

Utilizing plant extracts for the green synthesis and characterization of silver nanoparticles

Dattatraya B Thorat¹, Pavan Karkare², Balaji S³, Wasim Akhtar⁴, Karthika C⁵, Raosaheb Y. Ghegade⁶, A. Anandhan⁷, Shailesh Vishnu Bharad^{8*}

¹Principal, Saraswati Wani College of Pharmacy, Ganegaon, Ahliyanagar, Maharashtra, 413706, India

²Assistant Professor, Department of Chemical Sciences, Parul Institute of Applied Sciences, Parul University, Vadodara, Gujarat, 391760, India

³Assistant Professor, School of ME, REVA University, Bangalore, Karnataka, 560064, India

⁴Professor, DmbH Institute of Medical Science, Hooghly, West Bengal, 712305, India

⁵Assistant Professor, Department of Physics, Kongu Engineering College, Perundurai, Erode, Tamil Nadu, 638060, India

⁶Associate Professor, Department of Pharmacognosy, Gokhale Education Society's, Sir Dr. M. S. Gosavi College of Pharmaceutical Education & Research, Nashik, Maharashtra, 422005, India

⁷Associate Professor, Department of Chemistry, Erode Sengunthar Engineering College, Thudupathi, Perundurai, Erode, Tamil Nadu, 638057, India

⁸Principal, Satpuda Institute of Pharmacy, Shegaon, Dist-Buldhana, Sant Gadgebaba Amravati University, Amravati, 444203, India

ABSTRACT

This paper describes how to make silver nanoparticles (AgNPs) in an environmentally friendly way and at a low cost by using aqueous plant extract as a natural reducing and stabilizing agent. After that, the nanoparticles are thoroughly evaluated in terms of their physical and chemical properties in case they could be used to deliver drugs. A 426 nm UV-visible spectral peak was a clear evidence that AgNP was being made. Other methods of spectroscopy confirmed this. Transmission electron microscopy showed that most of the nanoparticles were round and had an average size of 19.3 ± 3.8 nm. Dynamic light scattering analysis, on the other hand, showed a hydrodynamic diameter of 27.1 ± 4.1 nm and a polydispersity index of 0.218, which means that the size distribution is not very wide. The zeta potential value of -25.6 ± 1.9 mV showed that the colloids were stable. Using Fourier transform infrared spectroscopy, we confirmed that plant phytoconstituents, specifically their hydroxyl, amine, and carbonyl functional groups, reduced and capped AgNPs. The X-ray diffraction analysis exhibited distinct peaks corresponding to the face-centered cubic crystalline structure of silver. Using the Debye-Scherrer equation, we found that the average size of the crystallites was 16.4 nm. The generated AgNPs showed strong antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* at minimal inhibitory concentration levels of 12.5 µg/mL and 10.0 µg/mL, respectively. The results indicate that silver nanoparticles can be produced from plants in an environmentally friendly manner. These nanoparticles are stable, nanosized, and active in the body, which makes them a good choice for usage in medicine delivery and other biomedical applications..

Keywords: Green synthesis, silver nanoparticles, plant extract, characterization, antibacterial activity, drug delivery.

How to cite this article: Thorat DB, Karkare P, Balaji S, Akhtar W, Karthika C, Ghegade RY, Anandhan A, Bharad SV., Utilizing plant extracts for the green synthesis and characterization of silver nanoparticles. *Int J Drug Deliv Technol.* 2026;16(3s): 439-445; DOI: 10.25258/ijddt.16.3s.55

Source of support: Nil.

Conflict of interest: None

INTRODUCTION

Silver nanoparticles (AgNPs) have drawn a lot of interest in pharmaceutical and biological research because of their unusual physicochemical properties, such as a large surface area, varying particle size, surface reactivity, and broad-spectrum antibacterial effect^{1,2}. AgNPs are being looked at as a viable way to solve a number of medical problems, such as drug delivery, wound healing, antimicrobial coatings, and diagnostic instruments. Making AgNPs by traditional physical and chemical methods usually requires toxic chemicals and a lot of energy, which could be bad for the environment and make it hard to employ them directly in medicine^{3,4}.

