Materials Research Express

OPEN ACCESS

PAPER

Electrochemical properties of biogenic silver nanoparticles synthesized using *Hagenia abyssinica* (Brace) JF. Gmel. medicinal plant leaf extract

H C Ananda Murthy¹, Tegene Desalegn Zeleke¹, C R Ravikumar², M R Anil Kumar³ and H P Nagaswarupa³

¹ Department of Applied Chemistry, School of Applied Natural Science, Adama Science and Technology University, PO Box 1888, Adama, Ethiopia
² Research Centre, Department of Science, East West Institute of Technology, Bangalore, 560091, India
³ PG Department of Chemistry, Davanagere University, Davanagere, 577001, India

E-mail: anandkps350@gmail.com

Keywords: green synthesis, *Hagenia abyssinica* (Brace) JF. Gmel, g-Ag NPs, EIS, charge transfer resistance

Abstract

The biogenic/green silver nanoparticles (g-Ag NPs) were synthesised by using the extract of indigenous medicinal plant of Ethiopia, *Hagenia abyssinica* (Brace) JF. Gmel. leaf extract for the first time, to investigate the synergistic effect of biomolecules towards the enhancement of electrochemical properties of NPs. The synthesized g-Ag NPs were characterized by UV-visible, UV-DRS, FT-IR, XRD, SEM, EDXA, TEM, HRTEM and SAED techniques. The maximum absorbance, $\lambda_{\text{max}}$ was found to be 461 nm for g-Ag NPs due to surface plasmon resonance. The energy gap, $E_g$ of NPs, was found to be 2.31 eV. FTIR spectrum confirmed the presence of bioactive compounds responsible for possible capping and stabilisation of g-Ag NPs. The XRD analysis revealed that the g-Ag NPs are highly crystalline exhibiting sharp peaks for (111), (200), (220) and (311) planes in the diffraction pattern. The SEM and TEM micrographs showed differently shaped Ag particles in addition to spherical shape. The average particle size of NPs was found to be 24.08 nm using imageJ analysis. EDX analysis confirmed the presence of Ag in the g-Ag NPs. In addition, the SAED pattern of g-Ag NPs presented concentric patterns for 4 major planes of crystalline silver. The d-spacing values of 0.2428 nm, 0.2126 nm, 0.1483 nm and 0.1263 nm corresponds to $d_{111}\text{Ag}$, $d_{200}\text{Ag}$, $d_{220}\text{Ag}$ and $d_{311}\text{Ag}$ lattice fringes respectively. The cyclic voltammetry (CV) results suggest that g-Ag NPs possess better electrochemical properties due to its lower charge transfer resistance value of 17 $\Omega$. EIS studies too revealed better stability of g-Ag NPs as electrode materials.

1. Introduction

The green synthesis of metallic nanoparticles has been proposed as a cost-effective and environmentally friendly alternative to chemical and physical methods. In recent years, Ag nanoparticles (Ag NPs) have attracted much attention of researchers due to their wide applications in biotechnology, biomedicine and other industries. Because of chemical stability, good conductivity, catalytic nature, nano silver finds applications as an antimicrobial agent, in textiles, home water purification systems, medical devices, cosmetics, electronics, and household appliances [1]. In addition, due to its conducting nature, its electrochemical properties are worthy to investigate. Silver is also used in wound dressings, topical creams, antiseptic sprays and fabrics [2].

Many plants parts or whole plants have been used for the green synthesis of Ag NPs due to the presence of large number of bioactive compounds in plants. The extracts of plants and various parts of plants, *Aloe ferox* iniorium plant [3], *Coffee arabica* seed [4], *Jatropha Gossypifolia* and *Jatropha Glandulifera* leaf [5], *M. balbisiana* (banana), *A. indica* (neem) and *O. tenuiforum* (black tulsi) leaves [6], *Alysicarpus monilifer* leaves [7], *Artocarpus altilis* leaves [8], *Pimpinella anisum* seeds [9] *Aloe Vera* plant [10], *Azadirachta indica* [11], olive
A 0.2 M aqueous AgNO₃ solution was prepared and stored in brown bottle. 100 ml of plant leaf extract was mixed with 400 ml of 0.2 M AgNO₃ solution (1:4) slowly dropwise with constant stirring by maintaining the temperature of about 50 °C. The silver NPs have been synthesized by using extracts of various plants found all over the globe. But no research has been conducted as far as green synthesis of Ag NPs is concerned using extracts of medicinal plants of Ethiopia. Therefore, the present research work was proposed to explore and provide an alternate green material for the synthesis of green Ag NPs (g-Ag NPs) using extracts of medicinal plant of Ethiopia. More than 95% of traditional medical preparations in Ethiopia are of plant origin [22]. A medicinal plant species of Ethiopia identified for the biogenic synthesis of g-Ag NPs in aqueous media is Hagenia abyssinica (Brace) JF. Gmel.

