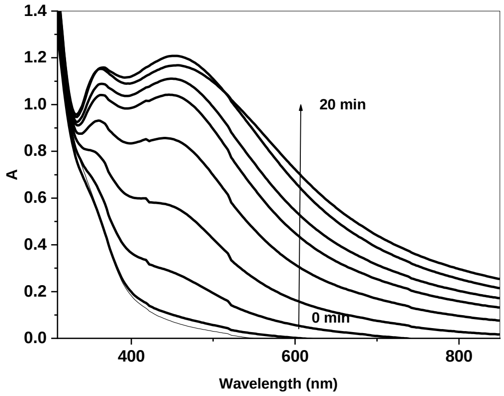

Figure (2): UV-Visible spectrum of silver nano particles over a period of 20 min.

Further, XRD patterns of AgNPs (Fig. 3) showed four peaks at 2 theta angles of 38.3 °, 44.5 °, 64.65 °, and 77.5°, which correspond to crystal planes (111), (200), (220), and (311), respectively. This confirms the presence of face cubic structured AgNPs (Mu˜noz et al., 2021, 126598; Alhaji & Sujatha, 2022, 5684-5689). The average crystal size of silver nanoparticle is 16 nm as recorded by XRD.

The UV-Vis/DR spectra of uncoated and coated fabrics were recorded (Fig. 4-6). Figures 4-6 show that the fabrics modified by ZnO or SiO_2 have a high intense absorption band at 460 nm with respect to unmodified samples. Addition of ZnO or SiO_2 to the fabric leads to increase the adsorption capacity of fabric from Ag nanoparticles.

Table 1 . Identification of samples

Sample Id	Conc. of AgNPs	Conc. of ZnO	Conc. of SiO_2
Pure cotton	0.1 g/ 20 mL	-	-

Polyester	0.1 g/ 20 mL	-	-
Pure cotton	0.1 g/ 20 mL	0.5 g/ 100 mL	-
Polyester	0.1 g/ 20 mL	0.5 g/ 100 mL	-
Polycotton	0.1 g/ 20 mL	0.5 g/ 100 mL	-
Pure cotton	0.1 g/ 20 mL	-	0.5 g/ 100 mL
Polyester	0.1 g/ 20 mL	-	0.5 g/100 mL
Polycotton	0.1 g/ 20 mL	-	0.5 g/100 mL

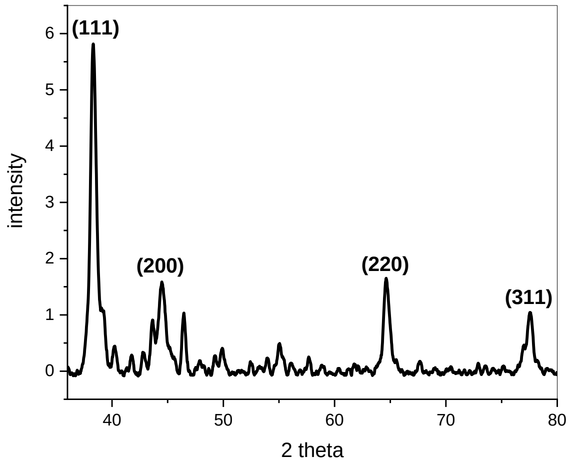

Figure (3): XRD pattern of AgNPs

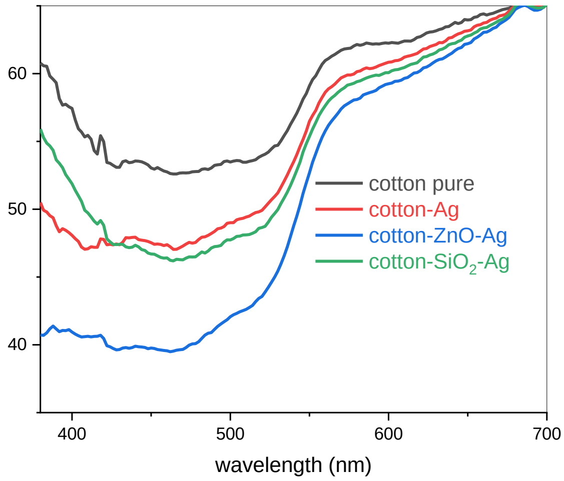

Figure (4): Spectral reflectance of uncoated and AgNPs coated cotton.

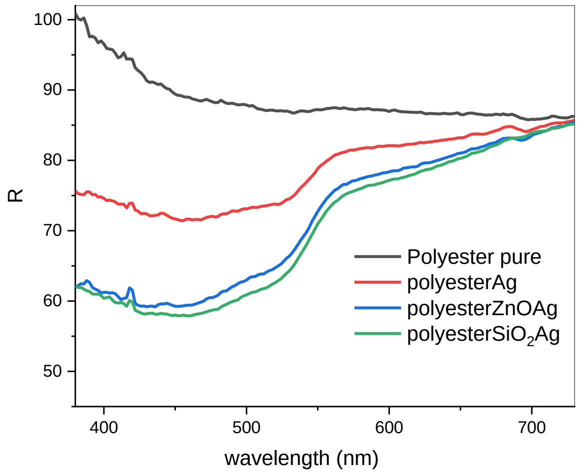

Figure (5): Spectral reflectance of uncoated and AgNPs coated polyester.

