RESEARCH PAPER

Structural and Spectroscopic Study of Ag-α-D-Glucose Nanoparticles for Promising Medical Applications

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ABSTRACT

Silver nanoparticles (AgNPs) were chemically synthesized and subsequently functionalized by adsorbing α-D-glucose onto their surfaces, resulting in a core–shell nanostructure with enhanced bioactivity. Comprehensive physicochemical characterization using field emission scanning electron microscopy (FESEM), UV–visible spectroscopy (UV–Vis), X-ray diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR) confirmed the successful formation and modification of the nanoparticles. The XRD patterns revealed distinct face-centered cubic (FCC) crystal structures with consistent nanoscale dimensions. FTIR analysis further supported the functionalization, showing the emergence of a broad O–H stretching band along with pronounced C–H and O–C vibrations, indicating strong interactions between glucose molecules and the nanoparticle surface. Low-frequency shifts also confirmed metal–ligand coordination, suggesting stable bonding rather than simple physical adsorption. A stabilizing biocorona, formed by the glucose layer, effectively reduces interparticle agglomeration, resulting in a slight increase in mean particle size and improved colloidal stability. FESEM micrographs verified the presence of quasi-spherical, uniformly distributed nanoparticles with minimal clumping, further indicating successful surface passivation and improved dispersion. Notably, the glucose coating expanded the nanostructures' capacity for secure and efficient biointeractions and greatly improved their biocompatibility. Thus, these hybrid nanomaterials offer intriguing platforms for cutting-edge biological applications such as tissue engineering interfaces, antimicrobial surface coatings, and targeted drug delivery.

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INTRODUCTION

The field of nanoscience has blossomed significantly over the last two decades, with researchers exploring more fields of application continuously. Nanotechnology is a method used to synthesize particles in the nanoscale range, from 1 to 100 nm [1]. At this size, their high surface-to-volume ratio enhances their optical characteristics [2].

Nanotechnology is currently amongst the

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fastest growing fields due to its many potential applications due to their particular chemical and physical properties. They have been used in a wide range of applications, including medication administration, amino acids, and as antimicrobials, and also show some promise in cancer treatment [3, 4].

The chemical synthesis of silver nanoparticles (AgNPs) is challenging in biomedical applications due to their high toxicity in some cases [5]. However, despite concerns about this toxicity, silver nanoparticles – whether chemically or biologically produced – exhibit cumulative anticancer activity across multiple cell lines, such as blood, colon, lung, and liver cells [6, 7].

Silver ions (+Ag) are positively charged in aqueous media and exhibit long-lasting antibacterial activity by interacting with bacterial cell membranes and disrupting essential cellular processes [8, 9]. Furthermore, the small size of silver nanoparticles (AgNPs) reduces the effect of gravity, improving their colloidal stability and bioavailability in physiological environments [10, 11]. The increased surface charge also enhances the electrostatic repulsive forces between the particles, preventing clumping and allowing them to remain homogeneously dispersed in water—crucial for maintaining their antibacterial efficacy and for their overall biomedical applications [12, 13]. There are many methods used for silver nanoparticle synthesis such as chemical reduction methods [14, 15], electrochemistry [16], γ-radiation [17], photochemistry [18] and laser ablation [19]; chemical reduction is the most popular method in current usage, as it is straightforward and relatively low cost [14, 20].

Silver nanoparticles can be coated with capping agents such as glucose, which gives them high stability and prevents their agglomeration, which can occur through surface interactions according to adsorption theory. These agents form a protective layer that binds to the silver particles via weak bonds such as hydrogen bonding and van der Waals interactions, maintaining their structural stability in the interaction medium. This stability enables them to be used in various medical applications, particularly in delivering active agents and, notably, combating cancer cells [21-23].

Several studies have focused on nanosilver, both in its pure form and when loaded with glucose, using analytical techniques such as FESEM, XRD, and UV-Vis.

