GREEN SYNTHESIS AND CHARACTERIZATION OF ANTIMICROBIAL AND CATALYTIC SILVER NANOPARTICLES USING *SOYMIDA FEBRIFUGA* AQUEOUS LEAF EXTRACT

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ABSTRACT

Green synthesis of nanoparticles has gained notable significance in the recent times because of the use of cost-effective and eco-friendly procedures. In the present study, one such simple, cost-effective and eco-friendly biosynthesis of silver nanoparticles [AgNPs] was developed. The synthesis of AgNPs from aqueous leaf extract of *Soymida febrifuga* was assessed by varying different reaction parameters like concentration of plant extract, the ratio of reactants, temperature and reaction time. Characterization using UV-Visible Spectrophotometry revealed a Surface Plasmon Resonance [SPR] peak at 429nm confirming the formation of AgNPs. Further, characterization of the AgNPs was carried out using X-Ray Diffractometer [XRD], Nanoparticle Analyzer, Scanning Electron Microscope [SEM] and Transmission Electron Microscope [TEM] which revealed the size, shape and crystallinity of the AgNPs formed. The Fourier Transform Infrared Spectroscopy [FTIR] study explained that biomolecules in *Soymida febrifuga* aqueous leaf extract have acted as the reducing and stabilizing agents during the synthesis. The *in-vitro* antimicrobial activity of the AgNPs was investigated against *Bacillus subtilis*, *Escherichia coli*, *Klebsiella pneumoniae* and *Staphylococcus aureus*. The catalytic activity of the AgNPs thus synthesized was investigated by studying the degradation of methylene blue dye by sodium borohydride. The AgNPs synthesized from aqueous leaf extract of *Soymida febrifuga* showed effective antimicrobial
and catalytic properties. The developed method can be used as substitute for the physical and chemical methods used for the synthesis of AgNPs.

KEYWORDS: Green synthesis; Soymida febrifuga; Silver nanoparticles; Characterization; Antimicrobial activity; Catalytic activity.

INTRODUCTION
The outbreak of research in nanotechnology captured the attention of the scientific community. Metal nanoparticles have found applications in various fields of medicine, science, engineering, technology, biosensing and forensic science. The synthesis of metal nanoparticles like silver, gold, palladium, platinum and other metals using physical and chemical methods have already been reported. However, these methods are associated with high risk credited to contamination by chemical precursor, toxicity of organic solvents and formation of toxic by-products. Therefore, development of alternative greener methods of synthesis of metal nanoparticles has become the need of the hour. Microorganisms such as bacteria, fungi, algae, viruses and plants have been widely used for the synthesis of metal nanoparticles. India, being a country with rich biodiversity, green synthesis of metal nanoparticles from plant extracts can be employed effectively. Owing to the easy availability, less maintenance and easy handling, plant extracts have been preferred over microorganisms for synthesis of metal nanoparticles. Formation of silver and gold nanoparticles from plants was first reported by Jose-Yacaman and co-workers. Among the various metal nanoparticles, AgNPs are promising. Due to the wide range of applications conferred to them, they are effectively being synthesized using green chemistry approach. AgNPs show biomedical applications such as antimicrobial, anti-inflammatory, antiviral, antitumor activity and many more. Besides their medical uses, AgNPs are also used in clothing, food industry, paints, electronics and other fields. They also exhibit catalytic activity in degradation of organic dyes. Hence, synthesis of AgNPs is being carried out extensively.

