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Functional Cotton Fabric Developed Using Carboxy Methyl Cellulose (CMC)-Stabilized Silver Nanoparticle: Synthesis, Characterization, and Antibacterial Performance

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Abstract

The development of high-performance cotton fabric is attracting growing interest as wearable material because of its appealing physical, chemical, and antimicrobial features. In this study silver nano particles (AgNPs) were synthesize using environmentally benign chemicals and coated on a cotton fabric using dip coating and sonication technique. The formation of AgNPs was confirmed by UV-Visible spectroscopy which showed maximum absorption at 427 nm. The chemical interaction of the Ag-coated cotton fabric was analysed using FTIR technique. The FTIR result revealed difference in peak intensity and positions due to surface modifications. The surface morphology of the Ag-coated cotton fabrics was examined using SEM which showed uniform coating of silver nanoparticles on the surface of fabrics. The antibacterial activities of the silver nanoparticle-coated fabric were investigated against the strain of Staphylococcus aureus culture, and it exhibited good antibacterial activity. This study may provide a simple, green technique for developing Ag-functionalized cotton for potential applications in textile industry.

Keywords: Silver nanoparticles, cotton fabric, anti-bacterial activity, UV-VIS spectra, SEM.

Introduction

The emergence of nanoscience and nanotechnology has led to significant advancements in the application of nanoscale materials and structures, typically ranging from 1-100nm. In recent decades, nanoparticles have been increasingly utilized in various scientific fields [1-3]. Among these, silver nanoparticles (AgNPs) have garnered considerable attention due to their exceptional antimicrobial and localized surface plasmon resonance properties, making them ideal for applications such as broad-spectrum antimicrobials [4-6], chemical and biological sensors, and biomedicine materials [7-9]. Various methods, including chemical, physical, photochemical, and biological routes, have been reported for synthesizing AgNPs. However, these methods often face challenges

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related to cost, scalability, particle size, and size distribution [13-14]. However, chemical methods remain the most widely used approach for AgNP production, offering a convenient and straightforward way to produce pure, well-defined nanoparticles under mild conditions.

Cotton fabric, while widely used for its comfort and breathability, is highly susceptible to microbial contamination and bacterial growth, which can lead to odors, fabric degradation, and potential health risks for the wearer[10]. Conventional treatments for imparting antibacterial properties often involve toxic chemicals or result in reduced fabric quality and durability. There is a crucial need to develop an eco-friendly, effective, and durable antibacterial treatment for cotton fabrics that enhances their functional properties without compromising comfort or safety. Silver nanoparticles have recognized antibacterial effects, but their synthesis and application can lead to agglomeration and instability, limiting their functional use on textiles. Using carboxymethyl cellulose (CMC) as a stabilizing agent may solve this problem by preventing nanoparticle aggregation, ensuring better dispersion and sustained antibacterial activity on cotton substrates [15,16]. Carboxymethyl cellulose is a renewable, biodegradable polymer that can stabilize silver nanoparticles, improving their dispersion and longevity.

The aim of this study is to synthesize silver nanoparticles (AgNPs) using a chemical reduction method, with carboxymethyl cellulose (CMC) serving as both a reducing agent and a stabilizing agent. The synthesized AgNPs will be coated onto cotton fabrics using two distinct techniques: dip coating and sonication. The resulting Ag-coated fabrics will be characterized to evaluate their physical and chemical properties, as well as their antimicrobial efficacy.

Experimental

Materials

Silver nitrate (99.9 %), Carboxymethyl cellulose (DP=350, DS=1.2) and sodium hydroxide were purchased from Sigma Aldrich Co. (Germany). Sodium bicarbonate (99.7%) and Staphylococcus aureus were purchased from Cardinal Chemicals and scientific supplies, Zaria, Nigeria. All chemicals were of analytical grade and used as purchased without further purification. Cotton fabric [100%] (165gm/m2 and 180 thread count) was obtained from a local market.