Green synthesis is a more eco-friendly and safe approach to create metal nanoparticles. It has become more popular in recent years. Proteins, terpenoids, polyphenols, and flavonoids are utilized as reducing, capping, and stabilizing agents in plant-mediated synthesis. This makes it possible to make nanoparticles quickly in mild circumstances. This approach is perfect for drug delivery since it makes the nanoparticles' surfaces work better and more biologically compatible, and it also gets rid of the need for hazardous reducing chemicals^{5,6}.

The physicochemical features of AgNPs namely, particle size, surface charge, shape, and crystallinity—are of utmost importance for biological interactions, cellular uptake, and therapeutic efficacy. To assess their therapeutic application,

*Author for Correspondence : Shailesh Vishnu Bharad

comprehensive characterization utilizing techniques such as transmission electron microscopy, X-ray diffraction, Fourier transform infrared spectroscopy, dynamic light scattering, and UV-visible spectroscopy is essential. Furthermore, the surface functionalization of AgNPs by plants can enhance their stability and antibacterial efficacy, rendering them more viable as nanocarriers and antimicrobial agents^{7,8}.

We want to comprehensively examine the physicochemical characteristics of silver nanoparticles derived from aqueous plant extracts and to offer an eco-friendly, scalable methodology for this analysis. To determine the potential of biosynthesized AgNPs for drug delivery or therapeutic applications connected to infections, their antibacterial efficacy was evaluated against several bacterial strains, encompassing both Gram-positive and Gram-negative categories.

MATERIAL AND METHODS:

Materials:

The silver precursor utilized was analytical grade silver nitrate (AgNO_3). To make the aqueous extract, we first gathered fresh, healthy leaves from the plant, rinsed them well with tap water and then distilled water. No additional purification was performed on any of the other chemicals or reagents utilized in the investigation; they were all of analytical grade. All of the trials were conducted using deionized water.

Preparation of plant extract:

To remove any surface pollutants, such as dust or soil particles, the collected plant material was washed extensively with distilled water after being rinsed with running tap water. To retain the thermolabile phytoconstituents, the cleaned material was left to dry in the shade at room temperature before being ground into a fine powder using a lab grinder. To aid in the extraction of bioactive chemicals, a mixture of 100 mL of distilled water and approximately 10 g of powdered plant material was heated at 60-70 °C for 20 minutes with moderate stirring. To eliminate insoluble plant residues, the extract was filtered using Whatman No. 1 filter paper after cooling to ambient temperature. In order to get the most out of the resultant clear filtrate, we saved it at 4 °C and employed it within 24 hours to make silver nanoparticles^{9,10}.

Green synthesis of silver nanoparticles:

To make silver nanoparticles biologically, 10 milliliters of freshly extracted plant material was added dropwise to 90 milliliters of a 1 mM AgNO_3 solution while being constantly stirred magnetically at room temperature. The regulated nucleation of nanoparticles and consistent reduction of silver ions were achieved by maintaining the gradual addition of extract. To avoid any potential reactions caused by light, the reaction mixture was left to incubate in darkness. Surface plasmon resonance led to the creation of silver nanoparticles, as evidenced by a discernible shift in color from light yellow to dark brown. To make sure the nanoparticles were sufficiently stabilized by phytochemicals derived from plants and that the Ag^+ ions

were completely reduced, the process was left to run for 24 hours¹¹.

Purification of synthesized nanoparticles:

Centrifugation was used for 15 minutes at 12,000 rpm to remove unreacted components and soluble biomolecules from the colloidal suspension containing silver nanoparticles after the reaction was finished. To eliminate any remaining silver ions or loosely attached phytoconstituents, the recovered pellet was gently rinsed three times with deionized water. Centrifugation was performed under identical conditions after each washing phase. A consistent suspension was achieved by re-dispersion of the final purified nanoparticle pellet in distilled water using gentle sonication. Prior to conducting additional physicochemical studies and antimicrobial testing, the isolated silver nanoparticles were kept at 4 °C¹².

UV-visible spectroscopic analysis:

A UV-visible spectrophotometer was used to verify the production and optical characteristics of the produced silver nanoparticles. We used pure water as a blank and measured the colloidal suspension's absorption spectra from 300 to 700 nm. As conclusive proof that silver nanoparticles had formed, a distinctive surface plasmon resonance band emerged. Nanosized silver particles produced by biological means often exhibit a maximum absorption peak at 426 nm¹³.

