

ECO-FRIENDLY ROUTES TO SILVER NANOPARTICLES: A REVIEW ON PLANT EXTRACT-BASED SYNTHESIS, STRUCTURAL CHARACTERISTICS AND APPLICATIONS**Ritika Giri, Dr. Savita Kumari and Dr. Leena Sarkar**

J. V. M.'s Mehta Degree College (Affiliated to University of Mumbai), Department of Chemistry, Mumbai, Maharashtra, India

ABSTRACT

Silver nanoparticles (AgNPs) have emerged as one of the most extensively studied nanomaterials due to their remarkable antimicrobial, anticancer, and catalytic properties. Conventional chemical and physical synthesis routes, while effective, often involve hazardous reagents and energy-intensive processes that raise concerns about environmental safety and biocompatibility. In recent years, biogenic synthesis using plant extracts has gained significant attention as a sustainable and eco-friendly alternative. Plant-derived phytochemicals such as flavonoids, phenolics, terpenoids, and alkaloids act as natural reducing and stabilizing agents, enabling rapid and cost-effective nanoparticle formation without toxic by-products. A wide variety of medicinal and aromatic plants have been explored, yielding nanoparticles with diverse morphologies and size distributions, typically ranging from 10–100 nm. Characterization techniques including UV–Visible spectroscopy, TEM, FTIR, and XRD confirm the successful synthesis and stability of these biogenic AgNPs. This review consolidates current knowledge on plant-mediated synthesis of AgNPs, and discusses their biomedical and environmental applications.

Keywords: Silver nanoparticles, plant extract, phytochemical

1. INTRODUCTION

Silver nanoparticles (AgNPs) have received significant scientific and technological attention owing to their exceptional physicochemical properties and wide-ranging biological activities. At the nanoscale (1–100 nm), silver exhibits a high surface-to-volume ratio, enhanced chemical reactivity, and unique optical characteristics arising from localized surface plasmon resonance. These features make AgNPs highly valuable for applications in biomedicine, agriculture, food packaging, environmental remediation, catalysis, and sensing technologies. In particular, AgNPs demonstrate potent antimicrobial, antioxidant, anti-inflammatory, anticancer, and catalytic properties, which have been extensively explored in recent decades [1, 2].

Conventional physical and chemical routes for AgNPs often involve hazardous reducing agents, high energy consumption, and environmentally unsafe by-products. These drawbacks have stimulated growing interest in green synthesis approaches that comply with the principles of sustainable and environmentally responsible chemistry [1]. Among various green routes, plant extract-mediated synthesis has emerged as a promising alternative due to its simplicity, cost-effectiveness, scalability, and minimal environmental impact [2].

Plant leaf extracts play a crucial role in the biosynthesis of silver nanoparticles, acting simultaneously as reducing, stabilizing, and capping agents. Leaves are rich in diverse phytochemicals, including flavonoids, phenolic acids, terpenoids, alkaloids, tannins, proteins, and carbohydrates. These biomolecules facilitate the reduction of Ag⁺ ions to metallic Ag⁰ while also regulating nucleation, growth, morphology, and stability of the nanoparticles [1, 3]. Consequently, plant-mediated AgNPs often exhibit superior biological activity and enhanced stability compared to chemically synthesized counterparts [2].

The chemical composition of the leaf extract significantly influence the physicochemical characteristics of the synthesized AgNPs. Polyphenol-rich leaves such as neem, guava, tea, and eucalyptus typically yield smaller and more stable nanoparticles with enhanced antioxidant and antimicrobial properties [3-7]. Extracts dominated by flavonoids favor rapid reduction and predominantly spherical morphologies, whereas terpenoid-rich extracts may promote anisotropic structures such as rods, plates, or triangular nanoparticles [8,13]. These variations in size, shape, and surface chemistry directly impact the antimicrobial efficacy, cytotoxicity, and catalytic performance of silver nanoparticles [13, 15]. This review critically discusses plant extract-based synthesis strategies for AgNPs, their structural characteristics, factors affecting nanoparticle formation, and their diverse applications.

2. LITERATURE REVIEW

2.1 ROLE OF PLANT PHYTOCHEMICALS AS REDUCING AND CAPPING AGENTS

One of the earliest reports on green synthesis of silver nanoparticles involved the use of *Azadirachta indica* (neem) leaf extract, where terpenoids and flavonoids acted as efficient reducing and stabilizing agents, enabling rapid conversion of Ag^+ to Ag^0 nanoparticles [3]. The resulting AgNPs exhibited strong antimicrobial activity against pathogenic bacteria, establishing neem leaves as a potent biogenic source.

Green tea (*Camellia sinensis*) leaf extract, rich in catechins and polyphenols, has also been successfully employed for AgNP synthesis. These antioxidant compounds facilitate fast reduction and controlled growth, producing stable spherical nanoparticles with enhanced bioactivity [4]. Similarly, *Psidium guajava* leaf extract containing phenolics and tannins yielded well-dispersed AgNPs with significant antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* [5].