In previously published work, the synthesis of AgNPs from gum Kondagogu [Cochlospermum gossypium], Cinnamon zeylanicum bark extract, Azadirachta indica leaf extract, tea leaf extract, callus and leaf extracts of Sesuvium portulacastrum, Aloe vera leaf extract, European black elderberry fruit extract, Trachyspermum ammi and Papaver somniferum extracts, Minusops elengi leaf extract and Dalbergia spinosa leaves have been reported. Several such studies have helped in exploring plant extracts for synthesis of AgNPs.
With the same conceptual framework, as a part of our current research, we have carried out investigations using aqueous leaf extract of *Soymida febrifuga* for synthesis of AgNPs. *Soymida febrifuga* belongs to the family Meliaceae. It is commonly called Chandra vallabha [Sanskrit], Indian redwood, Bastarol cedar [English], Somi, Somidha, Sumi [Telugu]. It is an indigenous lofty deciduous medicinal tree and monotypic genus endemic to India [Wealth of India, 1952]. It is found in dry forests of Western Peninsula and Indo-Malaysia. The present study aims at green synthesis, characterization and assessing the antimicrobial and catalytic properties of AgNPs synthesized from aqueous leaf extract of *Soymida febrifuga* which acts as a reducing and stabilizing agent. The synthesized AgNPs were characterized using UV-Visible spectroscopy, FTIR, XRD, Nanoparticle analyzer, SEM and TEM. The *in vitro* antimicrobial activity of the AgNPs was researched against various bacterial strains such as *Bacillus subtilis*, *Escherichia coli*, *Klebsiella pneumoniae* and *Staphylococcus aureus*. The catalytic activity of the AgNPs thus synthesized was investigated by studying the degradation of methylene blue [MB] dye by sodium borohydride [NaBH₄].

**MATERIALS AND METHODS**

**Reagents**

Analytical grade chemicals and reagents were used in the present study. Silver Nitrate was supplied by Sigma-Aldrich Quimica, Spain. Methylene Blue and Sodium Borohydride were supplied by Merck, Germany. All the solutions were prepared using double-distilled water. All glassware were thoroughly cleaned with double-distilled water and dried in an oven.

**Collection and processing of plant samples**

The healthy leaves of *Soymida febrifuga* were collected from Nallamala forest, Mahboobnagar district, Telangana, India. The collected specimen was verified in Herbaria of the Department of Botany, Osmania University, Telangana, India for authentication.

**Preparation of plant extract**

The leaves of *Soymida febrifuga* were cleaned with double-distilled water, shade dried and powdered in a conventional grinder to obtain a fine powder. The dried leaf powder was then sieved and used for preparation of aqueous leaf extract of *Soymida febrifuga*. 0.1g of fine dried leaf powder was weighed and boiled in 100ml double-distilled water at 60°C for 15 minutes. This extract was filtered through Whatman No. 1 filter paper and used for further experiments.
Synthesis of AgNPs

*Soymida febrifuga* aqueous leaf extract was used as a reducing agent for AgNPs synthesis. 50 ml of the aqueous leaf extract of *Soymida febrifuga* was mixed with 100 ml of 1mM AgNO₃ solution. The reaction mixture was then heated on a magnetic stirrer up to 80°C for 15 minutes. The noted change from straw yellow color to reddish brown color suggested the formation of AgNPs. The reaction mixture was analyzed by UV-Visible Spectroscopy to ascertain the formation of AgNPs. Further, the reaction mixture was subjected to centrifugation at 15000 rpm for 25 minutes at 20-22°C. The resulting pellet was washed twice with double distilled water. The resulting purified suspension was dried and used in solid form for characterization by FTIR & XRD. The reaction for the formation of AgNPs was systematically investigated by varying the concentration of plant extract [0.1%, 0.25%, 0.5%, 0.75%, 1% & 2%], the ratio of the reactants [1:0.5, 1:1, 1:2, 1:4 & 1:9], temperature [30°C, 60°C, 70°C, 80°C & 90°C] and time of reaction [0-30mins].

Characterization of AgNPs

**UV-Visible Spectroscopy**

The optical property of the bio-reduced AgNPs prepared from the aqueous leaf extract of *Soymida febrifuga* were analyzed by UV-Vis Spectroscopy using a Shimadzu Double Beam UV-Visible Spectrophotometer UV-2600 at room temperature. Optical absorbance of the synthesized nanoparticles was monitored between the wavelength 200 - 800 nm.

**Fourier Transform Infrared Spectrophotometer**

The functional groups and composition of AgNPs was analyzed using FTIR spectroscopy. The Fourier Transform Infrared Spectrophotometer [SHIMADZU IR Prestige21 FTIR Instrument] was used to get the FTIR spectra of the synthesized AgNPs by KBr pellet method. The scan was carried out in the range of 250 - 4000 cm⁻¹.

