International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Review Article)

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Silver nanoparticles: green synthesis and characterization

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International Journal of Science and Research Archive, 2025, 14(03), 1670-1673

Publication history: Received on 17 February 2025; revised on 27 March 2025; accepted on 29 March 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.14.3.0894

Abstract

Silver nanoparticles (AgNPs) have gained significant attention due to their antimicrobial, antibacterial, antifungal, and anti-inflammatory properties. Among various synthesis approaches, green synthesis utilizing plant extracts is considered a sustainable and eco-friendly alternative to conventional physical and chemical methods. Phytochemicals, particularly flavonoids, proteins, and secondary metabolites, play crucial roles as reducing and stabilizing agents in AgNPs biosynthesis. The exact mechanism of phytochemical-mediated AgNPs formation remains under investigation, with functional groups such as hydroxyl and carbonyl contributing to the bioreduction process. Characterization techniques like UV-Vis spectroscopy and Transmission Electron Microscopy (TEM) are essential for evaluating AgNPs' size, morphology, and stability. This review highlights the potential of green synthesis in nanoparticle fabrication, emphasizing the need for further research to optimize biosynthetic pathways and scale-up production for biomedical and industrial applications.

Keywords: Characterization; Green Synthesis; Silver Nanoparticles; Electron Microscopy

1. Introduction

Nanoparticles are units that have a very small size, ranging from 1-100 nm [1]. Among the various types of nano materials, silver nanoparticles (AgNPs) have received global attention because they have less toxic properties and higher antimicrobial, antibacterial, antifungal, and anti-inflammatory potential [2]. The synthesis of silver nanoparticles can be carried out through several methods, namely physical, chemical, and biological methods [3, 4, 5]. However, physical and chemical methods tend to be considered less effective because of the use of toxic chemicals as reducing agents and/or stabilizers, requiring high technology, and high operating costs [6].

Therefore, biological synthesis methods are considered better because of their low-cost, environmentally friendly approach and high thermal stability [7]. One method of biological silver nanoparticle synthesis is by utilizing secondary plant metabolite compounds such as flavonoids. Flavonoids will act as reducing agents of $Ag+$ into $Ag0$ metallic nanoparticles with very low toxicity and as capping agents [8]. Electrostatic interactions and charge transfer between the -OH groups of flavonoids and $Ag+$ are responsible for the biochemical interactions leading to bio-reduction [9]. After the silver nanoparticles are formed, flavonoids that act as reducing agents will also stick to the surface of the silver nanoparticles as capping agents to prevent particle aggregation [8].

2. Green synthesis of silver nanoparticles

Green synthesis refers to the utilization of plant extracts as sources of reducing and capping agents in the fabrication of AgNPs. Plant-derived biomolecules, including secondary metabolites such as vitamins, polysaccharides, amino acids,

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proteins, enzymes, polyphenols, flavonoids, and other phytochemicals, play crucial roles in the reduction of Ag ions to AgNPs [10]. Protein molecules within plant extracts also contribute significantly to AgNPs formation by acting as reducing agents and controlling nanoparticle size. Functional groups such as carboxylate (-COOH) from glutamine and aspartic acid residues, as well as hydroxyl (-OH) groups from tyrosine residues, stabilize Ag ions and promote the formation of small, monodisperse AgNPs [11].

The biochemical composition of plant extracts varies significantly among species and plant parts, affecting AgNPs synthesis. Despite extensive research on phytochemicals involved in biosynthesis, no single study has conclusively identified the specific biomolecules responsible for Ag+ reduction [9]. Jha and Prasad (2010) suggested that certain metabolites initiate the bioreduction process through redox activity involving dehydroascorbic acid/ascorbic acid, flavonoids, and other metabolites. Functional groups such as carbonyl and hydroxyl in flavonoids, terpenoids, carbohydrates, and phenolic compounds serve as reducing agents, facilitating AgNPs formation [8]. Additionally, proteins and peptides exhibit strong binding affinities to Ag0, forming stabilizing layers around AgNPs to enhance colloidal stability [12].