Methods

Synthesis of Silver Nanoparticles

Silver nanoparticles were synthesized via chemical reduction following a modified Hebeish et al. method.[18]. A colloidal solution of silver nanoparticles was prepared by dissolving 2 g/l of CMC in 0.4M NaOH. The solution was stirred with its temperature raised to 70°C. A solution of 0.05 M $AgNO_3$ was added at one time to the

mixture and stirred for 30 minutes to complete the process.

Coating of Silver Nanoparticles on Cotton Fabric.

Cotton fabric were first cleaned by washing in a solution containing 2 g/L sodium carbonate and 2 g/L commercial detergent at 60°C for 30 minutes, with a fabric-to-liquor ratio of 1:50. The fabrics were subsequently washed twice with deionized water and dried at room temperature. For the preparation of Ag-cotton fabric samples, a 4x4 cm^2 cotton fabrics were immersed (dip method) in the prepared colloidal AgNPs solution and kept for 24h at dark. In another study, sonication was performed for the cotton fabric/AgNPs colloidal solution for 2h. The Coated fabrics were washed to remove unbound agents such as reducing and stabilizing agents and dried at 60°C overnight

Characterization

The optical properties of the AgNPs solution were measured using UV-VIS (UV-2500PC series) spectrophotometer measured in the wavelength range of 250 to 600 nm. The chemical bonding and surface interaction of the cotton and Ag-coated cotton fabrics were investigated using FTIR (FTIR-8400S) spectrophotometer in the attenuated total reflection mode. Scanning electron microscopy (SEM,1034 Series) was applied to observe the surface morphology of the cotton and Ag-coated cotton fabrics, at 5Kv accelerating voltage.

Antibacterial Assay

The antibacterial activity of Ag-coated cotton fabric was evaluated using the disk diffusion method [4,5]. Staphylococcus aureus, a Gram-positive bacterium, was used as the test organism. The bacteria were cultured in Muller-Hinton broth for 24 hours at 37°C, then swabbed onto agar plates. Ag-coated and uncoated fabrics were placed on the inoculated plates, incubated at 37°C for 24 hours, and examined for zones of inhibition showing clear areas surrounding the fabric samples. The zones of inhibition were measured and the results documented using digital camera.

Results and Discussion

Formation of Silver Nanoparticles

The reaction mechanism for the formation of silver nanoparticles (AgNPs) using carboxymethyl cellulose (CMC) macromolecules has been documented in previous studies (18,20). In this process, CMC simultaneously acts as a reducing agent for silver ions (Ag+) and as a stabilizer for the resulting silver nanoparticles (Ag^0). The alcoholic and aldehydic groups in CMC contribute to both the reduction of silver ions and the stabilization of the formed nanoparticles. After formation, the AgNPs are stabilized by CMC's polymeric chains, which prevent aggregation of smaller particles that could otherwise form larger clusters. The progress of the reaction between silver nitrate and CMC was monitored by measuring the solution's absorbance. A visible color change was observed,

as color change from colorless to yellowish brown and then dark brown which indicated the formation of AgNPs, consistent with literature [18]. The intensity of coloration increased with reaction time, signifying growth of nanoparticles.

UV-Vis Spectra of AgNPs

Figure 1 presents the UV-Vis spectra of the diluted AgNPs colloidal solution, showing a clear absorbance peak at 427 nm (λmax) with significant intensity. Consistent with literature on AgNPs [18], this peak corresponds to the surface plasmon resonance of spherical AgNPs, confirming the complete reduction of Ag+ ions by CMC