**X-Ray Diffraction studies**

Phase formation and crystallinity of the synthesized nanoparticles was analyzed by XRD. XRD measurements were carried out on the X’pert Pro X-ray Diffractometer [Pan-alytical B. V., The Netherlands] operating at 40 kV and a current of 30 mA at a scan rate of 0.388 min⁻¹ using CuKα radiation [λ = 0.154nm] over a 20 range of 20-80° with a step size of 0.02°.
Scanning Electron Microscopy
The morphology of the AgNPs was characterized by Quanta 400 (FEI, The Netherland) Scanning Electron Microscope [SEM].

Nanoparticle Analyzer
The size of the synthesized AgNPs and zeta potential was recorded at 25°C using SZ 100 Nanoparticle Analyzer, Horiba Scientific, Germany.

Transmission Electron Microscope
The size, shape and surface morphology of AgNPs was recorded by casting the ultrasonicated nanoparticle suspension on carbon-coated copper grids and allowed to dry at room temperature. The carbon coated copper grid with the nanoparticle was then loaded into the TEM holder. The holder was then loaded into a Tecnai G2 (FEI, The Netherland) Transmission Electron Microscope which was operated at 200kV.

Antimicrobial assay
The antibacterial activity of the synthesized AgNPs was studied and assessed against Bacillus subtilis, Escherichia coli, Klebsiella pneumoniae and Staphylococcus aureus strains by Disc Diffusion assay method. The prepared nutrient media was poured into the sterilized petriplates and the bacterial strains were inoculated on the nutrient media separately and spread with a spreader. Then sterile discs dipped into different concentrations of AgNPs i.e., 5 μl, 10 μl, 15 μl and 20 μl were placed on the inoculated petriplates with a positive control, Ampicillin [10μg/10ml]. After 24 hours of incubation at 37°C, the formation of zone of inhibition was observed and measured.

Catalytic activity
The catalytic activity of the prepared AgNPs was studied on the degradation of methylene blue [MB] dye by sodium borohydride [NaBH₄] by mixing 1 ml of NaBH₄ [0.025M] with 5ml of MB [0.167 x 10⁻⁴M]. 50μl of AgNP colloidal solution was added to this mixture and continuously stirred followed by recording of UV-VIS absorption spectra at regular intervals of time.

RESULTS AND DISCUSSION

Synthesis of AgNPs: The formation of AgNPs was indicated by the change from light yellow to reddish brown color in solution as seen in Fig 1. This change is due to the excitation of free
electrons in nanoparticles\textsuperscript{[40]} which gives the Surface Plasmon Resonance [SPR] absorption band by the combined vibration of electrons of metal nanoparticles in resonance with light wave.\textsuperscript{[41]} Metal nanoparticles display different colors in solution due to their optical properties.\textsuperscript{[42]}

Fig 1: UV-Visible Spectra of \textit{Soymida febrifuga} aqueous leaf extract, 1mM AgNO\textsubscript{3} and synthesized AgNPs

Characterization

UV-Visible Spectroscopy

UV-Visible Spectroscopy is a simple, sensitive and indirect method which was employed to characterize the formation of AgNPs. As depicted in Fig 1, UV-VIS absorption spectra showed a Surface Plasmon Resonance [SPR] band at 429 nm which clearly indicated the formation of AgNPs. However, the intensity and the SPR band position changed with varying plant extract concentration, ratio of reactants, temperature and time of reaction.

Effect of plant concentration

The \textit{Soymida febrifuga} aqueous leaf extract was prepared in varying concentrations such as 0.1%, 0.25%, 0.5%, 0.75%, 1% & 2%. The Surface Plasmon Resonance [SPR] band for 0.1% plant extract was observed at 429 nm whereas for 0.25% and 0.5% leaf extract solutions, red shift of SPR band was observed. 0.75%, 1% & 2% leaf extract showed no band around 400-470 nm indicating no formation of AgNPs. This showed that 0.1% plant extract would yield smaller particles which are stable due to the SPR band position.
Effect of ratio of reactants

The *Soymida febrifuga* aqueous leaf extract and 1mM AgNO$_3$ were mixed in different ratios such as 1:9, 1:1, 1:2, 1:0.5 and 1:4. The ratio of 1:1, 1:9, 1:0.5 have shown synthesis of larger number of AgNPs however the SPR peaks have shown red shift. The SPR band for 1:2 ratio was found to be best. The peak corresponding to 1:4 ratio of reactants has shown synthesis of lesser number of nanoparticles. Therefore, 1:2 ratio of reactants has been chosen for further analysis.