Medicinal plants such as *Ocimum sanctum* and *Eucalyptus globulus* have been reported to produce stable AgNPs due to the presence of bioactive compounds like eugenol, rosmarinic acid, essential oils, and phenolics [6, 7]. *Aloe vera* leaf extract, rich in polysaccharides and vitamins, enabled controlled reduction and stabilization of biocompatible AgNPs suitable for wound healing and pharmaceutical applications [8].

Other plant sources including *Moringa oleifera*, *Murraya koenigii*, *Carica papaya*, and *Mentha piperita* have also demonstrated excellent potential for green synthesis of AgNPs. The phytochemical composition of these leaves significantly influences nanoparticle size, morphology, dispersion, and biological activity, highlighting the versatility of plant-mediated synthesis routes [9- 12].

2.2 STRUCTURAL CHARACTERISTICS OF SILVER NANOPARTICLES

Transmission electron microscopy (TEM) and X-ray diffraction (XRD) analyses consistently show that AgNPs synthesized via green routes possess a face-centered cubic (fcc) crystalline structure with prominent diffraction planes corresponding to (111), (200), and (220) reflections [13]. Shape-controlled synthesis studies have demonstrated that nanoparticle morphology—ranging from spherical and cubic to rod-like and plate-like structures—is strongly influenced by reaction kinetics and the nature of phytochemical capping agents [13,15].

Size-dependent investigations indicate that smaller AgNPs exhibit enhanced surface-related effects, influencing stability, optical behavior, and catalytic activity [14]. Shape-controlled nanostructures, such as nanocubes and nanoplates, retain the fcc lattice while exposing different crystallographic facets, thereby modulating their optical, electronic, and catalytic properties [15].

2.3 PARAMETERS AFFECTING SILVER NANOPARTICLE FORMATION

2.3.1 SILVER ION CONCENTRATION

The concentration of silver precursor, commonly AgNO_3 , plays a crucial role in nucleation and growth. Higher Ag^+ concentrations accelerate nucleation but may lead to aggregation and broad size distribution, whereas optimized concentrations yield uniform and stable nanoparticles [1,13].

2.3.2 NATURE AND CONCENTRATION OF REDUCING AGENTS

The reduction rate of Ag^+ ions depend on the strength and concentration of reducing agents. In green synthesis, phytochemicals such as flavonoids and phenolic compounds act as mild reducing agents, allowing controlled nanoparticle growth and morphology regulation [1, 3].

2.3.3 pH OF THE REACTION MEDIUM:

Reaction pH significantly influences reduction kinetics and nanoparticle stability. Alkaline conditions generally promote rapid reduction and formation of smaller, well-dispersed nanoparticles, whereas acidic environments may result in aggregation [1, 7].

2.3.4 TEMPERATURE:

Temperature affects nucleation rate, particle size, and crystallinity. Elevated temperatures enhance reduction kinetics and crystallinity, producing smaller nanoparticles, while lower temperatures favor slower growth and larger particle sizes [13].

3. APPLICATIONS OF SILVER NANOPARTICLES

3.1 ANTIMICROBIAL AND ANTIBIOFILM APPLICATIONS

Green-synthesized AgNPs exhibit strong antibacterial and antibiofilm activity against multidrug-resistant pathogens. Their mechanisms include membrane disruption, enzyme inhibition, and interference with quorum sensing pathways [2]. These properties make AgNPs suitable for medical device coatings, textiles, and water disinfection systems [14,15].

3.2 BIOMEDICAL AND WOUND HEALING APPLICATIONS

Biosynthesized AgNPs have demonstrated excellent wound healing potential by preventing infection, reducing inflammation, and accelerating epithelialization. Recent studies have reported AgNP-loaded hydrogels and nanofibers that significantly enhance wound closure while minimizing cytotoxicity [2, 8].

3.3 ENVIRONMENTAL REMEDIATION AND CATALYSIS

Silver nanoparticles act as efficient catalysts for the degradation of organic pollutants and dyes in wastewater. AgNPs immobilized on biopolymer or carbon-based supports show high catalytic efficiency and reusability under mild conditions, making them promising for sustainable environmental remediation [16].

3.4 SENSORS, DIAGNOSTICS, AND SMART MATERIALS

AgNPs are widely used in biosensors exploiting localized surface plasmon resonance for ultra-sensitive detection of biomolecules, pathogens, and heavy metals. Recent advancements include flexible sensors, wearable diagnostics, and point-of-care devices, driven by the superior optical and electrical properties of AgNPs [17].