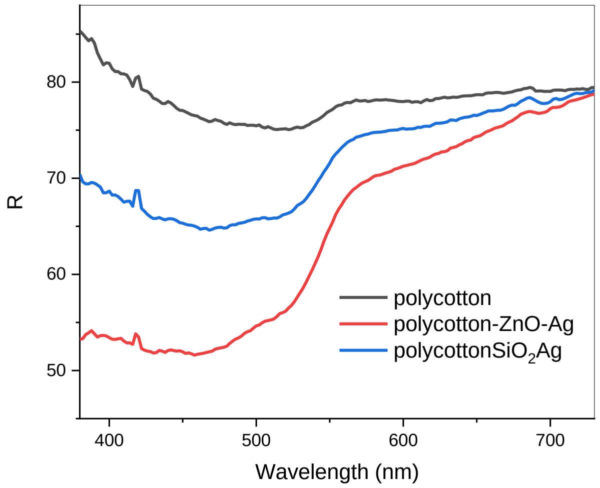

Figure (6): Spectral reflectance of uncoated and AgNPs coated polycotton.

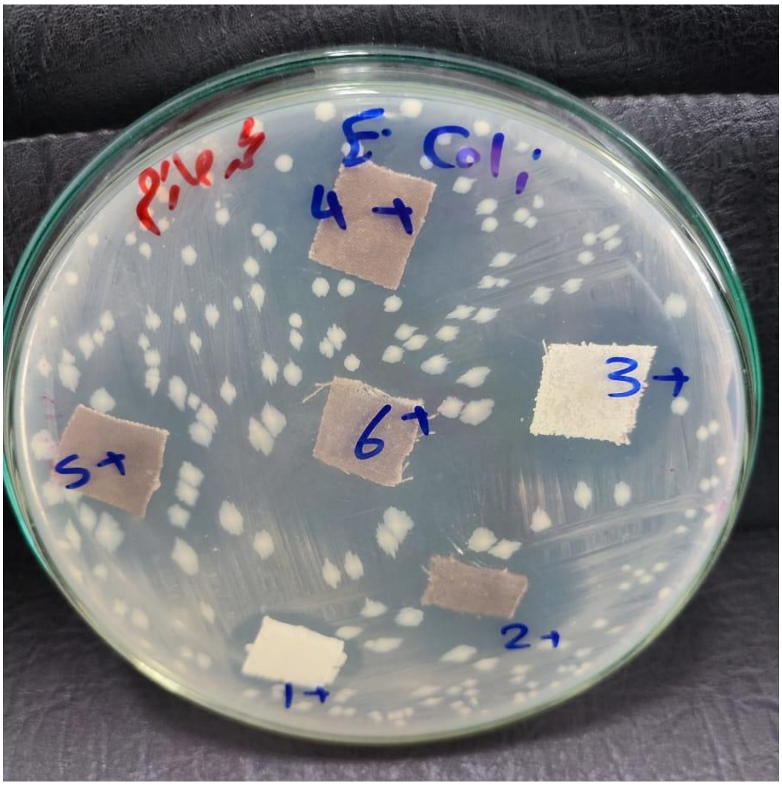

Figure (7): Antibacterial activity of uncoated fabric (1) and AgNPs coated fabrics: ZnO cotton (2), SiO_2 polycotton (3), SiO_2 polyester (4), ZnO polyester (5), ZnO polycotton (6) against E. coli.