Effect of temperature

Temperature is an important factor which controls the formation of AgNPs. With increase in temperature, there has been a gradual increase in absorbance in the Surface Plasmon Resonance peak formed at 429nm marking the formation of similarly sized AgNPs in larger number. So, the rise in temperature does not show any effect on the size of the AgNPs but will only help in the synthesis of more number of particles.

Effect of time of reaction

There has been no notable shift in the SPR band position suggesting the synthesis of stable nanoparticles which increase in number with increase in time of reaction. Therefore, an optimum time of reaction of 15 minutes has been employed for the synthesis of AgNPs.

Fourier Transform Infrared Spectroscopy

Interactions between silver and phytochemical constituents present in aqueous leaf extract of *Soymida febrifuga* were identified by FTIR analysis. These interactions may be responsible for synthesis and stabilization of AgNPs. As depicted in Fig 2, FTIR spectrum shows bands at 1670.35 cm$^{-1}$, 1639.49 cm$^{-1}$ and 1544.95 cm$^{-1}$ that correspond to the bending vibrations of amide I and amide II bands of biomolecules respectively and their corresponding C-O stretching band was observed at 1735.93 cm$^{-1}$. The bands at 2850.79 cm$^{-1}$, 2920.23 cm$^{-1}$, 3149.76 cm$^{-1}$ and 3275.13 cm$^{-1}$ may be due to N-H and O-H stretching vibrations of amide and phenolic groups present in these molecules. The band at 3728.40 cm$^{-1}$ can be assigned to O-H stretching frequency of carboxylic acid group belonging to the amino acids. The bands observed at 1384.89 cm$^{-1}$ and 1020.34 cm$^{-1}$ can be assigned to C-N stretching vibrations of aromatic and aliphatic amines respectively. FTIR spectrum of AgNPs clearly suggested binding of bioactive molecules with AgNPs which resulted in their stabilization and the structural characteristics of these molecules were not affected due to their reaction with silver ions or binding with AgNPs.
Fig 2: FTIR Spectra of AgNPs synthesized from aqueous leaf extract of Soymida febrifuga

X-Ray Diffraction Analysis

The phase formation and crystallinity of the AgNPs synthesized from Soymida febrifuga aqueous leaf extract was analyzed using XRD. Fig 3 shows distinct diffraction peaks of the synthesized AgNPs at the diffraction angles \[2\theta\] of 37.72°, 45.85°, 64.06° and 77.12°. These peaks are assigned to the reflections from [111], [200], [220] and [311] planes of the silver crystal respectively. This indicates the presence of face-centered cubic structure of AgNPs and confirms its crystalline nature [JCPDS File No. 04-0783]. The peak broadening is due to the formation of nanoparticles.

The Debye-Scherrer’s formula was used for the calculation of average size of the AgNPs. The Debye-Scherrer’s formula is

\[
D = \frac{0.94\lambda}{\beta \cos \theta}
\]

where \(D\) corresponds to the average crystallite domain size perpendicular to the reflecting planes, \(\lambda\) corresponds to the X-ray wavelength, \(\beta\) corresponds to the full width at half maximum [FWHM] and \(\theta\) is the diffraction angle. The crystallite size of the synthesized particle was 22.29 nm which was calculated using peak broadening profile of [111] peak at 37.72°. The particle size calculated from the XRD data ranges between 18nm-29nm.