Silver nanoparticles and glucose-loaded silver exhibit unique structural properties that may make them suitable for a variety of biological and medical applications. Ref. [24] shows that the synthesis of silver nanoparticles using a chemical reduction method at room temperature, using glucose as the reducing agent and PVA as the stabilizing agent, can be achieved. Their results showed that the optimal ratio for producing stable, spherical particles was 1:8 with 3% PVA, with particle sizes between 12.28 and 38.45 nm, suggesting their potential for use in antibacterial applications.

Silver nanoparticles have been synthesized using glucose as a reductant, and upon studying their structural properties, it was found that they possess antimicrobial activity, as studied by Panáček et al. [25].

Sarhan and Shiltagh studied the stability

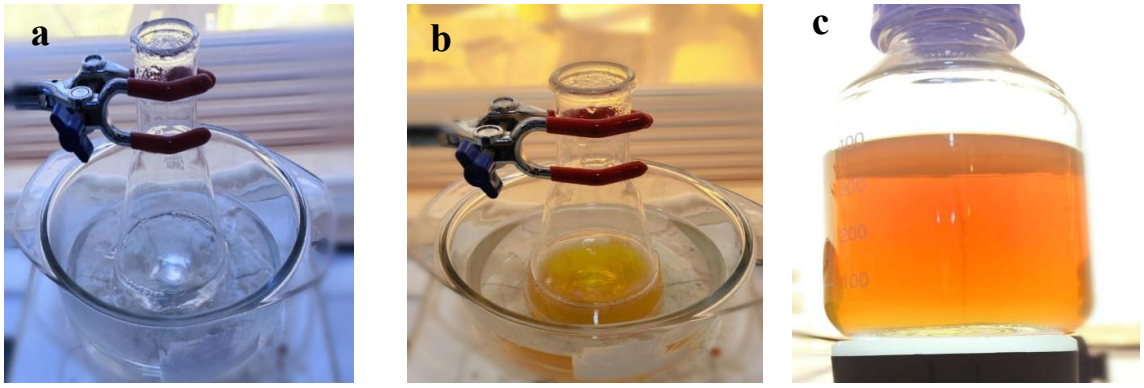

Fig. 1. Synthesis of pure silver nanoparticles: From precursors to purity.

of molecular structures resulting from the association of α-D-glucose molecules with silver atoms, with quantum chemical calculations using density functional theory (DFT) showing that the resulting configuration is energetically stable. This stability suggests the potential use of these species in medical applications due to their favorable structural and electronic properties [22].

Ag is a commonly used metal in NPs because of its low toxicity to the human skin. AgNPs are used because viruses, bacteria, and microorganisms are the smallest particles that live in biological organisms, and work effectively because the size of silver nanoparticles is lower than that of such pathogens [26].

Pattnaik et al. studied the green synthesis of glucose-coated silver nanoparticles, further analyzing their optical and structural properties. The particles demonstrated high stability and efficiency in detecting mercury ions (Hg^{2+}), suggesting their potential for medical applications, particularly in diagnostics and toxicology [27].

The aim of this work is to chemically prepare silver nanoparticles (AgNPs) using citrate as a reducing and stabilizing agent and then loading them with α-D-glucose molecules using an adsorption method. The aim is to produce nanocomposites with improved structural and spectroscopic properties, with a focus on minimizing the nanoparticle size while maintaining structural stability, making them suitable for future medical applications. All things considered, this work emphasizes how important it is to use biomolecule-assisted surface engineering techniques to modify the physicochemical characteristics of nanomaterials in order to increase their therapeutic and diagnostic potential.

MATERIALS AND METHODS

Synthesis of Silver Nanoparticles and Glucose Coating

Silver nitrate ($AgNO_3$) was used as the silver supply, and sodium citrate was used as a stabilizing and reducing agent in the chemical reduction process, as shown in Fig. 1(a), that produced silver nanoparticles (AgNPs) in an aqueous medium. Continuous stirring of the reaction mixture at 80°C resulted in a yellowish-brown solution, as per Fig. 1(b), which showed that the greater nucleation rate had formed nanoparticles with smaller particle sizes. As illustrated in Fig. 1(c), a final concentration of 50 µg/mL was successfully obtained after centrifugation and thorough washing of the resulting dispersion to remove residual byproducts.