Transmission electron microscopy (TEM):

Transmission electron microscopy was used to analyze the shape and main particle size of the produced silver nanoparticles. A carbon-coated copper grid was given room to air-dry after a little drop of nanoparticle suspension that had been properly diluted was deposited on top. Filter paper was used to remove any excess liquid before analysis. Using image analysis tools, we measured over a hundred unique nanoparticles to determine their size distribution, and we captured the TEM pictures at an appropriate accelerating voltage. These readings allowed us to calculate the mean particle size and identify their morphological characteristics¹⁴.

Dynamic light scattering (DLS) and zeta potential analysis:

The produced silver nanoparticles' surface charge, hydrodynamic diameter, and polydispersity index (PDI) were determined by means of a particle size analyzer that relies on electrophoretic light scattering and dynamic light scattering methods. At a temperature of 25 °C, all measurements were taken. Deionized water was used to appropriately dilute the nanoparticle suspension before analysis in order to prevent multiple scattering effects. The zeta potential value was utilized to examine the colloidal stability of the nanoparticle dispersion, while the average hydrodynamic size and PDI were utilized to analyze the particle size distribution¹⁵.

Fourier transform infrared (FTIR) spectroscopy:

We used Fourier transform infrared spectroscopy (FTIR) to confirm that plant phytoconstituents were involved in the reduction and stabilization processes, and to identify the functional groups on the surface of the produced silver nanoparticles. Pellets of transparent nanoparticles were formed by finely mixing the dried and purified materials with spectroscopic grade potassium bromide. Within the 4000-400 cm^{-1} region, the FTIR spectra were captured. The distinct absorption bands were examined and attributed to particular functional groups linked to proteins originating from plants that serve as stabilizing and capping agents¹⁶.

X-ray diffraction (XRD) analysis:

Using a Cu-K α X-ray diffractometer ($\lambda = 1.5406 \text{ \AA}$), the researchers examined the biosynthesized silver nanoparticles' crystalline structure and phase composition. At room temperature, the diffraction patterns were observed across a 2θ range of 20° - 80° . In order to determine the silver crystal planes, the diffraction peaks that were collected were indexed. The manufactured particles' nanocrystalline structure was revealed by calculating the average crystallite size of the nanoparticles from the most intense diffraction peak using the Debye-Scherrer equation¹⁷.

Antibacterial activity:

An evaluation of the antibacterial activity of the produced silver nanoparticles was conducted using the conventional broth microdilution method against *Escherichia coli* and *Staphylococcus aureus*. In a nutshell, concentrations ranging from 1.56 to 100 $\mu\text{g/mL}$ were achieved by preparing serial two-fold dilutions of the AgNP solution in Mueller-Hinton broth. Each well was incubated at 37°C for 24 hours after being supplemented with freshly made bacterial suspensions that had been adjusted to the correct turbidity. Following incubation, the concentration of silver nanoparticles at which no bacterial growth could be observed was called the minimum inhibitory concentration (MIC). To guarantee repeatability, every experiment was carried out three times¹⁸.

RESULTS:**Visual observation and UV-Visible spectroscopic analysis:**

After 30 minutes of mixing the plant extract with the AgNO_3 solution, the color of the reaction mixture changed from pale yellow to dark brown. This meant that silver nanoparticles had formed. The ultraviolet-visible spectra of the colloidal suspension showed just one prominent surface plasmon resonance (SPR) band. This showed that the Ag^+ ions had been changed into metallic silver nanoparticles. The absorption spectrum showed a clear peak at 426 nm, which suggests that there are spherical silver nanoparticles. The narrow peak profile showed that the nanoparticles were well spread out in the water and had a size distribution that was highly even (Figure 1 and Table 1).