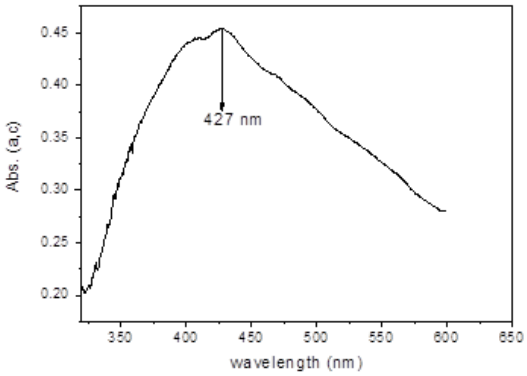


Fig 1: UV-VIS spectra of AgNPs

FTIR Analysis of AgNP-Coated Cotton Fabric

FTIR spectra (Figure 2) shows the spectra of uncoated cotton (Ao) and Ag-coated cotton fabrics (ad and As) prepared by dip and sonication methods. FTIR spectra showed characteristic peaks of cellulose in cotton fabric (Ao) at 3500–3200 cm^{-1} (O–H stretch), 2920–2850 cm^{-1} (C–H stretch) and 1650-1500 cm^{-1} (C=O or C=C band) respectively. New peaks were observed in coated samples (Ad and As) at 3700–3400 cm^{-1}, 1700–1600 cm^{-1}, and 1150–1050 cm^{-1}.The difference in peak intensity and position in the coated cotton fabrics(Ad and As)indicate changes in functional groups, bonding environment and interaction (e.g coordination, hydrogen bonding ,or surface modification).

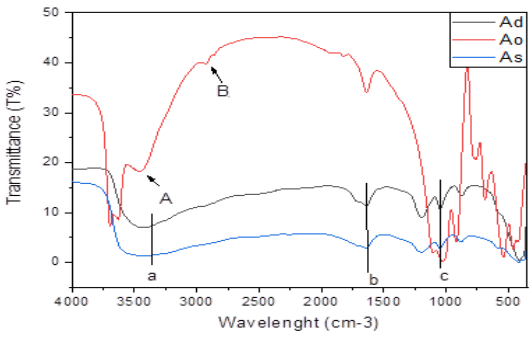


Figure 2: FTIR spectra of Uncoated cotton fabric (Ao), coated cotton fabric via Dip (Ad) and Sonication (As) method

SEM Morphology of AgNP-Coated Fabrics

The surface morphology of Ag-coated cotton fabrics was examined using scanning electron microscopy (SEM). Figure 3 shows the SEM images of uncoated fabric (Ao), and Ag-coated fabrics prepared by dip (Ad) and sonication (As) methods. The dip method (Fig. 3b) showed the presence of large particles (arrowed region) on the surface of the cotton fabric which could be due to particles agglomeration on the fabric surface during coating process which resulted in poor

AgNP dispersion. However, in the case of the sonication coating process, the silver nanoparticles uniformly dispersed on the surface of cotton fabric. Moreover, the sizes of deposited particles are smaller (arrowed region). This might be due to the sonication treatment helping to disperse the nanoparticles during the coating process. In sonication treatment, Sonication of a liquid induces two main effects: cavitation and heating (21). It was observed that the nanoparticle coating resulted from the physical adsorption of nanoparticles onto the substrate facilitated by sonication. Moreover, sonication enhanced the adsorption rate of AgNPs onto the cotton fabric surface, allowing the Ag NP coating to be completed in a significantly shorter time compared to the dip method.