There was no discernible color change after 30 minutes of stirring the AgNP solution with 1 g of α-D-glucose at room temperature, suggesting that the nanoparticles remained stable throughout the process without oxidizing or aggregating.

As required for additional research, working solutions with different concentrations were created by diluting the final suspension with deionized water.

Characterization

A comprehensive characterization approach was employed to investigate the structural and

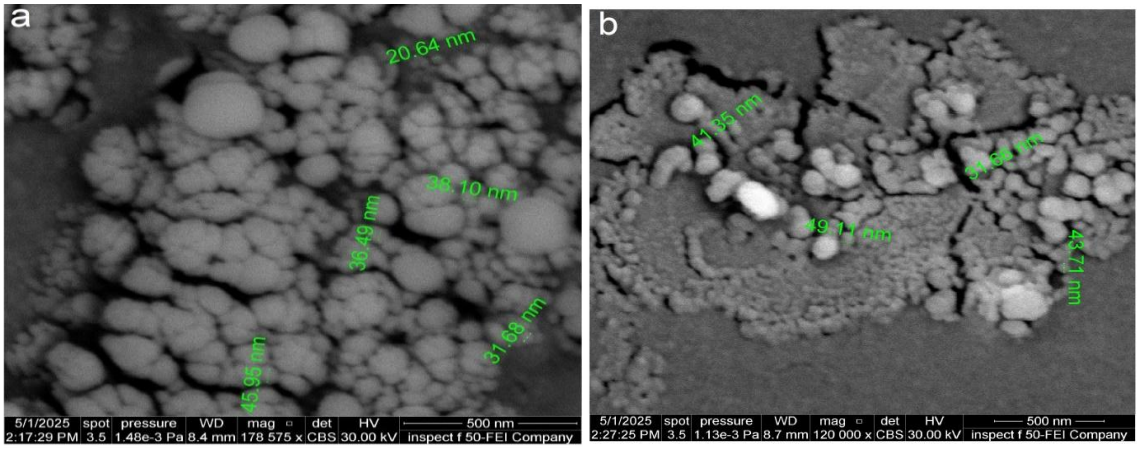

Fig. 2. (a) FESEM image of pure (AgNPs). (b) FESEM image of **α-D-glucose/**AgNPs.

optical features of the synthesized nanomaterials. Particle size distributions were assessed using Field Emission Scanning Electron Microscopy (FESEM), while UV-Visible spectroscopy (UV-Vis) was utilized to evaluate the optical absorbance behavior. The crystalline nature of the samples was examined through X-ray Diffraction (XRD) analysis using Cu Kα radiation (λ = 1.5406 Å), whilst crystallite size was estimated via the Scherrer equation based on the broadening of diffraction peaks. Fourier Transform Infrared Spectroscopy (FTIR) was used to determine which functional groups were present on the silver nanoparticles' surface and to verify that the surface alteration following glucose functionalization had been successful. Through the detection of distinctive absorption bands, this approach offers insights into molecular interactions and chemical bonds, enabling a clear comparison of the nanoparticle system before and after coating. These characterization techniques collectively provide a fundamental understanding of the physicochemical profile of the prepared solutions, which is crucial for establishing their potential relevance in biomedical-related frameworks.

RESULTS AND DISCUSSION

The shape and particle size distribution of pure (AgNPs) and glucose-loaded silver nanoparticles (α-D-glucose/AgNPs) can be determined from Field Emission Scanning Electron Microscopy (FESEM) images (Fig. 2). With an average particle size of about 35 nm and a range of 20–46 nm, the pure AgNPs have rather homogeneous spherical morphologies, as shown in Fig. 3(a). The α-D-glucose/AgNPs sample, on the other hand, exhibits somewhat larger and more aggregated particles, with an average size of roughly 41 nm and a size range between 31 and 49 nm, as shown in Fig. 3(b).