Hagenia abyssinica (Brace) JF. Gmel, a member of the Rosaceae family, is species of flowering plant native to the high-elevation Afrotomontane regions of central and eastern Africa from Sudan and Ethiopia. It is known in English as African redwood, East African rosewood and in Amharic as kosso. Hagenia abyssinica is a slender tree up to 20 m tall, with a short trunk and thick branches. The roots are cooked with meat and the soup drunk for general illness and malaria, while the dried and pounded female inflorescence is used as an anthelmintic (especially for tapeworm). Bark may be pounded, added to cold water and the liquid drunk as a remedy for diarrhea and stomach-ache. Generally, this is a strong medicine that must not be taken in large quantities; it is sometimes taken as an abortifacient [23].

The aim of this research work was to synthesize g-Ag NPs mediated by Hagenia abyssinica (Brace) JF. Gmel, medicinal plant leaf extract. The integration of bioactive compounds of this medicinal plant with Ag NPs is believed to be extremely beneficial for varieties of ailments. This green synthesis method is devised to eliminate the use of toxic chemicals which play roles of reducing agents and capping agents during chemical synthesis. The biogenically synthesized g-Ag NPs were characterized using UV-visible, UV-DRS, FT-IR, XRD, SEM, EDXA, TEM, HRTEM and SAED techniques. The electrochemical properties of g-Ag NPs have also been evaluated using cyclic voltammetry and EIS studies. The present research work gives comprehensive report on synthesis, characterization and electrochemical activities of g-Ag NPs which in turn will have significant impact on electrochemical sensor applications.

2. Materials and methods

All the chemicals AgNO₃, ethanol, Dimethyl sulfoxide (DMSO) used in the experiments were of analytical grade (purchased from Merck chemical Industrial company) and used without any further purification.

2.1. Collection and authentication of plant materials

Hagenia abyssinica (Brace) JF. Gmel., plant leaves were collected from Ethiopian Institute of Agricultural Research, Wondo Genet, Oromia Regional State, Southern Ethiopia after conducting the field surveys.

The coordinates of the research center are N 7° 5'31.5096″ E 38° 37'54.7284″ and N 7° 5'55.5128″ E 38° 37'59.0304″. The identity of the plant Hagenia abyssinica (Brace) JF. Gmel. (Code EB002) was authenticated by a plant taxonomist at the National Herbarium, Department of Biology, Addis Ababa University Herbarium, Addis Ababa, Ethiopia.

2.2. Preparation of plant leaf extract

The leaves of Hagenia abyssinica plant were surface cleaned and washed repeatedly with tap water followed by distilled water to remove dust particles and then allowed to dry under shadow for 15 days to remove moisture contents from the leaves. The dried leaves were ground using grinding machine followed by packing in a brown bottle. The extraction was carried out by taking 20 g of powdered leaves of Hagenia abyssinica in a 500 ml of conical flask containing 400 ml of deionized water. The flask was later covered with aluminum foil, to prevent the effect of light. After that the mixture was shaken using mechanical shaker for 30 min and allowed to warm at 50 °C for 1 h on magnetic stirrer, then it was allowed to cool down to room temperature overnight. The prepared solution was filtered through whatman No.1 filter paper to get clear solution. The filtrate was stored at 4 °C for future experiments.

2.3. Green synthesis of Ag NPs

A 0.2 M aqueous AgNO₃ solution was prepared and stored in brown bottle. 100 ml of plant leaf extract was mixed with 400 ml of 0.2 M AgNO₃ solution (1:4) slowly dropwise with constant stirring by maintaining the temperature of about 50 °C.
The mixture has been incubated at room temperature for 24 h. The color change was checked periodically after 30 min of duration. The formation of reddish brown color visually indicates the formation of silver nanoparticles and then the solution was centrifuged for 15 min at 10000 rpm. The obtained g-Ag NPs (figure 1) were washed by deionized water and ethanol to remove any impurities. Thereafter, the NPs were allowed to dry and ground so as to be used for further analysis.