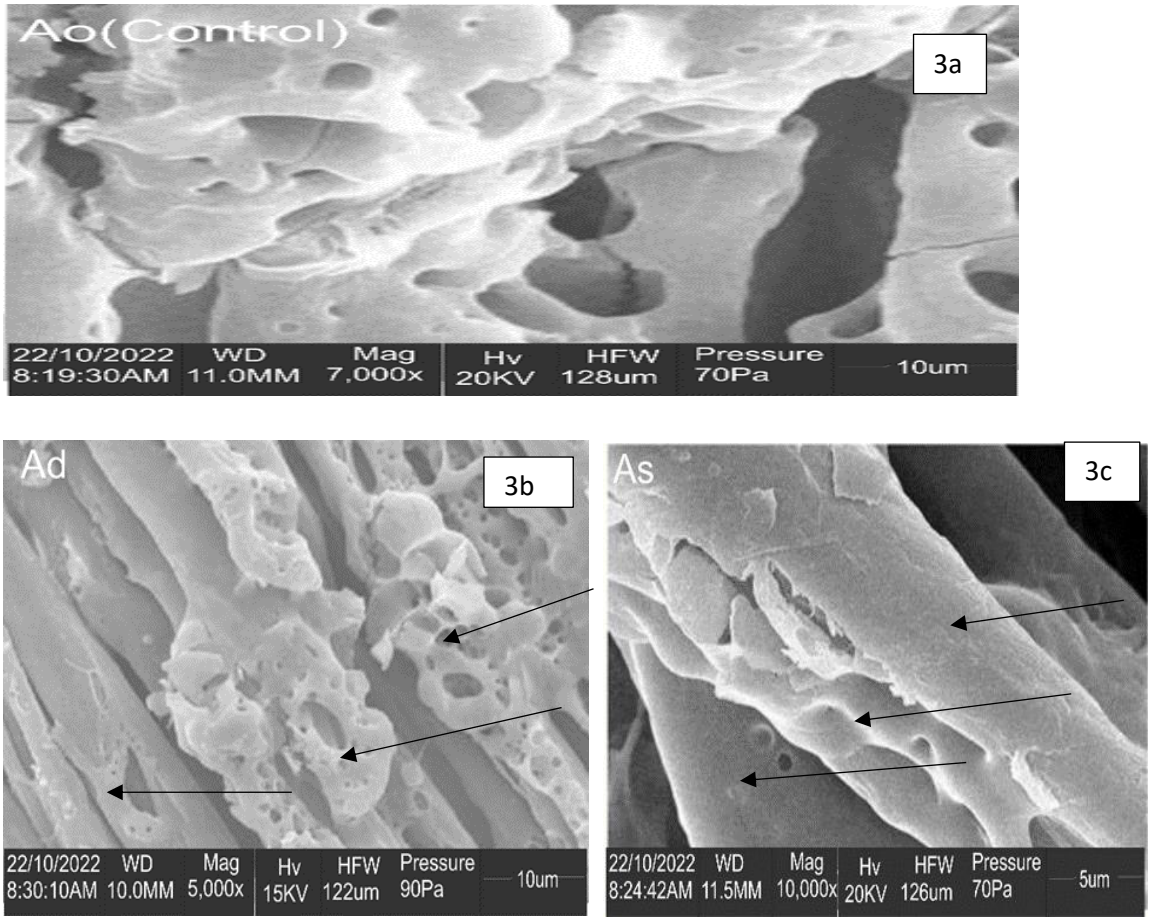


Fig 4: SEM images of cotton fabrics: Uncoated cotton fabric (Ao), Dip (Ad) and Sonicated (As) coating with AgNPs

Antibacterial Activity

The antibacterial properties of Ag NP-coated cotton fabric were assessed using the disk diffusion technique, with S. Aureus bacteria as the test organism [4,22]. The zone of inhibition measured for both Ag-coated cotton fabrics for Dip and sonication methods were: 5.5 mm and

7.5mm respectively. Figure 4 shows the antimicrobial activity of uncoated and Ag-coated fabrics (via dip and sonication method), with the uncoated fabric serving as a reference (control).

The uncoated cotton fabric did not show antibacterial activity because there was no zone of inhibition (i.e no zone of clearance). Ag-coated cotton fabrics **e**xhibited antibacterial activity against *Staphylococcus aureus*, as a zone of clearance (inhibition) was observed. However, the sonicated fabric displayed a broader inhibition zone (7.5mm) compared to the dip-coated fabric (5.5mm), suggesting a more pronounced antibacterial effect. The larger zone indicates that the silver nanoparticles are diffusing further into the agar at concentrations high enough to inhibit bacterial growth, likely suggesting a higher concentration of active silver nanoparticles on the fabric or better release/migration characteristics [4]. The larger inhibition zone diameter observed for the sonicated fabric underscores its enhanced antibacterial efficacy against S. aureus, highlighting the importance of uniform Ag NP dispersion in achieving optimal antimicrobial performance.

