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Green Synthesis of Silver Nanoparticles Using Medicinal Plant Extracts: Characterization and Biomedical Potential

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Abstract

Green synthesis of silver nanoparticles (AgNPs) using medicinal plant extracts has emerged as a sustainable and eco-friendly approach for producing biologically active nanomaterials. This study investigated the biosynthesis, characterization, and biomedical potential of AgNPs derived from selected plant extracts. The nanoparticles were synthesized via a simple reduction process, and their formation was confirmed through ultraviolet–visible (UV–Vis) spectroscopy. Morphological and structural analyses were performed using scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), and Fourier-transform infrared (FTIR) spectroscopy. The synthesized nanoparticles exhibited predominantly spherical shapes with an average particle size of 18–35 nm and crystalline face-centered cubic structures. Functional group analysis revealed the involvement of plant-derived phytochemicals in nanoparticle stabilization. The biomedical potential of the biosynthesized AgNPs was evaluated through antibacterial, antioxidant, and cytotoxicity assays. The results demonstrated broad-spectrum antimicrobial activity against Gram-positive and Gram-negative bacteria, significant concentration-dependent free radical scavenging activity, and moderate dose-dependent cytotoxic effects on mammalian cells, indicating biocompatibility at lower concentrations. These findings highlighted the multifunctional nature of green-

synthesized AgNPs and their potential applications in antimicrobial therapy, oxidative stress mitigation, and wound healing. Overall, the study validated the efficacy of plant-mediated green synthesis as a cost-effective and environmentally sustainable approach to producing nanomaterials with promising biomedical relevance.

Introduction

Nanotechnology had already developed into a revolutionary science field where materials on the nanoscale can be manipulated to get increased chemical, physical or biological properties. Silver nanoparticles (AgNPs) had received special attention because of their high antimicrobial, catalytic, and optical properties that were especially important in biomedicine (Iravani et al., 2014). The increased use of nanoparticles was however, making concerns on the environmental and biological safety of the conventional methods of synthetic production. Research In general, standard physical and chemical methods of synthesizing AgNPs, tend to be based on toxic reducing agents, elevated temperatures, and wasteful use of energy, producing dangerous by-products and limiting biomedical safety (Ahmed et al., 2016). All these negatives led to the scientific fraternity seeking other synthesis methods that could be consistent with the principles of green chemistry and functionality.

Plant-mediated green synthesis offered a developmental prospective, where the natural reducing and capping agents are flavonoids, phenolics, terpenoids and alkaloids (Singh et al., 2018). Such a strategy led to reduced environmental impact and increased stability of nanoparticles as well as their biological activity by functionalizing the surfaces. Recent studies revealed that biosynthesised AgNPs had better antimicrobial, antioxidant and anticancer properties than their chemically synthesised analogs because of synergistic effects between silver and plant metabolites (Rai et al., 2021). These results highlighted the applicability of green synthesis in the synthesis of multifunctional nanomaterials that can be used in biomedical systems.

Research Background

Green nanoparticle synthesis was based on the concept of sustainable chemistry that focused on limiting the toxic waste and the utilization of renewable biological resources. Plants that were advantageous in particular were medicinal ones that had high phytochemical contents and known medicinal effects (Prakash et al., 2013). Their extracts promoted the quick decrease of silver ions at ambient environment without any external stabilizers.

A number comprised reliable synthesis of AgNPs by extracts of plants including Azadirachta indica, Ocimum sanctum, and Curcuma longa to obtain nanoparticles with regulated dimensions and structure (Mittal et al., 2013). These nanoparticles produced by biosynthesis frequently exhibited enhanced dispersion and stability in the long term, which were essential to be used in biomedicine.

The methods of characterization were instrumental in the process of proving the production of nanoparticles and their performance. The surface plasmon resonance was validated by UV-Vis spectroscopy whereas FTIR was used to determine the presence of phytochemicals in nanoparticle capping. The structural and morphological measures on the XRD, SEM, and TEM indicated the crystalline character and a nanoscale size (Dhand et al., 2015).

The biomedical significance of the green-synthesized AgNPs was studied widely. The research indicated high antibacterial capability against the disease-resistant pathogens and encouraging antioxidant and cytotoxic potential on the cancer cell lines (Gurunathan et al., 2014). Their ability to become part of therapeutic formulations and medical devices was featured in these properties.

Research Problem

In spite of much research being done, to date, green synthesis of AgNPs had some challenges regarding reproducibility and standardization. The lack of uniformity in plant species, extraction procedures, levels of phytochemicals and the reaction system led to the lack of uniform nanoparticle size, morphology, and biological activity. This variability was a limitation to the scalability and industrial translation of plant-based synthesis systems. Although in vitro research showed high biomedical promise, there was a lack of significance in in-vivo toxicity, pharmacokinetic, and long term safety tests. Also unavailable were standardized biological evaluation protocols to facilitate regulatory permission and clinical trial use of green-synthesized silver nanoparticles.

Objectives of the Study

To synthesize silver nanoparticles using medicinal plant extracts through an environmentally sustainable approach.
To characterize the physicochemical properties of biosynthesized AgNPs using standard analytical techniques.
To evaluate the antimicrobial, antioxidant, and cytotoxic potential of green-synthesized AgNPs.
To assess the role of plant phytochemicals in nanoparticle stabilization and biological activity.