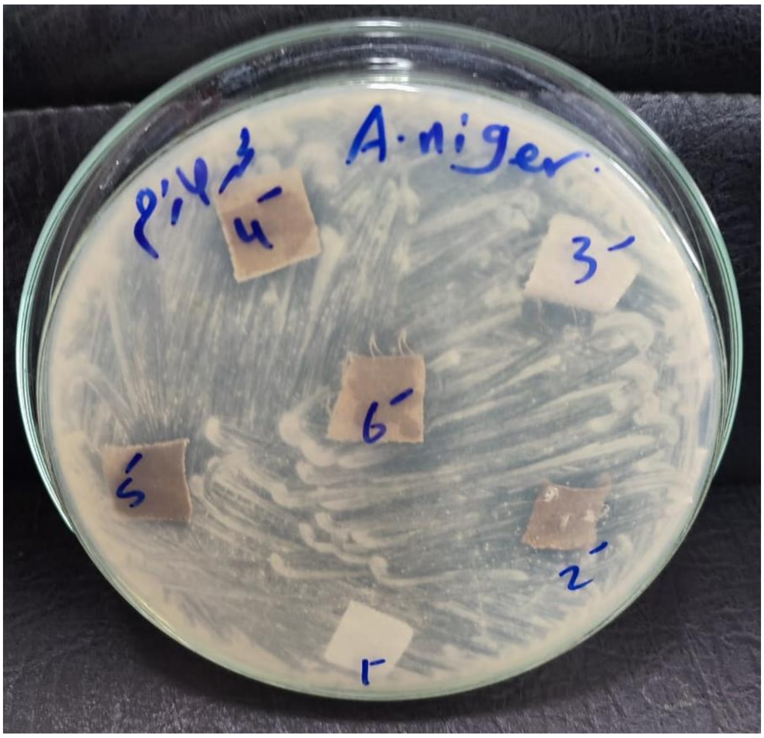

Figure (8): Antifungal activity of uncoated fabric (1) and AgNPs coated fabrics: ZnO cotton (2), SiO_2 polycotton (3), SiO_2 polyester (4), ZnO polyester (5), ZnO polycotton (6) against Aspergillus niger

4.2. Antimicrobial activity

Some selected fabrics were screened for antimicrobial potential. Polycotton and polyester treated with AgNPs/SiO_2 showed the highest antibacterial activity against E. coli (Figure 7), which was comparable with standard Gentamycin. Polycotton impregnated by AgNPs/ZnO revealed similar activity to gentamycin. While AgNPs/ZnO coated cotton showed moderate activity. Only, AgNPs/SiO_2 coated polyester and cotton soaked with AgNPs/ZnO exhibited highest antifungal potential against Aspergillus niger. The other coated fabrics revealed no antifungal Activity (Fig. 8).

5. Interpretation of Results

In the present work, we successfully applied synthesized AgNPs using green tea extract. Among the biologically active compounds contained in green tea, the potent antioxidant agents are catechins. Thus catchins reduce Ag^+ into AgNPs (Ssekatawa et al., 2021). UV-Vis spectroscopy registered absorbance band at 460 nm, confirming the formation of AgNPs. The formation of Ag nanoparticles was aslo confirmed by XRD pattern, which confirms the formation of cubic structured AgNPs with average crystal size of 16 nm (Khatami et al., 2018, 9–15; Alhaji & Sujatha, 2022, 5684-5689).

Moreover, spectral reflectance of uncoated and coated fabrics revealed that the absorbance of cotton is according to the following order:

AgNPs/ZnO cotton > AgNPs/SiO_2 cotton > AgNPs cotton > pure cotton.

In addition, the absorbance of polyester is as follow:

AgNPs/SiO_2 polyester > AgNPs/ZnO polyester > AgNPs polyester > pure polyester.

Finally, the absorbance of AgNPs/ZnO polycotton is higher than AgNPs/SiO_2 polycotton. The absorbance of the latter is higher than the absorbance of pure polycotton. Thus, ZnO and SiO_2 binder increase the adsorption and concentration of AgNPs on three different fabrics.

Antimicrobial activity of some selected covered textiles was carried out using zone of inhibition test (ZOI), where pieces of the coated fabrics were placed on agar plates of E. coli and Aspergillus niger and incubation at 37 ° for 24 h. Then, the diameter of the possible zone was measured as indication for inhibition of the fabrics against the test microorganisms. The ZOI results showed that polycotton and polyester treated with AgNPs/SiO_2 showed the highest antibacterial activity against E. coli, which was comparable with standard Gentamycin. Polycotton impregnated by AgNPs/ZnO revealed similar activity to gentamycin. While AgNPs/ZnO coated cotton showed moderate antibacterial activity. Only, AgNPs/SiO_2 coated polyester and cotton soaked with AgNPs/ZnO exhibited highest antifungal potential against Aspergillus niger. The other coated fabrics revealed no inhibition zone of the fungal growth. The suggested antibacterial mechanism of AgNPs is by penetrating cell membrane and changing the permeability of the membrane causing damage to the bacteria. AgNPs can also release Ag^+ into the surrounding medium, thus destroying subcellular structures and disturbing the metabolism of microbial species (Gao et al., 2013, 397–404; Assis et al., 2019, 9927; Prabhu & Poulose, 2012, 32).

The above results offer evidence on the use of the antimicrobial AgNPs/SiO_2 coated polyester, AgNPs/ZnO coated cotton, polycotton covered with AgNPs/SiO_2 and AgNPs/ZnO coated polycotton in dressings, wound bandage and home cleaning.

6. Conclusion

AgNPs were synthesized using green tea extract and deposited onto pure cotton, polycotton, and polyester textiles using ZnO/ SiO_2 as binder. The reflectance spectra of the textiles revealed that ZnO and SiO_2 increase the absorbance of AgNPs on different textiles. Polycotton and polyester coated with AgNPs/SiO_2 showed the highest antibacterial activity against E. coli. Polycotton impregnated by AgNPs/ZnO revealed similar activity to gentamycin. While AgNPs/ZnO coated cotton showed moderate activity.

AgNPs/SiO_2 coated polyester, and cotton soaked with AgNPs/ZnO exhibited highest antifungal activity against Aspergillus niger. Thus, AgNPs coated fabrics can be used as antibacterial dressings, in purification of medical equipment and home cleaning.

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