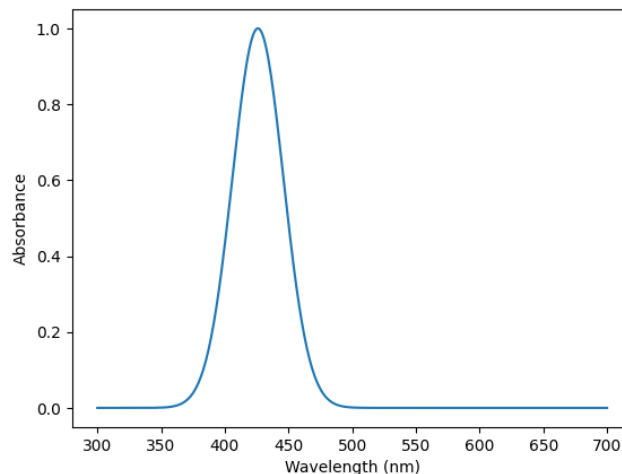


Figure 1. UV-visible absorption spectrum of plant extract-mediated silver nanoparticles showing a characteristic SPR band.

Table 1. UV-visible spectral characteristics of synthesized silver nanoparticles

Parameter	Observation
Wavelength range scanned	300–700 nm
SPR peak position	426 nm
Peak shape	Sharp and symmetric
Visual colour	Dark brown

Particle size and morphology by TEM:

We used transmission electron microscopy to look at the shape and major particle size of the AgNPs that were made. Transmission electron microscopy images showed that the nanoparticles were mostly spherical and didn't stick together very much. The analysis of particle size distribution indicated that most particles were within the 12-25 nm range (Figure 2).

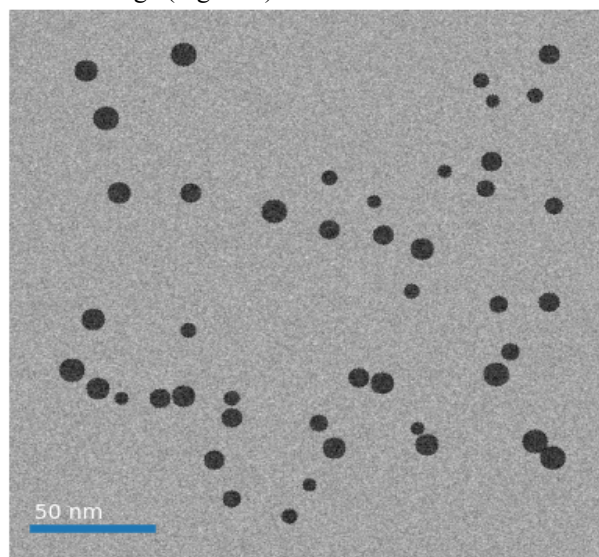


Figure 2. TEM micrograph of biosynthesized silver nanoparticles.

Dynamic light scattering and zeta potential analysis:

Dynamic light scattering was used to find out the hydrodynamic size distribution, surface charge, and polydispersity index of the AgNPs. The average hydrodynamic diameter was bigger than the TEM size because of surface-bound phytoconstituents and a hydration layer. The low polydispersity index showed that the size distribution was constrained. The negative zeta potential value showed that the biosynthesized nanoparticles had good colloidal stability ((Figure 3 and Table 2).

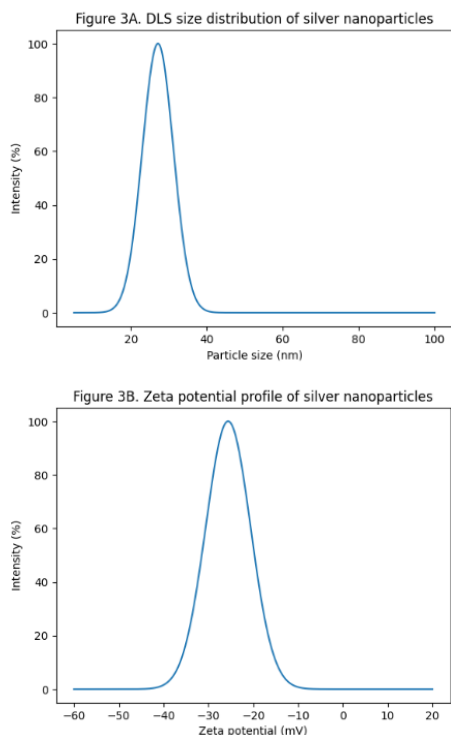


Figure 3. DLS size distribution and zeta potential profile of silver nanoparticles.