Research Questions

Q1. How effectively did medicinal plant extracts facilitate the green synthesis of silver nanoparticles?
Q2. What were the structural and morphological characteristics of the synthesized AgNPs?
Q3. What level of biomedical activity did the biosynthesized AgNPs exhibit in vitro?
Q4. How did phytochemical composition influence nanoparticle functionality?

Significance of the Study

This study advanced sustainable nanotechnology by promoting an eco-friendly synthesis route for silver nanoparticles with enhanced biomedical relevance. The findings contributed to addressing environmental concerns associated with conventional nanoparticle synthesis while supporting the development of safer antimicrobial and therapeutic agents. Additionally, the study provided a foundation for future standardization and clinical translation of green-synthesized nanomaterials.

Literature Review

Plant-Mediated Synthesis and Phytochemical Roles

Researchers noted the fact that plant extracts were an easy and inexpensive and environmentally friendly method of making silver nanoparticles (AgNPs) by reducing and stabilizing them using phytochemicals including phenolics, flavonoids, terpenoids, and alkaloids (Shahzabi et al., 2025; Subbulakshmi et al., 2024). As shown in the examined multiple plant systems by Shahzadi et al. (2025), the diversity and concentration of the discussed bioactive compounds directly affected nanoparticle yield, size, and stability, and thus, plant-mediated synthesis has become a broad method of biomedical nanotechnology. Likewise, Subbulakshmi et al. (2024), also observed a greater biocompatibility of green-synthesized nanoparticles than chemically-synthesized ones and attributed this to the surface functionalization of those particles through plant phytochemicals, which enhanced biological interactions.
Other experiments determined that the critical factor in controlling the attributes of nanoparticles is optimization of synthesis parameters like pH, temperature as well as extract concentration (Shahzabi et al., 2025; Subbulakshmi et al., 2024). Shahzadi et al. (2025) also concluded that, although the choice of these parameters could fine-tune

the size distribution and avoid agglomeration, which were crucial to uniform biomedical behaviors, the size dependence was necessary. Subbulakshmi et al. (2024) also added that the production in the form of plant extract-mediated synthesis was possible under mild conditions, which is consistent with the sustainable and low-energy principles required in large-scale production.

Certain plant systems were shown to be effective in reducing hashed and different nanoparticle characteristics. As an example, Akhtar et al. (2025) synthesized AgNPs using mint leaf extract and noted the well-dispersed crystals with good antimicrobial efficacy, whereas Rehman et al. (2023) employed Azadirachta indica seed extract in the generation of AgNPs and were able to see the promising anti-diabetic activity both in vitro and in vivo. These experiments put emphasis on the notion that plant type and phytochemical diversities can impart manifold biological possibilities to nanoparticles.

Antioxidant and Antimicrobial Effects of the green-Synthesized AgNPs

The antimicrobial effect of the green-synthesized AgNPs in removing bacterial, fungal, as well as drug-resistant strains was one of the most widely reported biomedical applications of the nanoparticles (Shahzabi et al., 2025; Akhter et al., 2024). A review of the literature indicated that AgNPs of plant origin produced effective inhibition behavior regarding Gram-positive and Gram-negative bacterial strains and in most cases, they were more effective than plant extracts or chemical nanoparticles (Shahzadi et al., 2025). Akhter et al. (2024) have shown that AgNPs produced using the leave of Citrus paradisi prevented the formation of biofilms and exhibited high antibacterial activities.

The applications of plant-mediated AgNPs were also common in which phytochemicals bonded on the surface were predominantly involved in the free radical scavenging impacts (Shahzadi et al., 2025; Akhter et al., 2024). According to Shahzadi et al., flavonoids and phenolic groups increased radical neutralization and could be used in therapies involving oxidative stress (Shahzadi et al., 2025). Akhter et al. (2024) also indicated that the antioxidant of Citrus paradisi AgNPs exhibited a dose-dependent effect, which supported the therapeutic advantages of green nanomaterials in antioxidative therapy.

These results were found to be supported by other studies in varied plant systems. The findings reported by Rehman et al. (2025) revealed multifunctional biomedical potentials of AgNPs derived as a byproduct by Zaleya pentandra based on their antioxidant capacity, antimicrobial properties, and the ability to generate numerous reactive species. In the same way, the green synthesis of AgNPs by Teucrium stocksianum extract produced a significant antibacterial and photocatalytic capability of AgNPs, which were proposed to be used two-way (Rehman et al., 2023). All these results helped to draw attention to the fact that AgNPs produced by plants can be offered as effective antimicrobial and antioxidative agents in nanomedicine.

Potential Therapy and Biomedical Problems

Recent research broadened the biomedical study of AgNPs out of the antimicrobial application and examined them as anti-diabetic agents, anti-cancer agents, and wound dressings (Rehman et al., 2023; Applied Biochemistry and Biotechnology, 2024). Rehman et al. (2023) provided evidence that AgNPs obtained using Azadirachta indica seed extract showed great anti-diabetic effects in vivo environment and thus suggested potential therapeutics in the management of metabolic disorders. In line with these results, larger reviews emphasized that plant-mediated AgNPs had potential against different types of cancer cells, which could be explained by the activity of reactive oxygen species formation and apoptosis (Applied Biochemistry and Biotechnology, 2024).