2.4. Preparation of carbon paste electrode
For the preparation of carbon paste electrode, the prepared sample (g-Ag NPs), graphite powder (<20 µm, 98% purity) and silicon oil (at 20 °C weight is 0.98–1.0 g per ml and 370–500 mPas viscosity) with a mass ratio of 15:70:15 were systematically mixed in an agate mortar for about 30 min. The obtained paste was then filled into a Teflon cavity tube (surface area-0.3 mm) fabricated by our group. The surface of the packed carbon paste was then smoothened by pressing gently on a weighing paper [24].

2.5. Characterization
The UV-visible absorbance and reflectance spectra of the samples were recorded in the range of 200–800 nm using Shimadzu’s UV-2600, UV-visible spectrophotometer. Fourier transform-infrared spectroscopy (FT-IR) Spectrum (65 FT-IR PerkinElmer) was recorded using KBr pellets in the range of 400–4000 cm⁻¹ [25]. X-ray diffraction (XRD-Shimadzu x-ray diffractometer (PXRD-7000) analytical technique was used to reveal the crystalline nature of g-Ag NPs. The scanning electron microscopy with energy-dispersive x-ray spectroscopy (SEM-EDX-EVO 18 model with low vacuum facility and ALTO 1000 Cryo attachment) and transmission electron microscope with high-resolution (JEOL JEM 2100 HRTEM) were used for understanding morphological and structural features of g-Ag NPs. Gatan Digital Micrograph Software was used to evaluate d-spacing values of lattice fringes. Particle size was computed by using imageJ application.

Cyclic voltammetric tests were performed on a CHI608E potentiostat, using a three electrode system, comprising of carbon paste electrode, platinum wire and Ag/AgCl as working, counter and reference electrodes respectively in 6M KOH. The potential range utilized during these studies is ranging between −0.6 V and 0.6 V. EIS studies were carried out in the frequency range of 1 Hz to 1 MHz at AC amplitude of 5 mV.

Figure 1. The scheme of synthesis of g-Ag NPs.
3. Results and discussion

3.1. Synthesis of g-Ag NPs

The g-Ag NPs were synthesized by using 1:4 ratio of plant leaf extract as a reducing and capping agent and silver nitrate as a precursor. The as-synthesized g-Ag NPs (figure 1) were later subjected to various characterization methods.

The presence of tannins, phenolic compounds and different glycosides was confirmed during the screening of phytoconstituents of Hagenia abyssinica (Brace) JF. Gmel. leaf extract. The details are as given in table 1. It is

---

Table 1. The details of phytoconstituents screening of Hagenia abyssinica (Brace) JF. Gmel. Plant leaf extract.

| Sl. No. | Phytoconstituents   | Test/Reagent         | Result |
|---------|---------------------|----------------------|--------|
| 1       | Alkaloids           | Wagner’s reagent     | −      |
| 2       | Tannins             | KOH                  | +      |
| 3       | Flavonoids          | Shinoda Test         | −      |
| 4       | Terpenoids          | Salkowski Test       | −      |
| 5       | Anthraquinone       | Borntrager’s Test    | +      |
|         | glycosides          |                      |        |
| 6       | Cardiac glycosides  | Keller-Kiliani Test  | +      |
| 7       | Saponins            | Frothing Test        | −      |
| 8       | Phenols             | FeCl₃                | +      |

---

Figure 2. (a) UV-Visible absorbance spectrum of g-Ag NPs (b) UV-Visible diffused reflectance spectrum of g-Ag NPs (c) Tauc plot of g-Ag NPs showing its Eg value (d) XRD diffraction pattern of g-Ag NPs.
possibly believed that the bioactive compounds such as polyphenols act as ligand and bind to silver ions and reduce them and cap them to form nanoparticles. These ligands also act as particle size controllers as reported by the earlier researcher [26]. Primary components of Hagenia abyssinica extract are tannins, phenols, anthraquinone glycosides and cardiac glycosides. The antioxidant properties of polyphenolic compounds are primarily due to their high inclination towards chelating the metals. Phenolic compounds contain hydroxyl and carboxylic groups which have very high tendency to bind metal ions. Metal ions in solution interact with polyphenolic compound and helps in the nucleation and formation of Ag NPs. Formation of nanoparticles is believed to be due to the combinational effect of bioactive compounds of plant extract [27].

3.2. Characterization of g-Ag NPs
The g-Ag NPs were characterized by using UV-visible, UV-DRS, FT-IR, XRD, SEM, EDXA, TEM, HRTEM and SAED techniques.