CONCLUSION

Silver nanoparticles represent one of the most versatile and promising classes of nanomaterials due to their unique physicochemical properties and broad application potential. This review highlights that subtle variations in synthesis parameters and plant phytochemical composition significantly influence nanoparticle formation, structure, and performance. The increasing adoption of plant extract-mediated synthesis reflects a global shift toward sustainable nanotechnology, offering safer and environmentally benign alternatives to conventional methods. While green-synthesized AgNPs show remarkable promise in biomedical, environmental, and sensing applications, their large-scale deployment requires comprehensive toxicity evaluation and regulatory standardization. Continued interdisciplinary research will be essential for translating laboratory-scale developments into safe and commercially viable technologies.

4. REFERENCES

1. Iravani S, Korbekandi H, Mirmohammadi SV, Zolfaghari B. Synthesis of silver nanoparticles: chemical, physical and biological methods. *Res Pharm Sci.* 2014; 9:385–406.
2. Ahmed S, Ahmad M, Swami BL, Ikram S. A review on plant extracts mediated synthesis of silver nanoparticles for antimicrobial applications. *J Adv Res.* 2016; 7(1):17–28. <https://doi.org/10.1016/j.jare.2015.02.007>
3. Shankar SS, Rai A, Ahmad A, Sastry M. Rapid synthesis of Au, Ag, and bimetallic Au core–Ag shell nanoparticles using neem (*Azadirachta indica*) leaf broth. *J Colloid Interface Sci.* 2004; 275(2):496–502. <https://doi.org/10.1016/j.jcis.2004.03.003>
4. Vilchis-Nestor AR, Sánchez-Mendieta V, Camacho-López MA, Gómez-Espinosa RM, Arenas-Alatorre JA. Solventless synthesis and optical properties of Au and Ag nanoparticles using *Camellia sinensis* extract. *Mater Lett.* 2008; 62:3103–3105. <https://doi.org/10.1016/j.matlet.2008.01.138>
5. Raghunandan D, et al. Anti-microbial studies of silver nanoparticles synthesized using guava leaf extract. *Int J Nanomater Biostruct.* 2011; 1:22–27.
6. Singhal G, Bhavesh R, Kasariya K, Sharma AR, Singh RP. Biosynthesis of silver nanoparticles using *Ocimum sanctum* leaf extract and screening its antimicrobial activity. *J Nanopart Res.* 2011; 13:2981–2988. <https://doi.org/10.1007/s11051-010-0193-y>

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7. Dubey M, Bhadauria S, Kushwah BS. Green synthesis of nanosilver particles from extract of *Eucalyptus hybrida* leaf. *Dig J Nanomater Biostruct.* 2009; 4(3):537–554.
8. Chandran SP, Chaudhary M, Pasricha R, Ahmad A, Sastry M. Synthesis of gold nanotriangles and silver nanoparticles using *Aloe vera* plant extract. *Biotechnol Prog.* 2006; 22(2):577–583. <https://doi.org/10.1021/bp0501423>
9. Sathyavathi R, Krishna MB, Rao DN. Biosynthesis of silver nanoparticles using *Moringa oleifera* leaf extract and its application to optical limiting. *J Nanosci Nanotechnol.* 2011; 11(3):2031–2035.
10. Vazhacharickal P, Mathew J, Sajeshkumar N, Sebastin A. Synthesis of silver nanoparticles from curry leaf (*Murraya koenigii*) extract and its antibacterial activity. *Int J Sci Res.* 2015; 4:2319–3891.
11. Jain D, Daima HK, Kachhwala S, Kothari SL. Synthesis of plant-mediated silver nanoparticles using papaya fruit extract and evaluation of their antimicrobial activities. *Dig J Nanomater Biostruct.* 2009; 4:557–563.
12. Prasad TN, Elumalai EK. Biofabrication of Ag nanoparticles using *Moringa oleifera* leaf extract and their antimicrobial activity. *Asian Pac J Trop Biomed.* 2011; 1(6):439–442. [https://doi.org/10.1016/S2221-1691\(11\)60096-8](https://doi.org/10.1016/S2221-1691(11)60096-8)
13. Sun Y, Xia Y. Shape-controlled synthesis of gold and silver nanoparticles. *Science.* 2002; 298(5601):2176–2179. <https://doi.org/10.1126/science.1077229>
14. Kiss FD, Miotto R, Ferraz AC. Size effects on silver nanoparticles' properties. *Nanotechnology.* 2011; 22:275708. <https://doi.org/10.1088/0957-4484/22/27/275708>
15. Wiley B, Sun Y, Mayers B, Xia Y. Shape-controlled synthesis of metal nanostructures: the case of silver. *Chemistry.* 2005; 11(2):454–463. <https://doi.org/10.1002/chem.200400927>
16. Palani G, et al. Silver nanoparticles for wastewater management. *Molecules.* 2023; 28:3520. <https://doi.org/10.3390/molecules28083520>
17. Tan P, Li H, Wang J, Gopinath SCB. Silver nanoparticles in biosensors and bioimaging: clinical perspectives. *Biotechnol Appl Biochem.* 2021; 68(6):1236–1242. <https://doi.org/10.1002/bab.2045>