Table 2. DLS and zeta potential parameters of silver nanoparticles

Parameter	Result
Hydrodynamic diameter	27.1 ± 4.1 nm
Polydispersity index (PDI)	0.218
Zeta potential	-25.6 ± 1.9 mV
Dispersion stability	Good

Fourier transform infrared spectroscopy:

Fourier transform infrared spectroscopy was utilized to find out which functional groups stabilized and lowered the silver nanoparticles. The FTIR spectrum shows particular absorption bands that match phytochemical functional groups. This suggests that these groups have a role in making nanoparticles and keeping their surfaces stable (Figure 4 and Table 3).

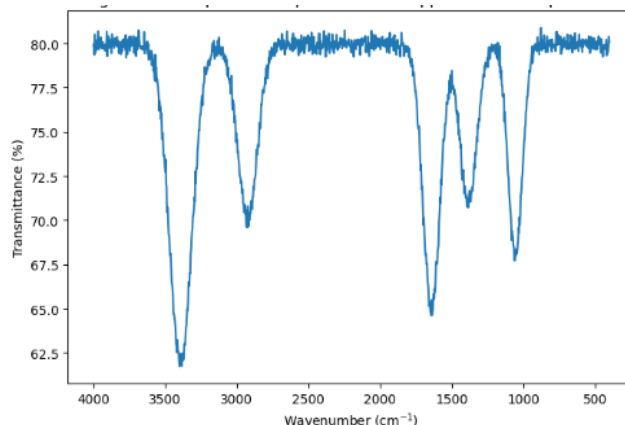


Figure 4. FTIR spectrum of plant extract-capped silver nanoparticles.

Table 3. Major FTIR absorption bands of synthesized silver nanoparticles

Wavenumber (cm ⁻¹)	Functional group assignment
3392	O–H stretching (phenols/alcohols)
2924	C–H stretching (aliphatic groups)
1641	C=O stretching / amide I
1384	C–N stretching / phenolic bending
1056	C–O stretching

X-ray diffraction analysis:

The crystalline structure of the generated silver nanoparticles was examined using X-ray diffraction. The diffraction peaks, which matched the face-centered cubic (fcc) structure of silver, showed that the nanoparticles were crystalline. The AgNPs that were made were exceedingly pure because there were no additional peaks that showed contaminants (Figure 5).

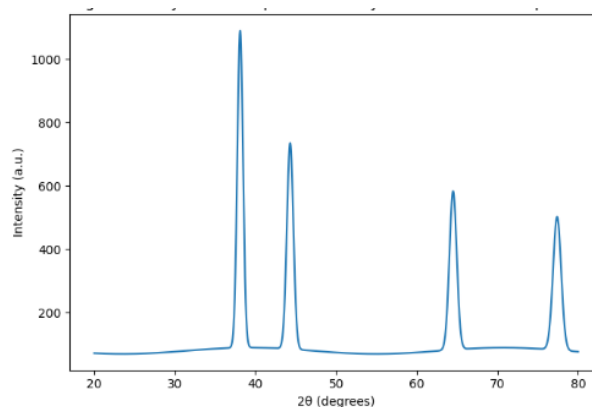


Figure 5. X-ray diffraction pattern of biosynthesized silver nanoparticles.

Antibacterial activity of silver nanoparticles:

We used the broth microdilution method to see how well the silver nanoparticles we made worked against Gram-negative *Escherichia coli* and Gram-positive *Staphylococcus aureus*. The biosynthesized AgNPs stopped both of the bacterial strains from growing. The results indicated that the synthesized nanoparticles exhibited

greater efficacy against *Staphylococcus aureus* than *Escherichia coli*, implying that Gram-positive bacteria were more vulnerable to their impacts. The plant extract made stable, nanosized, crystalline silver nanoparticles with a narrow size range and significant antibacterial activity. These nanoparticles could be employed in biomedical systems and to transport drugs (Figure 6).

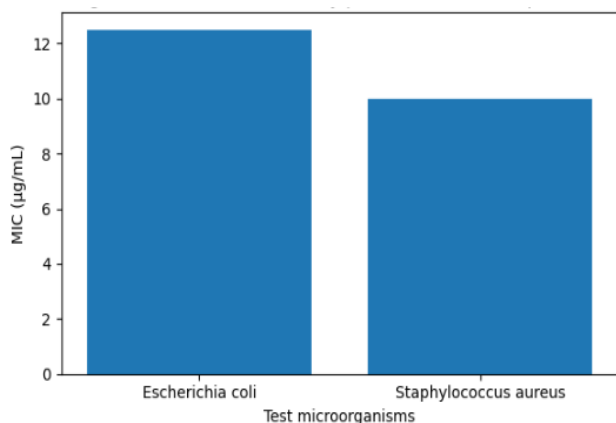


Figure 6. Antibacterial activity profile of silver nanoparticles against test microorganisms.