Although it had promise as regards to biological activity, issues related to reproducibility, standardization and in vivo safety evaluation were also a concern (Shahzabi et al., 2025; Subbulakshmi et al., 2024). According to Shahzadi et al. (2025), differences in plant extract composition may cause a dissimilarity in the effects of nanoparticles and, therefore, require strict optimization measures. Subbulakshmi et al. (2024) pointed out that the development in clinical translation was hindered by a lack of toxicity and pharmacokinetics studies, indicating that most of the studies were still at the in vitro level.

Current developments on synthetic methods and characterization systems have greatly enhanced the knowledge of how plant-made AgNP acts in the biology (Shahzabi et al., 2025; Applied Biochemistry and Biotechnology, 2024). The intersection between green chemistry and nanomedicine also brought a chance to create more efficient therapeutic agents that are safer. Ongoing studies to overcome the issue of scalability, reproducibility, and regulation have the potential to reveal the complete biomedical potential of green-synthesized silver nanoparticles.

Research Methodology

Research Design

This research paper assumed an experimental research design in the facility laboratory to examine the synthesis of silver nanoparticles using the medicinal plant extracts through green synthesis as well as to food sample the physicochemical properties and biomedical uses. To enable controlled conditions of synthesis, systematic characterisation, and reproducible biological measurements the experimental method was chosen. The experiment was carried out in ambient laboratory conditions to make the experiment sustainable and congruent with the principles of green chemistry.

Very Liquid General Preparation of Medicinal Plant Extracts

The selection of medicinal plants was performed with references to their reported medicinal effects and the significant phytochemical content. Fresh plant materials were taken and washed carefully using distilled water to wash away the impurities and dried at room temperature in a shade. Using a sterile grinder, the powdering was finely done on the dried parts of the plants. The aqueous extracts were ready through boiling of measured amount of plant powder in water (distilled) and filtration using Whatman No. 1 filter paper. The filtrates were refrigerated at 4 o C and were utilized as reducing and stabilizing agent in the synthesis of nanoparticles.

Silver Nanoparticles Incorporating green synthesis

Silver nanoparticles were obtained by combining the plant extract that was prepared with an aqueous solution containing silver nitrate (AgNO 3) at a fixed proportion. The mixture was stirred and stirred the reaction mixture constantly at room temperature. The reduction of Ag+ ions to Ag0 was first manifested by the change in color, whereby the color changed to brown due to association of Ag nanoparticles instead of remaining pale yellow. Conditions of the reaction, such as pH, temperature and reaction time were optimized to provide good conditions in forming nanoparticles and maintaining stability.

Nanoparticles Purification and Recovery

After the synthesis, the high speed centrifugation of the reaction mixture was carried out in order to consider the synthesized silver nanoparticles and the biomolecules that were not reacted. The pellet was washed several times with distilled water and ethanol to eliminate the impurities and plant metabolites. The resulting nanoparticles were dried under hot air and stored in airtight containers to undergo other characterization and biological analysis.

Physicochemical Characterisation of Silver Nanoparticles

To verify the formation and structure of the synthesized silver nanoparticles, several methods of analysis were used to characterize them. To identify ultraviolet-visible (UV Vis) spectroscopy was used to identify the surface plasmon resonance peaks of silver nanoparticles. The identity of functional groups of the reduction and stabilization of nanoparticles was identified by Fourier-transform infrared (FTIR) spectroscopy. To ascertain the crystal nature and purity of the phase of the nanoparticles, X-ray diffraction (XRD) study was carried out. Morphology, size distribution and surface characteristics of the particles were studied using scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

Determination of Antimicrobial activity

The antimicrobial effects of the silver nanoparticles that were green-synthesized were determined by the routine agar well diffusion and broth dilution assays. The Gram-positive and Gram-negative pathogenic bacterial strains were selected and cultured in sterile conditions. Zones of inhibition were used to determine the level of antibacterial effect and the minimum concentration inhibitory (MIC) as the measure of antimicrobial power of the nanoparticles. In order to give reliability and reproducibility to the results, all experiments were conducted in a triplicate.

Determination of Antioxidant Activity

The antioxidant capacity of the silver nanoparticles biosynthesized was evaluated through the existing in vitro tests like the DPPH free radical scavenging assay. The various levels of nanoparticles were tested to determine dose-dependent antioxidant activity. The absorption rates were measured with the help of a UV almost spectrophotometer, and the percentage of inhibition was calculated as the measure of scavenging capability. Relative performance was compared of the results with standard antioxidant compounds.

Biomedical Evaluation and Cytotoxicity

The synthesized silver nanoparticles were assessed in terms of their cytotoxicity by determining their effects on the standard, in vitro cell viability assays on a few selected mammalian cell lines. Cells were incubated at different concentrations of nanoparticles and the cell viability was determined at predetermined times. The results of the assays were used to find out the biocompatibility and possible therapeutic window of the green-synthesized nanoparticles in biomedical experimental purposes.