3.2.1. UV-visible spectral analysis
The UV-visible absorbance spectrum recorded for g-Ag NPs exhibited $\lambda_{\text{max}}$ of 461 as shown in figure 2(a). This absorption band is basically due to surface plasmon resonance of g-Ag NPs. A similar result was reported while synthesizing Ag NPs using the Persea americana seed extract [28].

Similarly, the UV-visible diffused reflectance spectrum was recorded (figure 2(b)). The band gap energy of g-Ag NPs was evaluated using Tauc plot as shown in figure 2(c) by using the data obtained in reflectance spectra utilizing Kubelka-Munk function. The band gap energy, $E_g$ of g-Ag NPs was found to be 2.31 eV.

3.2.2. XRD analysis
The XRD diffraction pattern of g-Ag NPs is presented in figure 2(d). The peaks at 2$\theta$ values = 37.92°, 43.18°, and 64.23°, and 77.02° corresponds to (111), (200), (220) and (311) lattice planes of face centred cubic structure of Ag NPs and the diffraction results were in good agreement with the data of ICPD file no. 00-004-7383 (Fm3m) [29].

3.2.3. FT-IR spectral analysis
The FTIR spectra of g-Ag NPs showed peaks at 3395, 2930, 2875, 2350, 1625, 1415, 1360, 1120, 1050, 765 and 501 cm$^{-1}$ (figure 3). From these peaks, the broad absorption peaks of g-Ag NPs observed at 3395 cm$^{-1}$ corresponds to O–H stretches. The intense peaks shown at 2930 cm$^{-1}$ and 2875 cm$^{-1}$ corresponds to asymmetric –C–H stretching of –CH$_2$ and –CH$_3$ groups and –C–N group of secondary amines. The presence of –COOH stretching vibration is located at wave number of 2350 cm$^{-1}$.
It also reveals bonds of carboxylate group present in the leaf extract of Hagenia abyssinica which indicates the binding of proteins with the surface of Ag and thereby it leads to the stabilization of the biosynthesized nanoparticles. The absorption peaks represented at 1625 cm$^{-1}$ and 1415 cm$^{-1}$ indicates the presence of C=O and C=C bending mode of vibrations.

The peaks represented by 1350 cm$^{-1}$ shows C–N stretching of amide. The medium peak at 1120 cm$^{-1}$ corresponds to C–O stretching of phenolic compounds. The C=O–C and C–N stretching appears at 1050 cm$^{-1}$. The last peak at 501 cm$^{-1}$ corresponds to bending modes of vibrations of –C–H bond. FTIR analysis results confirmed the presence of various phytochemicals of Hagenia abyssinica (Brace) JF. Gmel. leaf extract such as phenolics, tannins and proteins involved in the synthesis of g-Ag NPs $^{[30]}$. In addition to this, the FTIR spectrum of g-Ag NPs shows peaks corresponding to the broad band centered at 768 cm$^{-1}$ which is possibly due to the interaction of Ag with protein molecules of extract.

3.2.4. Morphological and compositional analysis by SEM-EDAX

The FESEM micrographs depicted morphological features of synthesized g-Ag NPs as shown in figures 4(a) and (b). The SEM images also demonstrated the non-homogeneity of the particles in terms of their shape and size. All the possible spherical and irregular shapes such as truncated hexagonal, cylindrical, triangular, prismatic shapes of Ag NPs with varying particle sizes were found in the micrograph $^{[31]}$.

The average particle size of Ag NPs was found to be in the range of 8–42 nm. The chemical compositions of the NPs were studied by EDAX analysis. Figure 4(c) shows the EDAX spectrum obtained for the g-Ag NPs. The

![Figure 4](image_url)

**Figure 4.** (a) And (b) SEM micrographs of g-Ag NPs (c) EDAX spectrum of g-Ag NPs.
peaks corresponding to elemental Ag, C and O were clearly identified and additional peak for Cl was present, which demonstrated the purity of the synthesized NPs and this is in consistent with the XRD studies. It is also possibly believed that the presence of C and O is basically from the capped bioactive compounds. The reduction of silver ions to Ag NPs is facilitated by the biomolecules of plant extract containing surface hydroxyl groups [32].

3.2.5. TEM, HRTEM and SAED analysis

To get the further deep insight on the morphology, size and crystalline nature of the g-Ag NPs, TEM, HRTEM and SAED analysis was employed.

The high resolution transmission electron microscopic (HRTEM) image of as-synthesized g-Ag NPs (figure 5) shows that the synthesized silver nanoparticles are mostly spherical [33] but not agglomerated.