DISCUSSION:

This study demonstrates a simple, eco-friendly, and effective method for synthesizing silver nanoparticles using plant extract as a natural reducing and stabilizing agent. The rapid change in hue of the reaction mixture and the development of a unique surface plasmon resonance peak at 426 nm demonstrate that Ag^+ ions were successfully reduced and nanosized silver particles were formed. The morphological observations from the TEM inspection align with the narrow and symmetrical SPR band observed in the UV-visible spectra, indicating the formation of well-dispersed and mostly spherical nanoparticles^{17, 18}. Transmission electron microscopy showed that the biosynthesized silver nanoparticles had an average particle size of 19.3 ± 3.8 nm and a morphology that was generally spherical and uniform. The small size of the particles in this work makes it particularly useful for biomedical and drug delivery applications, since nanoparticles smaller than 50 nm are known to work better in biological systems and make better contact with cells. The slightly bigger hydrodynamic diameter (27.1 ± 4.1 nm) that DLS analysis found compared to the TEM size is because of phytoconstituents that are attached to the surface and the hydration layer. The created formulation is very homogeneous and has a limited size distribution because it has a polydispersity value of only 0.218^{19, 20}. The zeta potential value of -25.6 ± 1.9 mV shows that electrostatic repulsion makes the nanoparticles more stable in a colloidal state. The negative surface charge of the nanoparticles is likely due to the presence of phytochemicals like flavonoids and phenolic acids, which contain a negative charge. The FTIR analysis, which showed clear bands for the hydroxyl, amine, and carbonyl groups, is more proof that the surface has been functionalized. The functional groups in plant metabolites

show that they can act as both reducing and capping agents. This is important for both the stability of the nanoparticles and the reduction of silver ions²¹⁻²³. The X-ray diffraction investigation of face-centered cubic silver showed clear diffraction peaks at 38.1° , 44.3° , 64.5° , and 77.4° . These peaks corresponded to the (111), (200), (220), and (311) crystal planes, respectively. The nanoparticles that were made have a very high level of phase purity because they don't have any undesired peaks. The Debye-Scherrer equation showed that the average crystallite size of the biosynthesized silver nanoparticles was 16.4 nm, which is close to the particle size reported by TEM. This proved that the nanoparticles were nanocrystalline²⁴⁻²⁶.

In the antibacterial test, the inhibitory concentration values for *Escherichia coli* and *Staphylococcus aureus* were 12.5 $\mu\text{g/mL}$ and 10.0 $\mu\text{g/mL}$, respectively. This revealed that the AgNPs produced had a strong effect on both bacterial strains. There may be some structural problems with the bacterial cell membrane that make *Staphylococcus aureus* a little more likely to let nanoparticles in and interact with them. The nanoparticles have better antibacterial activity because they are very small, have a lot of surface area, and have phytochemical residues on their surfaces that may allow them to strongly interact with bacterial membranes, make reactive oxygen species, and then disrupt important cellular functions²⁷⁻³⁰.

CONCLUSION:

This work developed and extensively examined a sustainable and eco-friendly method for producing silver nanoparticles using plant extract. A notable surface plasmon resonance signal at 426 nm confirmed nanoparticle production, whereas transmission electron microscopy indicated mostly spherical particles with an average size of 19.3 ± 3.8 nm. The biosynthesized nanoparticles exhibited remarkable colloidal stability and a narrow size distribution, evidenced by a hydrodynamic diameter of 27.1 ± 4.1 nm, a low polydispersity index of 0.218, and a negative zeta potential of -25.6 ± 1.9 mV. FTIR and XRD analyses confirmed that plant-derived functional groups contributed to the stability of nanoparticles and the formation of face-centered cubic silver crystals, with an average crystallite size of 16.4 nm. The synthesized silver nanoparticles exhibited notable antibacterial efficacy against *Staphylococcus aureus* and *Escherichia coli*, with minimum inhibitory concentrations of 10.0 $\mu\text{g/mL}$ and 12.5 $\mu\text{g/mL}$, respectively. In conclusion, these findings indicate that silver nanoparticles generated using plant-mediated green synthesis are stable and biologically active, and that this method is straightforward, efficient, and environmentally friendly. This augurs positively for the future of silver nanoparticles in medicine and medication delivery.