The inclusion of glucose molecules functioning as capping and stabilizing agents, which lowers

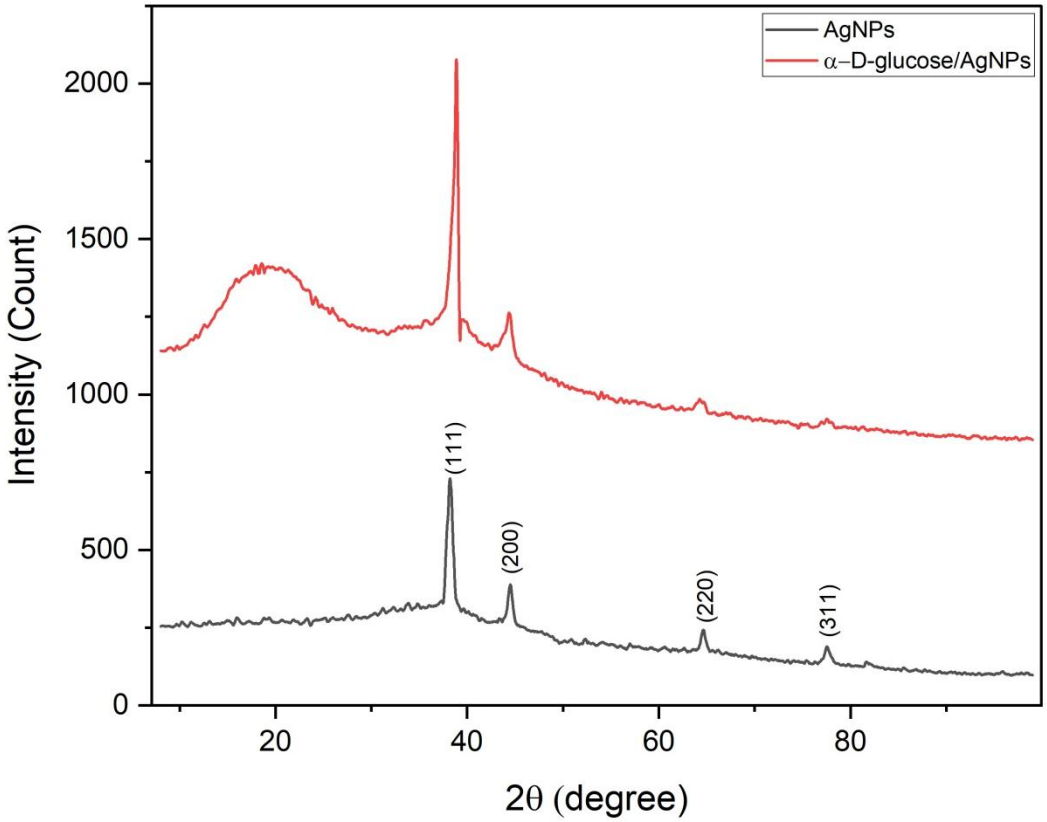

Fig. 3. XRD spectra of AgNPs and **α-D-glucose/**AgNPs.

particle growth rate but may encourage mild agglomeration due to hydrogen bonding, is responsible for the modest increase in average particle size observed for the glucose-coated sample. This coating improves stability and could make the nanoparticles more biocompatible.

Overall, the FESEM results show that glucose loading successfully alters the surface properties and size distribution of silver nanoparticles, confirming the successful manufacture of nanoscale particles with regulated sizes.

These results are consistent with earlier research showing that organic molecules, like polysaccharides or plant extracts, can serve as stabilizing and capping agents, and causing a modest increase in particle size as an organic layer forms around the nanoparticles [28].

Separate diffraction peaks in the XRD patterns of the pure silver nanoparticles and the D-glucose-coated silver nanoparticles (Fig. 3) show the face-centered cubic (FCC) structure of metallic silver. The main diffraction peaks for both materials may be indexed to the (111), (200), (220), and (311) planes of silver (JCPDS card no. 04-0783), and are found at about 2θ = 38°, 44°, 64°, and 77°.

A prominent broad hump in the coated sample, as can be seen in Fig. 3 at lower angles (2θ ~ 15–25°), shows the presence of an amorphous organic layer caused by the glucose coating.