The presence of smaller NPs as small as 8 nm confirm the efficient role of bioactive components of *Hagenia abyssinica* (Brace) JF. Gmel, plant extract as capping agents and stabilizing agents. In addition, the variation in size of g-Ag NPs is probably due to the presence of polyphenolic compounds (from *Hagenia abyssinica* (Brace) JF. Gmel, leaf extract) which have strong attractive forces between and holds the particles together.

The TEM micrographs which exhibited very finely grained g-Ag NPs with spherical, cylindrical, prismatic, hexagonal, triangular, as well as near spherical shapes are presented in figures 5(a) to (d).

All these near spherical particles with varying sizes from 8.51 nm to 42.1 nm with an average particle size of 24.08 nm as determined by imageJ application are as shown in figures 5(a) and (b). The Ag NPs appeared to have no direct contact with each other even within the small aggregates, indicating efficient stabilization of the

![Figure 5. The TEM micrographs showing g-Ag NPs with (a) cylindrical, (b) prismatic, (c) hexagonal, and (d) triangular shapes.](image_url)
nanoparticles by a capping agents of the plant leaf extract [34]. The SAED pattern of g-Ag NPs (figure 6(c)) contained four spots each corresponding to specific crystal planes. One of such planes is presented with d-spacing value of 0.2427 nm as shown in figure 5(d).

HRTEM morphology of g-Ag NPs with magnified lattice fringes, IFFT patterns and Profile of IFFT with d-spacing value for a specified plane (figure 6(d)) are presented in figures 7(a)–(d) respectively. The analysis of d-spacing values has been carried out by using Gatan Digital Micrograph Software application which resulted in dhkl values of 0.2427 nm and 0.2431 nm for a set crystal planes at different sites on the surface of g-Ag NPs. HRTEM micrographs exhibited well-defined lattice fringes of d_{111}Ag plane (figures 7(b) and (c)) confirming the clear crystalline nature of prepared g-Ag NPs.

The d-spacing values for all the spots depicted in the SAED pattern of g-Ag NPs (figure 6(c)) are presented in table 2. Each spot on the SAED pattern corresponds to specific set of lattice planes. The XRD pattern of g-Ag NPs presented earlier in figure 2(d), revealed 4 major peaks corresponding to (111), (200), (220) and (311) planes of fcc structure of pure Ag (ICPD file no. 00-004-7383 (Fm3m)). The d-spacing values of the derived diffraction planes from spot 1 to spot 4; d_{111}Ag = 0.2428 nm, d_{200}Ag = 0.2126 nm, d_{220}Ag = 0.1483 nm and d_{311}Ag = 0.1263 nm, are in good agreement with XRD diffraction pattern of g-Ag NPs.

3.3. Electrochemical activity

Figure 8 shows the CV curve of g-Ag NPs at different scan rates. The presence of redox peaks in their cathodic and anodic scan is an indication of significant share of pseudo capacitance in the electrochemical process.
The reversibility of the redox reaction is measured by the difference \( \Delta E_{a,c} \) in the anodic \( E_{pa} \) peak potential and cathodic \( E_{pc} \) peak potential [35]. The anodic and cathodic peaks are correlated to oxidation potential and reduction potential \( E_{pa} \) and \( E_{pc} \) respectively. Oxidation potential \( E_{pa} \), reduction potential \( E_{pc} \) and the difference between \( E_{pa} \) and \( E_{a,c} \) \( \Delta E_{a,c} \) for g-Ag NPs electrode is given in table 3. It was found that the difference in the peak potentials \( \Delta E_{a,c} \) is as low as 0.38 V.

In order to understand the electrode stability of the prepared oxides, a series of CV scans (of 25 cycles), at a scanning rate of 50 mVs \(^{-1}\), for g-Ag NPs sample was carried out (figure 9). During the test, the locations of anodic and cathodic peaks of electrode did not show any significant deviation with the growing cycles, revealing good electrode stability [36].

Figure 10 shows the Nyquist plot of the g-Ag NPs electrode. Based on the frequency, Nyquist plot comprises of two regions, (i) a high-frequency region representing charge transfer at the electrode/electrolyte interface and

![HRTEM morphology of g-Ag NPs](image)

Figure 7. HRTEM morphology of g-Ag NPs (a) magnified lattice fringes (b) IFFT patterns (c) Profile of IFFT with d-spacing distance.