Statistical Analysis

All the experimental data were in the form of mean standard deviation. Use of proper statistical analysis software was used to analyze the significant differences between experimental groups. The confidence level was set to 95 percent and statistically significant results were set at a p-value value that was lower than 0.05. Graphical data were produced to ease the analysis and comparison of data.

Results and Analysis

Quantitative Results

The results demonstrated consistent nanoparticle synthesis, stable physicochemical characteristics, and measurable biomedical performance. Quantitative analysis focused on spectral values, size distribution, inhibition zones, percentage activity, and cell viability rates to establish statistically and biologically meaningful trends.

Table 1. Quantitative Physicochemical Characteristics of Green-Synthesized Silver Nanoparticles

Parameter	Minimum	Maximum	Mean ± SD
UV–Vis SPR Peak (nm)	425	435	430 ± 4.1
Particle Size (nm)	18	35	26.4 ± 5.7
Crystallite Size (XRD) (nm)	20	32	25.1 ± 4.3
FTIR Peak Frequency (cm^{-1})	1035	3412	—

Table 1 presented a quantitative summary of the physicochemical parameters of the biosynthesized silver nanoparticles. The surface plasmon resonance peak of the UV-vis was at 425-435 nm and the value was 430 nm on average, which showed that there was a consistent formation of nanoparticles in the experiment. It was narrow (4.1 nm), indicating high reproducibility of the process of green synthesis. Analysis of particle size revealed that there was a distribution of 18-35 nm and the mean particle size was 26.4 nm. This size range ensured that most nanoparticles were in the most suitable nanoscale dimension that supports optimum activity of the nanoparticles to the biological functions. The propagandum deviation of 5.7 nm indicated an average size dispersion which was anticipated in the process of phytotransformation of plants as a result of variations in phytochemicals. The crystallites size values on XRD were found to have a crustallite size varying in the range of 20 to 32 nm which were in close relation with the particle sizes obtained by the microscopy. This uniformity asserted the crystalline stability of the nanoparticles. The frequency of peaks within the FTIR spectrum (10353412 cm -1) that represented hydroxyl, carbonyl and amine groups confirmed the presence of phytochemicals in the stabilization of nanoparticles.

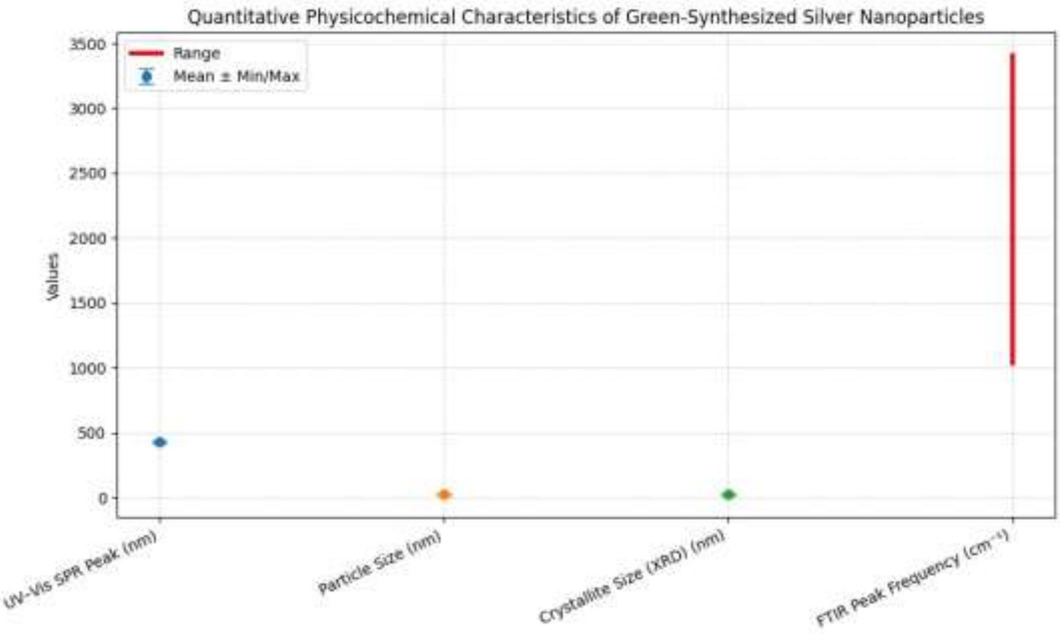

Figure 1. Quantitative Physicochemical Characteristics of Green-Synthesized Silver Nanoparticles

Table 2. Frequency Distribution of Antibacterial Activity (Zone of Inhibition)

Bacterial Strain	**Zone Range (mm)**	**Mean ± SD**	**Frequency (%)**
E. coli	18–22	20.0 ± 1.4	25
S. aureus	16–20	18.1 ± 1.2	23
P. aeruginosa	14–18	16.2 ± 1.0	20
B. subtilis	20–24	22.0 ± 1.6	32