Sharp and intense diffraction peaks in the XRD spectra demonstrate that the crystalline silver nanoparticles were successfully synthesized. As is common for silver nanoparticles produced by chemical reduction, the prominent (111) reflection shows that the nanoparticles mostly grow along this plane.

Peak broadening and a modest decrease in the intensity of the primary silver peaks are seen upon coating with D-glucose. This implies that the interaction with the glucose molecules caused a modest reduction in crystallite size and/or an increase in lattice strain. Additionally, the D-glucose/AgNPs sample's broad amorphous peak at low angles suggests the presence of an organic shell, which provides an amorphous halo instead of contributing to crystalline peaks.

This coating layer may provide steric hindrance, stabilizing the nanoparticles and preventing them from clumping together. Furthermore, the coated sample's modest shift and decreased peak intensity suggest that the glucose molecules may interact with the nanoparticle surface, potentially altering growth behavior and surface energy during synthesis.

The XRD analysis reveals that the silver nanoparticles maintain their crystalline FCC structure after the coating process. Simultaneously, the glucose shell imparts amorphous characteristics and enhances the dispersion stability of the nanocomposite system.

Debye Scherer's equation [29] and the XRD data were used to estimate the crystallite size of

Table 1. Crystallographic data and crystallite size of silver nanoparticles.

2-Theta(deg.)	d(nm)	FWHM (β) (deg.)	hkl	Crystal size (nm)
38.201	0.2354	0.552	111	15
44.492	0.20347	0.628	200	13
64.687	0.14398	0.55	220	17
77.6	0.12293	0.59	311	17

Table 2. Crystallographic data and crystallite size of **α-D-glucose** \AgNPs.

2-Theta(deg.)	d(nm)	FWHM (β) (deg.)	hkl	Crystal size (nm)
38.915	0.23124	0.367	111	23
44.337	0.20414	0.621	200	14
64.249	0.14486	0.668	220	14
77.436	0.12315	0.734	311	14

anatase AgNPs:

$$D=K\lambda/\beta\sin\theta$$

where K = 0.94, λ is the X-ray wavelength of Cu-kα radiation in nm, D is the mean crystallite size in nm, θ is the degree of the diffraction peak, β is the peak width of the diffraction peak profile at half maximum due to the tiny crystallite size in radians (Tables 1 and 2).

The XRD peaks for glucose-capped AgNPs show a small broadening and shift, which is consistent with earlier results for biogenic or biomolecule-assisted nanoparticle formation and suggests a slight increase in crystallite size due to the presence of the organic covering [30].

Both pure and glucose-capped AgNPs display distinct SPR peaks in the UV-Vis spectrum (Fig. 4), demonstrating their nanoscale metallic character. The α-D-glucose-functionalized AgNPs showed a red shift to 435 nm, while the pure AgNPs' surface plasmon resonance (SPR) peak was detected at 429 nm. Our findings are consistent with the published data, since Jyoti et al. (2016) reported an SPR peak for AgNPs at 414 nm [31]. Both the potential increase in particle size brought on by the glucose coating and the modification of the local dielectric environment surrounding the nanoparticles, which modifies the plasmon oscillation frequency, are responsible for this red shift. The glucose-coated AgNPs' notable higher absorbance and modest redshift in the SPR band indicate a more stable colloidal state and a changed surface environment.

This glucose shell controls the plasmonic response and prevents aggregation. This behavior has medical significance since these nanoparticles show promise in certain biological applications such as photothermal treatment, targeted drug administration, and biosensors due to the SPR band's sensitivity to its surroundings. Enhancing dispersibility and improving interaction with biological tissues are two benefits of the biocompatible glucose layer.

These findings are in line with earlier studies showing that organic coatings and surface alterations can successfully modify the SPR characteristics of metallic nanoparticles to allow for improved biological performance [32].