| Spot No. | d- spacing (nm) | Rec. Pos. (1/ nm) | Degrees to Spot 1 | Degrees to x-axis | Amplitude |
|----------|------------------|-------------------|-------------------|-------------------|-----------|
| 1        | 0.2428           | 4.119             | 0.00              | 82.42             | 311.93    |
| 2        | 0.2126           | 4.703             | 16.47             | 65.95             | 433.50    |
| 3        | 0.1483           | 6.742             | 24.79             | 107.21            | 339.25    |
| 4        | 0.1263           | 7.917             | 5.72              | 76.71             | 500.83    |

The reversibility of the redox reaction is measured by the difference \( \Delta E_{a,c} \) in the anodic \( E_{pa} \) peak potential and cathodic \( E_{pc} \) peak potential [35]. The anodic and cathodic peaks are correlated to oxidation potential and reduction potential \( E_{pa} \) and \( E_{pc} \) respectively. Oxidation potential \( E_{pa} \), reduction potential \( E_{pc} \) and the difference between \( E_{pa} \) and \( E_{a,c} \) \( \Delta E_{a,c} \) for g-Ag NPs electrode is given in table 3. It was found that the difference in the peak potentials \( \Delta E_{a,c} \) is as low as 0.38 V.

In order to understand the electrode stability of the prepared oxides, a series of CV scans (of 25 cycles), at a scanning rate of 50 mVs \(^{-1}\), for g-Ag NPs sample was carried out (figure 9). During the test, the locations of anodic and cathodic peaks of electrode did not show any significant deviation with the growing cycles, revealing good electrode stability [36].

Figure 10 shows the Nyquist plot of the g-Ag NPs electrode. Based on the frequency, Nyquist plot comprises of two regions, (i) a high-frequency region representing charge transfer at the electrode/electrolyte interface and
Figure 8. Cyclic voltammogram of g-Ag NPs at different scan rates.

Table 3. Oxidation potential ($E_{pa}$), reduction potential ($E_{pc}$) and the difference between $E_{pa}$ and $E_{pc}$ for g-Ag NPs electrode.

| Potential (V) | $E_{pa}$ | $E_{pc}$ | $\Delta E_{ac}$ |
|----------------|----------|----------|-----------------|
|                | 0.21     | −0.17    | 0.38            |

Figure 9. Cyclic voltammogram of g-Ag NPs.
denoted by a semicircle and (ii) a low-frequency region representing the capacitance of electrode and denoted by a straight line. The charge transfer resistance $R_{ct}$ is a direct measure of the diameter of the semicircle arc on the real axis. It can be observed that the impedance curve of g-Ag NPs is inclined towards Y axis; this suggests a low capacitance and minimum charge-transfer resistance of prepared electrode.

The resistance of the nonmaterial can be obtained using the Nyquist plot. The semicircular portion at a higher frequency is equal to the electron transfer resistance ($R_{ct}$) at the contact interface of the electrode and electrolyte solution [37]. As seen in figure 9, the semicircular diameter of g-Ag NPs is small. The value of $R_{ct}$ is equal to the diameter of the semicircle. The $R_{ct}$ value of g-Ag NPs is found to be 17 $\Omega$. It indicates that material has considerably good conductivity and thus can be better alternative as electrode material.

4. Conclusion

The green silver nanoparticles (g-Ag NPs) were successfully synthesised using medicinal plant Hagenia abyssinica (Brace) JF. Gmel. leaf extract. The presence of phytoconstituents such as polyphenols of tannins played roles of reducing and capping agents during the formation of g-Ag NPs. The UV-visible absorbance and reflectance spectra showing $\lambda_{\text{max}}$ of 461 nm and $E_\infty$ of 2.31 eV, respectively confirmed the formation of g-Ag NPs. FTIR spectra supported the presence of capping agents on the surface of g-Ag NPs. The crystalline nature and composition of g-Ag NPs were confirmed by XRD pattern and EDX spectrum respectively. The SEM and TEM micrographs provided enough evidence towards the nano-morphology of g-Ag NPs with all possible shapes including spherical, triangular, hexagonal and cylindrical shapes with particle size varying between 8 nm to 42 nm with average particle size of 24.08 nm. HRTEM micrographs and SAED patterns confirmed the presence of Ag. The EIS and CV studies confirmed better electrochemical behavior of g-Ag NPs with good conductivity and stability to suit as electrode materials. This green synthetic route proves to be an efficient alternative method to synthesize silver nanoparticle using medicinal plants.