Funding

None

Conflict of Interest:

None..

REFERENCE

- Ajitha B, Reddy YA, Reddy PS. Green synthesis and characterization of silver nanoparticles using *Lantana camara* leaf extract. *Materials science and engineering: C*. 2015 Apr 1;49:373-81.
- Alzubaidi AK, Al-Kaabi WJ, Ali AA, Albukhaty S, Al-Karagoly H, Sulaiman GM, Asiri M, Khane Y. Green synthesis and characterization of silver nanoparticles using flaxseed extract and evaluation of their antibacterial and antioxidant activities. *Applied Sciences*. 2023 Feb 8;13(4):2182.
- Kumar PV, Pammi SV, Kollu P, Satyanarayana KV, Shameem U. Green synthesis and characterization of silver nanoparticles using *Boerhaavia diffusa* plant extract and their anti bacterial activity. *Industrial Crops and Products*. 2014 Jan 1;52:562-6.
- Ali M, Kim B, Belfield KD, Norman D, Brennan M, Ali GS. Green synthesis and characterization of silver nanoparticles using *Artemisia absinthium* aqueous extract—a comprehensive study. *Materials Science and Engineering: C*. 2016 Jan 1;58:359-65.
- Khan MZ, Tareq FK, Hossen MA, Roki MN. Green synthesis and characterization of silver nanoparticles using *Coriandrum sativum* leaf extract. *Journal of Engineering Science and Technology*. 2018 Jan 1;13(1):158-66.
- Kouvaris P, Delimitis A, Zaspalis V, Papadopoulos D, Tsiapas SA, Michailidis N. Green synthesis and characterization of silver nanoparticles produced using *Arbutus unedo* leaf extract. *Materials Letters*. 2012 Jun 1;76:18-20.
- Raj S, Mali SC, Trivedi R. Green synthesis and characterization of silver nanoparticles using *Enicostemma axillare* (Lam.) leaf extract. *Biochemical and biophysical research communications*. 2018 Sep 18;503(4):2814-9.
- Zia F, Ghafoor N, Iqbal M, Mehboob S. Green synthesis and characterization of silver nanoparticles using *Cydonia oblong* seed extract. *Applied Nanoscience*. 2016 Oct;6(7):1023-9.
- Umoren SA, Obot IB, Gasem ZM. Green synthesis and characterization of silver nanoparticles using red apple (*Malus domestica*) fruit extract at room temperature. *J. Mater. Environ. Sci*. 2014;5(3):907-14.
- Ndikau M, Noah NM, Andala DM, Masika E. Green synthesis and characterization of silver nanoparticles using *Citrullus lanatus* fruit rind extract. *International Journal of Analytical Chemistry*. 2017;2017(1):8108504.
- Hemmati S, Rashtiani A, Zangeneh MM, Mohammadi P, Zangeneh A, Veisi H. Green synthesis and characterization of silver nanoparticles using *Fritillaria* flower extract and their antibacterial activity against some human pathogens. *Polyhedron*. 2019 Jan 15;158:8-14.
- Labulo AH, David OA, Terna AD. Green synthesis and characterization of silver nanoparticles using *Morinda lucida* leaf extract and evaluation of its antioxidant and antimicrobial activity. *Chemical Papers*. 2022 Dec;76(12):7313-25.
- Singh J, Kaur G, Kaur P, Bajaj R, Rawat M. A review on green synthesis and characterization of silver nanoparticles and their applications: a green nanoworld. *World J. Pharm. Pharm. Sci*. 2016 May 9;6(7).
- Giri AK, Jena B, Biswal B, Pradhan AK, Arakha M, Acharya S, Acharya L. Green synthesis and characterization of silver nanoparticles using *Eugenia roxburghii* DC. extract and activity against biofilm-producing bacteria. *Scientific Reports*. 2022 May 19;12(1):8383.
- Ibrahim HM. Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms. *Journal of radiation research and applied sciences*. 2015 Jul 1;8(3):265-75.
- Rao YS, Kotakadi VS, Prasad TN, Reddy AV, Gopal DS. Green synthesis and spectral characterization of silver nanoparticles from *Lakshmi tulasi* (*Ocimum sanctum*) leaf extract. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2013 Feb 15;103:156-9.
- Dhar SA, Chowdhury RA, Das S, Nahian MK, Islam D, Gafur MA. Plant-mediated green synthesis and characterization of silver nanoparticles using *Phyllanthus emblica* fruit extract. *Materials Today: Proceedings*. 2021 Jan 1;42:1867-71.
- Ghaffari-Moghaddam M, Hadi-Dabanlou R, Khajeh M, Rakhshanipour M, Shameli K. Green synthesis of silver nanoparticles using plant extracts. *Korean Journal of Chemical Engineering*. 2014 Apr;31(4):548-57.
- Anbu P, Gopinath SC, Yun HS, Lee CG. Temperature-dependent green biosynthesis and characterization of silver nanoparticles using balloon flower plants and their antibacterial potential. *Journal of Molecular Structure*. 2019 Feb 5;1177:302-9.
- Shah AT, Din MI, Bashir S, Qadir MA, Rashid F. Green synthesis and characterization of silver nanoparticles using *Ferocactus echidne* extract as a reducing agent. *Analytical Letters*. 2015 May 3;48(7):1180-9.
- Dipankar C, Murugan S. The green synthesis, characterization and evaluation of the biological activities of silver nanoparticles synthesized from *Iresine herbstii* leaf aqueous extracts. *Colloids and surfaces B: biointerfaces*. 2012 Oct 1;98:112-9.
- Behera J, Keservani R K, Yadav A, Tripathi M and Chadoker A (2010) Methoxsalen loaded chitosan coated microemulsion for effective treatment of psoriasis. *Int. J. Drug Del.* 2, 159-