Several studies have explored the mechanism of bioreduction. Trouillas et al. (2006) employed density-functional theory (DFT) to investigate the interaction of phytochemicals with silver ions, revealing that catechol hydroxyl groups in flavonoids possess lower dissociation energy than other hydroxyl groups, enhancing their reducing ability. Similarly, Bose and Chatterjee (2016) demonstrated that flavonoid-derived carbonyl and hydroxyl groups play a crucial role in metal chelation during AgNPs biosynthesis using Psidium guajava leaf extract. Recent studies have identified specific flavonoids, such as flavan-3-ol, flavan-3,4-diol, and flavan-4-ol, as reducing and capping agents in the synthesis of AgNPs using Shorea robusta leaf extract [9]. The bio-reduction mechanism involves tautomeric transformation of flavonoids into flavones and/or flavonols, wherein reactive hydrogen atoms from hydroxyl-containing groups (flavan, flavanonol, and flavonol) participate in Ag+ reduction.

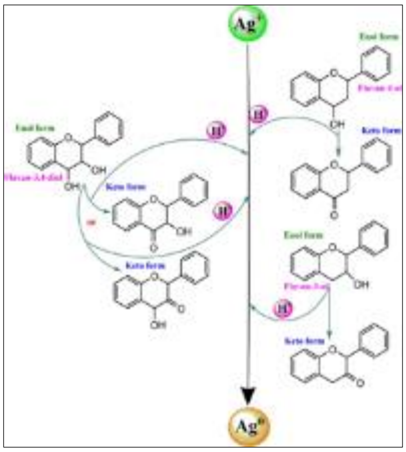

Figure 1 The role of phytochemicals Flavan-3-ol, Flavan-3,4-diol, and Flavan-4-ol in AgNPs biosynthesis [9]

3. Characterization of silver nanoparticles

The physicochemical properties of AgNPs, such as size, morphology, stability, and optical behavior, influence their biological activity and potential applications. Characterization techniques such as UV-Vis spectroscopy and Transmission Electron Microscopy (TEM) are widely employed to assess these properties [13].

UV-Vis spectrophotometry is a fundamental technique for analyzing nanoparticle synthesis. This method measures the absorbance of light transmitted, reflected, or emitted as a function of wavelength, typically within the 200-900 nm range [14]. A typical UV-Vis spectrophotometer consists of a light source, collimator, prism or grating for light selection, a cuvette for sample placement, a blank reference, and a photodetector [15].

UV-Vis spectroscopy provides qualitative and quantitative information on AgNPs synthesis. The maximum absorbance wavelength (λmax) is indicative of nanoparticle size, with larger AgNPs exhibiting red-shifted λmax values. Additionally, the phenomenon of Surface Plasmon Resonance (SPR) contributes to the distinct coloration of AgNPs solutions. Changes in SPR indicate particle aggregation, dissolution, or morphological alterations [16].

TEM is a high-resolution imaging technique used to determine the size, shape, and structural characteristics of nanoparticles. Unlike conventional optical microscopes, TEM employs electron beams instead of light waves and uses electromagnetic fields to focus electrons onto the sample surface. This results in highly magnified images, making TEM a crucial tool in nanomaterial research [15, 16]. TEM operates with multiple lenses, including Objective lens, Primary focusing lens responsible for high-resolution imaging. Intermediate lens, Corrects spherical aberrations from the objective lens. Projector lens, Magnifies the image for viewing. Additionally, Scanning Electron Microscopy (SEM) is used to analyze nanoparticle surface morphology in three-dimensional detail.

4. Conclusion

Green synthesis of AgNPs presents a sustainable and eco-friendly approach to nanoparticle fabrication. Plant extracts act as natural reducing and stabilizing agents, with flavonoids, proteins, and secondary metabolites playing a critical role in the biosynthesis process. Despite advances in understanding phytochemical interactions, the exact mechanism of AgNPs formation remains elusive. Characterization techniques such as UV-Vis spectroscopy and TEM provide essential insights into nanoparticle properties, ensuring their effective application in biomedical and industrial fields. Future research should focus on elucidating the precise roles of phytochemicals in AgNPs biosynthesis and optimizing green synthesis methodologies for large-scale production.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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