Fig. 5 shows the FTIR spectra of AgNPs before

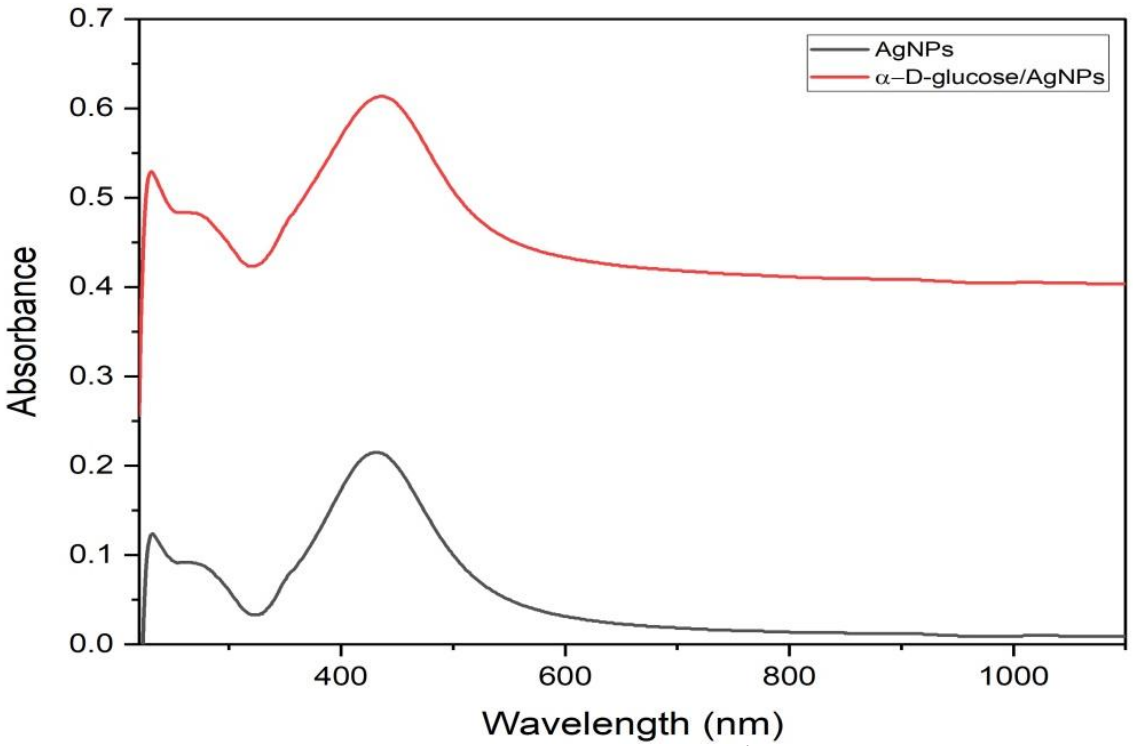

Fig. 4. UV-Vis spectra of AgNPs and α-D Glucose/AgNPs.

and after α-D-glucose coating, highlighting the chemical changes due to functionalization. Before coating, The produced AgNPs' FTIR spectrum shows a pattern that is almost identical to that seen in previous research [31], suggesting that functional groups play an equal role in the creation of nanoparticles. Subsequent to glucose functionalization, several notable changes appear: a broad O–H stretching band at around 3417 cm^{-1} emerges, indicating the presence of hydroxyl groups from glucose molecules. Additionally, clearer C–H and C–O–C absorption bands confirm the successful attachment of glucose on the nanoparticle surface. Shifts observed below 600 cm^{-1} suggest strong metal–ligand interactions between the silver core and glucose, which contribute to improved nanoparticle stability. These results align with previous studies [33], confirming the transition from bare silver nanoparticles to glucose-capped biohybrid structures with enhanced surface properties and colloidal behavior.

The current findings for α-D Glucose/AgNPs demonstrate a general concordance in the