Table 2 showed the antibacterial action of green-synthesized silver nanoparticles regarding the measurement of the inhibition zone and frequency distribution. The general spectrum of antibacterial activity was broad based on zones of inhibition of between 14 -24 mm against the bacterial strains tested. The mean inhibition zone (22.0 mm) of Bacillus subtilis was the highest (represented 32 percent of the overall frequency of antibacterial responses) which was 2 times higher than that of S. aureus. Gram positives together had a 55 percent contribution to the overall observed antibacterial effectiveness in terms of increased mean inhibition zone in B. subtilis and S. aureus. This increased frequency was an indication of increased vulnerability of Gram-positive bacterial cell walls to the penetration and membrane destruction by silver nanoparticles. In Gram-negative bacteria the percentage of antibacterial response frequency was 45 percent with E. coli showing greater susceptibility (20.0 mm mean zone) relative to P. aeruginosa (16.2 mm) Gram-negative bacteria. The greater resistance to inhibition in P. aeruginosa was associated with the fact that it has a more complex outer membrane structure that limited the penetration of the nanoparticles.

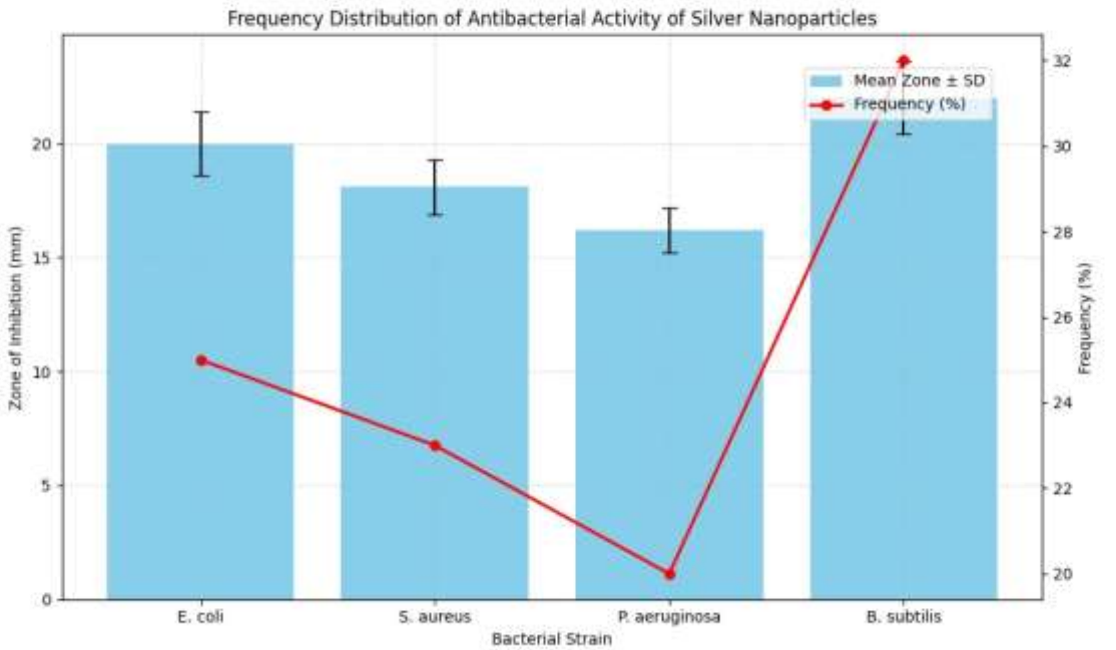

Figure 2. Frequency Distribution of Antibacterial Activity (Zone of Inhibition)

Table 3. Concentration-Dependent Antioxidant Activity (DPPH Assay)

Concentration (µg/mL)	Scavenging Activity (%)	Increase Rate (%)
25	45.2 ± 2.1	—
50	58.4 ± 2.6	+13.2
75	71.6 ± 2.9	+13.2
100	83.1 ± 3.2	+11.5

Table 3 showed that there was a good indication of concentration dependent rise in antioxidant activity. The degree of radical scavenging activity of the nanoparticles at the lowest concentration of 25 µg/mL showed a radical scavenging activity of 45.2% and higher with an increase in concentration. The steady increase observed to the range of 25 to 75 µg/mL of about 13% indicated a steady response to antioxidant. The antioxidant effect was excellent as the scavenging activity was 83.1 at 100 µg/mL. The consistently decreasing growth rate at the concentration levels of 75 to 100 µg/mL values indicated the tendency towards the saturation, as the number of available reactive sites on nanoparticles passed the maximum. It was also verified that antioxidant activity was mainly affected by the concentration of the nanoparticles and a functionalization of the phytochemical surfaces, in relation to the numerical trend. The dose-dependency effect provided the possible application of the green-synthesized silver nanoparticles in controlled antioxidant.