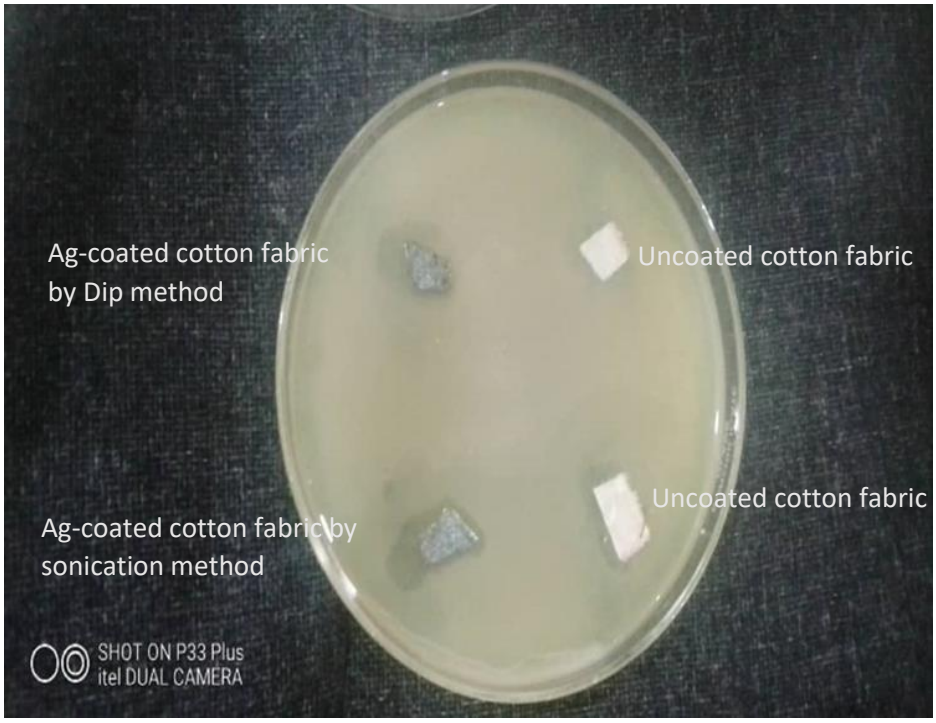


Fig 4: Digital photograph image of antibacterial activity of uncoated, coated Ag-cotton fabrics against *Staphylococcus aureus*

Conclusion

Silver nanoparticles were successfully synthesized via a chemical method, utilizing

carboxymethyl cellulose (CMC) as a dual-functional agent that reduces silver ions and stabilizes the resulting nanoparticles. The synthesized AgNPs were subsequently coated onto cotton fabric to enhance its functional properties, leveraging the antimicrobial potential of silver.

Two coating techniques, dip and sonication, were employed to deposit AgNPs onto the cotton fabric. Scanning electron microscopy (SEM) analysis revealed that dip method showed the presence of large particles on the surface of the cotton fabric which was be due to particles agglomeration on the fabric surface during coating process resulting in poor AgNP dispersion while sonication method revealed that the AgNPs were uniformly dispersed on the surface of the cotton fabric This uniform distribution was attributed to the physical and chemical interactions between the AgNPs and the fabric/ Notably, the fabric coated with AgNPs using sonication exhibited superior antibacterial activity against S. aureus, outperforming the dip-coated fabric based on the values obtained.

The advantages of this process is its ease of operation, nontoxic and efficient. The coating can be carried out using a solution immersion. This study provides a simple yet effective approach for producing antimicrobial textiles with potential applications in medical and textile industries, where hygiene and infection control are paramount.

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