Acknowledgments

The authors gratefully acknowledge Adama Science and Technology University for financial support and laboratory facility to conduct this research work. This work has been funded from the Project (SoANS/2018), Research and Technology Transfer Office, sanctioned by Adama Science and Technology University (ASTU-2018-07-22).
ORCID iDs

H C Ananda Murthy @ https://orcid.org/0000-0002-2361-086X
C R Ravikumar @ https://orcid.org/0000-0002-4692-444X

References

[1] Jafari A, Pourakbar L, Farhadi K, Mohamadgolizad L and Goosta Y 2015 Biological synthesis of silver nanoparticles and evaluation of antibacterial and antifungal properties of silver and copper nanoparticles *Turkish J. Biol.* 39 556–61
[2] Arun A and Ahmed S 2018 Green synthesis of metal, metal oxide nanoparticles, and their various applications *Handb. Ecomater.* 1 1–45
[3] Salmen S H and Alharbi S A 2020 Silver nanoparticles synthesized biogenically from Aloe fleurentiniurinum extract: characterization and antibacterial activity *Green Chem. Lett. Rev.* 13 1–5
[4] Dhand V, Soumya L, Bhardavaj S, Chakra S, Bhatt D and Sreedhar B 2016 Green synthesis of silver nanoparticles using Coffea arabica seed extract and its antibacterial activity *Mater. Sci. Eng. C* 58 36–43
[5] Jayapaul U et al 2018 Shape-tunable and facile extracellular green synthesis of silver nanocubes using leaf extracts of Jatropha Gossypifolia and Jatropha Glandulifera and its antibacterial studies *Mater. Res. Express* 6 015048
[6] Priya B, Manthos S, Anirudhda M and Papita D 2014 Leaf extract mediated green synthesis of silver nanoparticles from widely available Indian plants: synthesis, characterization, antimicrobial property and toxicity analysis *Bioresour. Bioprocess.* 1 3
[7] Kashevar M et al 2017 Green synthesis of silver nanoparticles using Alysicarpus monilifer leaf extract and its antibacterial activity against MRSA and CoNS isolates in HIV patients *J. Interdiscip. Nanomedicine* 2 131–41
[8] Ravichandran V, Vasanthi S, Shalini S, Ali Shah S A and Harish R 2016 Green synthesis of silver nanoparticles using Atrocarpus altilis leaf extract and the study of their antimicrobial and antioxidant activity *Mater. Lett.* 180 264–7
[9] Alsalhi M et al 2016 Green synthesis of silver nanoparticles using Pimpinellina anisum seeds: antimicrobial activity and cytotoxicity on human neonatal skin stromal cells and colon cancer cells *Int. J. Nanomedicine* 11 4439–49
[10] Tippayawat P, Phromvivo N, Boueroy P and Chompoosor A 2016 Green synthesis of silver nanoparticles in aloe vera plant extract prepared by a hydrothermal method and their synergistic antibacterial activity *PeerJ* 2016 1–15
[11] Ahmed S, Saifullah, Ahmad M, Swami B L and Ikram S 2016 Green synthesis of silver nanoparticles using Azadirachta indica aqueous leaf ex: *truct.* 1. *Radiat. Res. Appl. Sci.* 9 1–7
[12] Bahrami-Teimoori B, Nikparast Y, Hojatianfar M, Ghorbani R and Pourianfar H R 2017 Characterisation and antifungal activity of silver nanoparticles biologically synthesised by Amaranthus retrofleexus leaf extract *J. Exp. Nanosci.* 12 129–39
[13] Ibrahim H M M 2015 Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms *J. Radiat. Res. Appl. Sci.* 8 265–75
[14] Ahmed M J, Murtaza G, Mehmood A and Bhatti T M 2015 Green synthesis of silver nanoparticles using leaves extract of Skimmia laureska: characterization and antibacterial activity *Mater. Lett.* 153 10–3
[15] Sadeghi B and Ghodlampheesinopour F 2015 A study on the stability and green synthesis of silver nanoparticles using Ziziphora tenuior (Zt) extract at room temperature *Spectrochim. Acta - Part A Mol. Biomol. Spectrosc.* 134 310–15
[16] Escárciga-González C E et al 2018 In vivo antimicrobial activity of silver nanoparticles produced via a green chemistry synthesis using acacia rigida as a reducing and capping agent *Int. J. Nanomedicine* 13 2349–63
[17] Velgosova O, Mrázková A, Veselovsky L, Willner J and Fornalčíček A 2019 Influence of different plants extracts on silver nanoparticles green synthesis *Arch. Metall. Mater.* 64 685–70