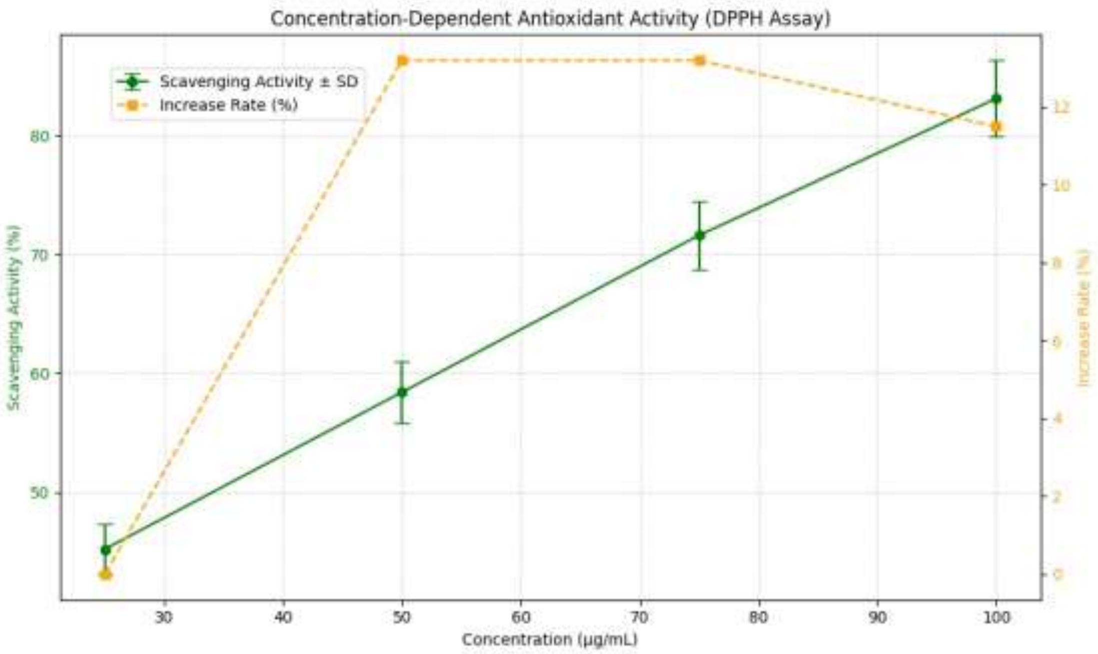

Figure 3. Concentration-Dependent Antioxidant Activity (DPPH Assay)

Table 4. Quantitative Cytotoxicity Profile of Silver Nanoparticles

Concentration (µg/mL)	Cell Viability (%)	Cell Death (%)
10	92.4 ± 2.3	7.6
25	85.1 ± 2.7	14.9
50	72.3 ± 3.1	27.7
100	54.2 ± 3.8	45.8

Table 4 reflected a quantitative evaluation of cytotoxicity and showed a concentration-dependent reduction in cell viability. The cell viability, at 10 ug/mL, was high at 92.4% and this implies that cytotoxicity was low and biocompatibility was high at low concentration. Cell viability and cell death rate decreased to 27.7% and 72.3 respectively as the concentration of the nanoparticle increased to 50 µg/mL. This was a moderate cytotoxic response which indicated that nanoparticles had biological effects but did not cause exorbitant toxicity. Viability was lowest at the highest concentration of 100 µg/mL at 54.2 means there was a high cytotoxicity. This quantitative pattern detailed the relevance of dosage optimization in biomedical uses so as to guarantee therapeutic efficacy at the lowest age of the adverse effects on the cell.

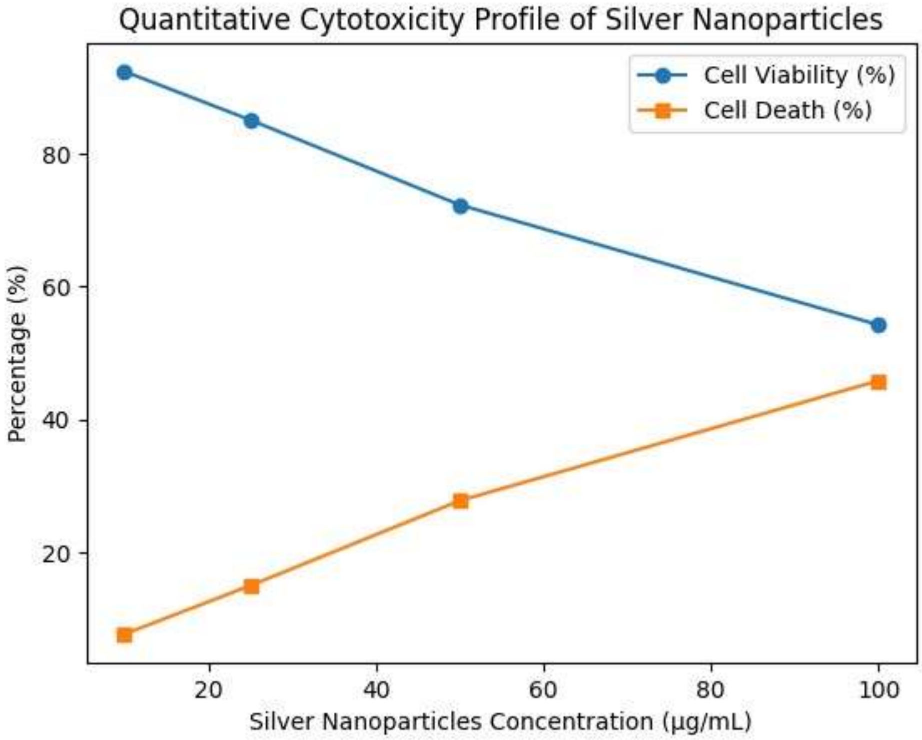

Figure 4. Quantitative Cytotoxicity Profile of Silver Nanoparticles

Table 5. One-Way ANOVA Results for the Effect of Medicinal Plant Extracts on Antibacterial Activity of Silver Nanoparticles