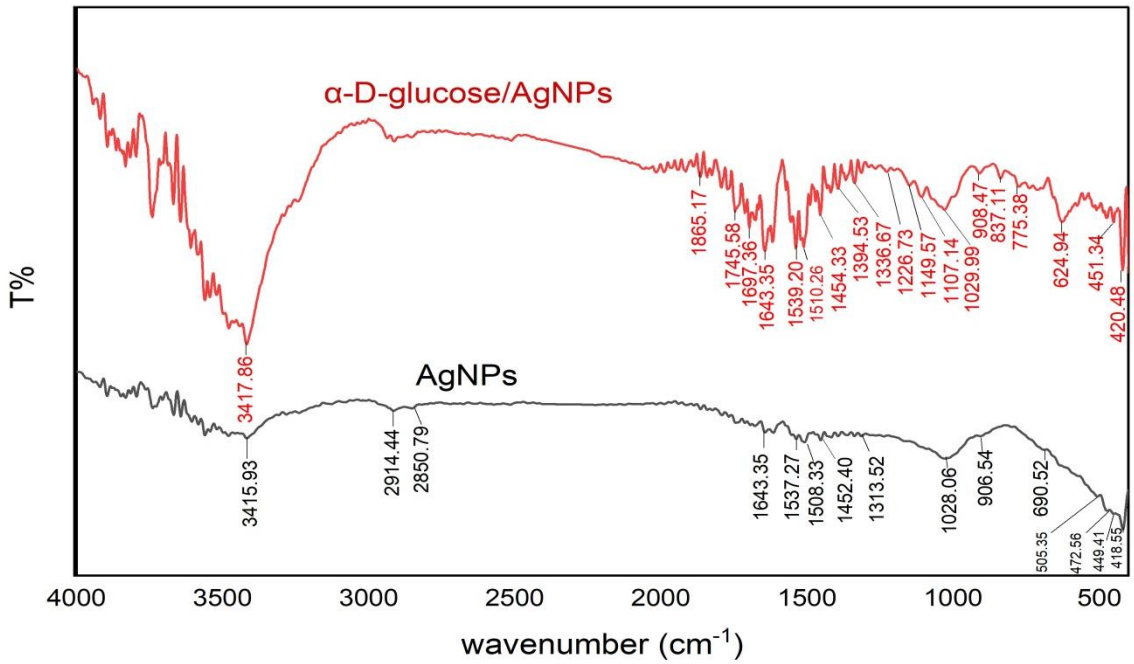

Fig. 5. FTIR spectra of AgNPs and α-D Glucose/AgNPs.

Table 3. Main FTIR bands of α-D-glucose/AgNPs compared to prior data for the system.

Functional Group/Vibration mode	Experimental (cm^{-1})	Reported in Literature (cm^{-1})[22]	Observation
O-H Stretch	3417	3577-3703	Significant red shift indicating strong Ag-O interaction
C-H Stretch	2850-2914	3037-3073	Small shift brought on by changes in the surface environment
C-O-C/C-O Stretch	1029-1107	1066-1038	Good agreement with a few small differences
C-C/C-H Bending	1313-1463	1309-1500	Comparable range with small shifts
Metal-Ligand (Ag-O) Vibrations	420-624	391-472	Ag-O presence validates glucose's attachment to silver.

spectral values with those documented in [22], with minor discrepancies attributed to variations in preparation conditions, glucose concentration, or the quantity of bound silver atoms. This agreement demonstrates the trustworthiness of the experimental data and enhances the validity of the spectrum interpretation related to the binding of glucose molecules to the surface of silver nanoparticles.

To illustrate the similarities and differences between this study and the reference study, a comparative table has been developed. Table 3 compares the practical values acquired in this experiment to the values specified in the source. Additionally, the effective range for each spectral band has been identified.

CONCLUSION

The combined XRD, FESEM, and UV-Vis investigations confirmed the successful synthesis of silver nanoparticles with well-defined crystallinity, controlled nanoscale size, and stable dispersion. The slight increase in particle size seen for glucose-capped nanoparticles, which is supported by both FESEM and peak broadening in XRD, is beneficial for biological applications since it enhances stability and provides a biologically friendlier surface. UV-Vis spectra showed distinct SPR peaks, indicating tunable optical properties that are highly sensitive to particle size and surface modification. Overall, the close connection between plasmonic behavior, surface characteristics, and particle size indicates that enhancing the size and surface chemistry of nanoparticles can improve their performance in cancer-related applications such as biosensing, targeted drug delivery, and plasmonic photothermal therapy. These results highlight the need for biocompatible functionalization and exact size control in creating secure and effective nanomedical systems.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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