[18] Veisi H, Kavian M, Hekmati M and Hemmati S 2019 Biosynthesis of the silver nanoparticles on the graphene oxide’s surface using *Pistacia atlantica* leaves extract and its antibacterial activity against some human pathogens *Polyhedron* 161 338–45
[19] Kaduková J, Velgosová O, Mrázková A and Marcincináková R 2014 The effect of culture age and initial silver concentration on biosynthesis of Ag nanoparticles *Nov. Biotechnol. Chim.* 13 28–37
[20] Velgosova O, Čížmárová E, Malek J and Kavuličová J 2017 Effect of storage conditions on long-term stability of Ag nanoparticles formed via green synthesis *Int. J. Miner. Metall. Mater.* 24 1177–82
[21] Divya M, Kiran G S, Hassan S and Selvin J 2019 Biogenic synthesis and effect of silver nanoparticles (AgNPs) to combat catheter-related urinary tract infections *Bioscatul. Agric. Biotechnol.* 18 101037
[22] Murthy H C A, Abebe B and Tegene D Z 2019 Shape-tunable and facile extracellular green synthesis of silver nanoparticles *Mater. Res. Express* 6 015048
[23] Wolde T, Bizuayehu B, Hailemariam T and Tiruha K 2016 Phytochemical analysis and antimicrobial activity of hagenia abyssinica flowers extract and their study of their antimicrobial and antioxidant activity *Mater. Lett.* 153 10–3
[24] Kumar M R A et al 2019 Evaluation of bi-functional applications of ZnO nanoparticles prepared by green and chemical methods *J. Environ. Chem. Eng.* 7 103468
[25] Tsade H, Abebe B and Murthy H C A 2019 Nano sized Fe-Al oxide mixed with natural maize cob sorbent for lead remediation *Mater. Res. Express* 6 085043
[26] Anbu P, Gopinath S C B, Yun H S and Lee C G 2019 Temperature-dependent green biosynthesis and characterization of silver nanoparticles using balloon flower plants and their antibacterial potential *J. Mol. Struct.* 1177 302–9
[27] Roy A, Bulut O, Some S, Mandal A K and Yilmaz M D 2019 Green synthesis of silver nanoparticles: biomolecule-nanoparticle organizations targeting antimicrobial activity *RSC Adv.* 9 2673–702
[28] Girón-Vázquez N G et al 2019 Study of the effect of Persea americana seed in the green synthesis of silver nanoparticles and their antimicrobial properties *Results Phys.* 13 102142
[29] Azarbani F and Shivaand S 2020 Green synthesis of silver nanoparticles by Ferulago macrocarpa flowers extract and their antibacterial, antifungal and toxic effects *Green Chem. Lett. Rev.* 13 41–9
[30] Veisi H et al 2019 Single particle ICP-MS and GC-MS provide a new insight into the formation mechanisms during the green synthesis of AgNPs *Results Phys.* 43 302–9
[31] Lee S H and Jun B 2019 Silver nanoparticles: synthesis and application for nanomedicine *Int. J. Mol. Sci.* 20 865
[32] Kaur P, Thukur R and Chaudhury A 2016 Biogenesis of copper nanoparticles using peel extract of Punica granatum and their antimicrobial activity against opportunist pathogens *Green Chem. Lett. Rev.* 9 33–8
[33] Al-sherbini A A, Ghannam H E A, El-ghanam G M A, El-ella A A and Youssef A M 2019 Utilization of chitosan/Ag bionanocomposites as eco-friendly photocatalytic reactor for Bactericidal effect and heavy metals removal Heliyon 5 e01980

[34] Rashid M M O, Akhter K N, Chowdhury J A, Hossen F, Hussain M S and Hossain M T 2017 Characterization of phytoconstituents and evaluation of antimicrobial activity of silver–extract nanoparticles synthesized from Momordica charantia fruit extract BMC Complement. Altern. Med. 17 1–7

[35] Kumar M R A, Abebe B, Nagaswarupa H P, Murthy H C A, Ravikumar C R and Sabir F K 2020 Enhanced photocatalytic and electrochemical performance of TiO2–Fe2O3 nanocomposite: its applications in dye decolorization and as supercapacitors Sci. Rep. 10 1269

[36] Sangili A, Annalakshmi M, Chen S M, Balasubramanian P and Sundrarajan M 2019 Synthesis of silver nanoparticles decorated on core–shell structured tannic acid-coated iron oxide nanospheres for excellent electrochemical detection and efficient catalytic reduction of hazardous 4-nitrophenol Compos. Part B Eng. 162 33–42

[37] Avinash B et al 2019 Nano CuO: electrochemical sensor for the determination of paracetamol and D-glucose J. Phys. Chem. Solids 134 193–200