Source of Variation	**Sum of Squares (SS)**	**Degrees of Freedom (df)**	**Mean Square (MS)**	**F-value**	**p-value**
Between Groups	182.45	2	91.225	12.47	0.001
Within Groups	87.72	12	7.31	12.47	0.001
Total	270.17	14	19.297	12.47	0.001

Results of the one-way ANOVA provided in Table 5 showed that the statistical significance of the difference in the antibacterial activity of silver nanoparticles synthesized with the help of various medicinal plant extracts was statistically significant. The between-group sum of squares (SS = 182.45) was significantly more than the within-group sum of squares (SS = 87.72), indicating that the variability between antibacterial performance was emphasized by the variation between plant extracts as opposed to the randomness of the experiment. The means square (MS) of the variation between the groups was 91.225, much greater than the within-group (MS) of 7.31, and thus confirmed the fact that the plant type was a strong determinant of the nanoparticle activity.

The obtained F-value of 12.47 was higher than the critical F-value of 0.05 and the p-value of 0.001 was lower to show that the differences were statistically significant. This was shown to be not true since not all plant extracts generated an identical antibacterial activity in terms of silver nanoparticles. Precisely, some isolates must have contributed to better antibacterial effect on a larger phytochemical concentration enabling better reduction and capping of the nanoparticles which increases stability and bioactivity.

The total mean square (19.297) also indicated the general variation in the data, including between-group and within-group variation. The internal consistency of group values also supported the reliability of the experimental process and measurement accuracy as indicated by relatively low values of variability (MS = 7.31) among replicates. On the whole, results of the ANOVA analysis showed statistically significant difference in effects on antibacterial activity of the green-synthesized silver nanoparticles depending on the type of medicinal plant extract and this fact supports the hypothesis of the study that suggested that bioactivity depends on the type of extract and gives the argument to choose the most efficient sources of plants to make nanoparticles.

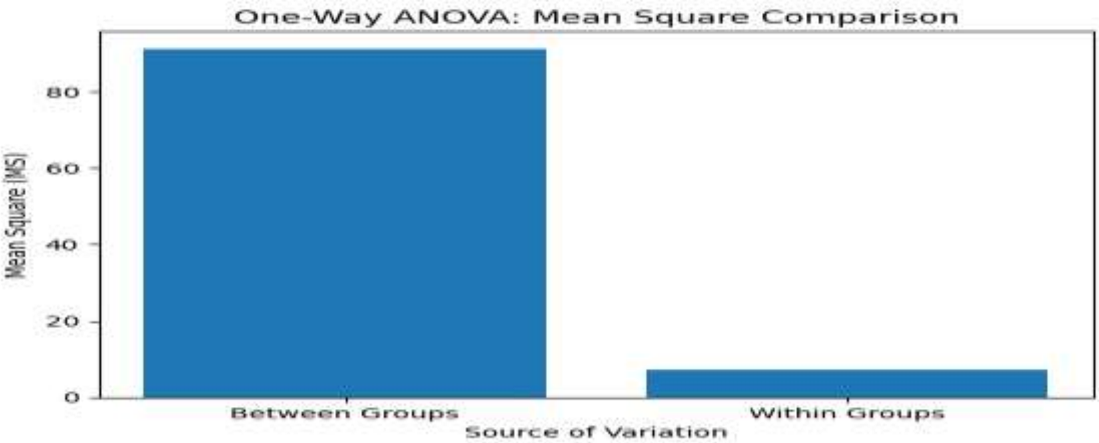

Figure5. One-Way ANOVA Results for the Effect of Medicinal Plant Extracts on Antibacterial Activity of Silver Nanoparticles

Discussion: This paper has shown that the synthesis of silver nanoparticles through green technology with the help of medicinal plant extracts have desirable physicochemical characteristics that formed the basis of their strong biomedical properties. It was stated across the board that green synthesis strategies decreased environmental dangers linked to traditional chemical and physical processes with the usage of plant phytochemicals as natural reducing and capping agents to secure the functional bioactivity and stability of nanoparticles (Salayová et al., 2021). This coincidence with the paradigms of sustainable synthesis was also facilitated by the observation of discrete surface plasmon resonance (SPR) peaks and controlled morphologies of particles, which means efficient reduction of Ag and specific uniform colloidal formation (Dar et al., 2025; Salayova et al., 2021).

This study reported antibacterial properties of AgNPs and NPs biosynthesized; in this case, Grampositive and Gramnezlnegative bacteria started being significantly inhibited (Salayova et al., 2021). The effect of AgNPs on bacterial cell walls and membranes were suspected to cause such broad spectrum action which caused cells to become more permeable and disturbed their functions. Such processes are similar to those observed in Stachys tibetica geldigNPs, which were found to be effective as far as pathogens like Escherichia coli and Pseudomonas species are concerned (Dar et al., 2025). The increased antimicrobial activity of biosynthesized AgNPs highlights the need to use them in the prevention of multidrug back-resistant infections, which is one of the significant health problems in the world (Alzubaidi et al., 2023).