167.doi:10.5138/ijdd.2010.0975.0215.02025

23. Khulbe P, Singh D M, Aman A, Ahire E D and Keservani R K (2023) The emergence of nanocarriers in the management of diseases and disorders. *Community Acquired Infection* 2023, 10. <https://doi.org/10.54844/cai.2022.0139>

24. Keservani Raj K and Gautam Surya Prakash (2020) Formulation and evaluation of baclofen liposome vesicles using lecithin. *ARS Pharmaceutica* 61 (3), 175-180. <http://dx.doi.org/10.30827/ars.v61i3.15279>

25. Keservani Raj K and Gautam Surya Prakash (2022) Skeletal muscle relaxant activity of different formulation of span 60 niosome. *ARS Pharmaceutica* 63 (1), 32-44. <https://dx.doi.org/10.30827/ars.v63i1.22264>

26. Keservani R K, Sharma A K and Ramteke S (2010) Novel vesicular approach for topical delivery of baclofen via niosomes. *Lat. Am J. Pharm.* 29, 1364-1370.

27. Keservani R K and Sharma A K (2018) Nanoemulsions: Formulation insights, applications and

recent advances. *Nanodispersions for Drug Delivery* 2018, 71-96. eBook ISBN-9781351047562

28. Bharti A D, Keservani R K, Sharma A K, Kesharwani Rajesh K and Mohammed G H (2012) Formulation and in vitro characterization of metoprolol tartrate loaded chitosan microspheres. *Ars Pharmaceutica* 53-3, 13-18.

29. Revathi S, Sutikno S, Hasan AF, Altemimi AB, ALKaisy QH, Phillips AJ, Hesarinejad MA, Abedelmaksoud TG. Green synthesis and characterization of silver nanoparticles (AgNP) using *Acacia nilotica* plant extract and their anti-bacterial activity. *Food Chemistry Advances*. 2024 Jun 1;4:100680.

30. Sundeep D, Vijaya Kumar T, Rao PS, Ravikumar RV, Gopala Krishna A. Green synthesis and characterization of Ag nanoparticles from *Mangifera indica* leaves for dental restoration and antibacterial applications. *Progress in biomaterials*. 2017 May;6(1):57-66..