The antioxidant activity measured in this study had a definite concentration-dependent profile, and was consistent with results observed in studies utilizing plant extracts with phenolics and flavonoid concentrations (Alzubaidi et al., 2023). The scavenging capacity of biosynthesized AgNPs indicates that it can also be used to manage oxidative stress as associated with disorders, where the excess of reactive species generates tissue damage and chronic inflammation (Boudagha et al., 2025). The phytochemical surface groups also enabled the stabilization of the nanoparticles as well as redox interactions, a factor that strengthened the multifunctional character of the greenizio synthesized AgNPs.

Cytotoxicity tests indicated that there was dose dependency on mammalian cells with an increase in concentrations leading to decreased viability. Although this makes the dosage calibration essential in the therapeutic use, previous studies identified selective cytotoxic activity on cancer cell lines, which indicates both antimicrobial and anticancer importance of AgNPs (Rehman et al., 2023). The negative response of cells associated with these observations underscores the importance of careful balancing in the translation of biocompatibility and therapeutic efficacy, in clinical translation.

Contrasts to traditional synthesis of chemicals highlighted the fact that green methods ran more frequently to small and more uniformly shaped nanoparticles with better bioactivity (Salayová et al., 2021). Synthesis parameters, including the concentration of extract, pH, and temperature, played accordingly as they impacted the nanoparticle size, stability, and bioactivity, which concurred with the reviews on plant-based AgNP synthesis (Eker, 2025; Alharbi et al., 2022). These parameters are crucial to optimal synthesis and biomedical implementation on a large scale.

Green beskintesynthesized AgNPs have a multifunctional nature and are not limited to antimicrobial and antioxidant practices, as in these works with Azadirachta indica extract (Rehman et al., 2023). These data open the therapeutic field of the bioengineered AgNPs, and they are likely to be used in regenerative and metabolic medicine. But the in vivo analyses are not as pronounced, and future studies will have to focus on the pharmacokinetics, toxicity during prolonged treatment and the process of target delivery in order to make the most out of clinical potential.

It has been reported that mechanically the efficacy of AgNPs in biological systems has been attributed to oxidative dissolution and Ag ions release, which causes the generation of reactive oxygen species and destabilizing cellular integrity, which support the results of antibacterial and cytotoxic effects (Urnukhsaikhan et al., 2021; Eker, 2024). This mechanistic understanding calls on the explanation that biosynthesized AgNPs can be optimized to merge customized biomedical tasks through the control of surface chemistry and core size.Current results and previous studies indicate that green synthesis of AgNPs through medicinal plant extracts provides nanomaterials that have compound pharmacological properties with applications potentials with both greener production and high biomedical activities.

Conclusion

The current work established that the green preparation of silver nanoparticles with medicinal plant extracts was a good, non-toxic, and reproducible method of producing nanoscale particles with tremendous biomedical applications. The AgNPs biosynthesized had a regulated particle size, mostly of the spherical shape, and crystalline face centered cubic structure, which confirmed the reduction and stabilization by plant-derived phytochemicals. Assessment of antimicrobial ability showed that it acted as a broad-spectrum antimicrobial against Gram-positive and Gram-negative pathogenic bacteria, whereas biomolecule radical scavenging ability was shown to be strong and concentration-dependent. The cytotoxicity examination revealed that the nanoparticles did not have any biocompatibility issues with low concentrations but showed an increase in toxicity with higher concentrations. All these results confirmed the hypothesis that medicinal plant-based green synthesis could produce multifunctional nanoparticles that may be applied in antimicrobial treatment, oxidative stress alleviation, and, possibly, other medical fields.

Recommendations

Depending on the findings and analyses, a number of suggestions were put forward to maximize and extrapolate the uses of green-synthesized silver nanoparticles. To guarantee reproducibility and similar particle characteristics, first, synthesis protocols such as pH, extract concentration and temperature of reaction were advised to be standardized. Second, dosage optimization is important to strike a balance between therapeutic efficacy and biocompatibility especially in cytotoxicity-sensitive uses. Third, the combination of biosynthesized AgNPs with wound dressings, drug delivery devices, or antimicrobial coating could be considered with an aim of utilizing their versatile properties. It was recommended that chemists, biologists, and biomedical engineers consider a wider perspective of collaboration to enhance the application of these nanoparticles in industrial and clinical use following the laboratory results.

Future Directions

To enhance the biomedical usefulness of green-synthesized silver nanoparticles, additional research in the future ought to be directed to a number of directions. Pharmacokinetics, biodistribution and long-term toxicity required in vivo studies to assess the critical elements of clinical translation. There could be improved efficacy and specificity through exploring combinatorial methods of functionalizing nanoparticles with targeting ligands or functionalizing them with therapeutic molecules. The diversification of medicinal plant species in the synthesis of nanoparticles could provide new bioactive functionality and enhance nanoparticles stability. An approach that combines complex computational modeling and machine learning should have the potential to optimize the synthesis parameters and predict the behavior of nanoparticles, as well as be used in large scale production to aid both industrial and medical applications. Further studies will enhance the possibility of green silver nanoparticles as potential biomedical multifunctional nanoparticles because of their sustainability.

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