Since the method involved use of biomolecules for reduction of silver, crystallization of the bioorganic phase occurred on the surface of AgNPs which resulted in a few unassigned peaks [marked with stars]. Similar results have been reported in AgNPs synthesized using edible mushroom extract\,[43], geranium leaves\,[44] and Coelus Aromaticus leaf extract.[45]
Fig 3: XRD pattern of AgNPs synthesized from aqueous leaf extract of *Soymida febrifuga*

**Scanning Electron Microscope [SEM]**

A further insight into the surface morphology, size and shape of the synthesized AgNPs was provided by SEM analysis. The Fig 4 shows the SEM image of AgNPs synthesized from aqueous leaf extract of *Soymida febrifuga*. The particles are predominantly spherical in shape. The availability of biomolecules in the extract has resulted in the synthesis of spherical AgNPs.

Fig 4: SEM image of AgNPs synthesized from aqueous leaf extract of *Soymida febrifuga*

**Nanoparticle analyzer**

Nanoparticle analyzer helps in determining the size of the particle, size distribution, polydispersity index [PDI] and the zeta potential value. Fig 5A indicates the mean particle size of the nanoparticle from the nanoparticle analyzer data as 20.5nm and Fig 5B shows the
zeta potential of the synthesized AgNPs. AgNPs carry a charge of -24.2 mV and have a PDI of 0.474. It may be noted that PDI greater than 0.5 indicates the aggregation of nanoparticles. Since the PDI is less than 0.5, the AgNPs synthesized from aqueous leaf extract of Soymida febrifuga do not exhibit aggregation. Zeta potential measures the potential stability of the particles in the colloidal suspension and AgNPs generally carry a negative charge. AgNPs synthesized from Soymida febrifuga showed negative charge and were stable at room temperature.

Fig 5: Nanoparticle analyzer data of synthesized AgNPs: (A) Mean diameter of synthesized nanoparticles (B) Zeta potential of AgNPs synthesized from aqueous leaf extract of Soymida febrifuga

Transmission Electron Microscope [TEM]
TEM analysis is a confirmatory analysis used for characterization of AgNPs. TEM micrograph of AgNPs synthesized using aqueous leaf extract of Soymida febrifuga is shown in Fig 6A and 6B. The TEM results revealed well dispersed and mostly spherical AgNPs. Maximum particles were in the size range of 10 - 20 nm and few particles were found above the range of 30 nm. The corresponding size distribution is represented by a histogram in the Fig 6D. The polycrystalline rings observed in the Selected Area Electron Diffraction [SAED] pattern in Fig 6C can be indexed to cubic-phase metal silver. Hence, the SAED pattern reveals the crystalline nature of metallic AgNPs thus synthesized. The TEM results were in good agreement with the results obtained by UV-VIS Spectroscopy, XRD and SEM.
Fig 6: TEM images of AgNPs synthesized from aqueous leaf extract of *Soymida febrifuga*: (A) AgNPs at magnification of 20nm. (B) AgNPs at magnification of 50nm. (C) SAED pattern of synthesized AgNPs (D) Histogram showing the particle size distribution.

**Antimicrobial activity**

Silver is known to show antimicrobial properties which are exploited in the medical field as well as in environmental studies. The AgNPs synthesized by this method have displayed effective antibacterial activity against *Bacillus subtilis* [gram positive], *Streptococcus aureus* [gram positive], *Klebsiella pneumoniae* [gram negative] and *Escherichia coli* [gram negative]. Clear zones of inhibition were observed as depicted in the Fig 7A, 7B, 7C and 7D. The mean diameter of zone of inhibition exhibited against each bacterial strain has been depicted in Table I and Fig 8. In the present study, AgNPs showed greater antimicrobial activity in comparison with the standard antibiotic Ampicillin. The activity exhibited by AgNPs was found to be dose-dependent. With increase in concentration of the AgNPs, there was also a simultaneous increase in the zone of inhibition showing an increase in the
antibacterial activity exhibited by the green synthesized AgNPs. However, the dose-dependent effect of AgNPs was observed only up to 15µl of AgNPs and remained constant after 15 µl.

The highest antibacterial activity was observed against *Bacillus subtilis* whereas *Klebsiella pneumoniae* and *Escherichia coli* were inhibited moderately. In comparison with the aforesaid strains, AgNPs synthesized from aqueous leaf extract of *Soymida febrifuga* exhibited low antibacterial activity against *Streptococcus aureus*. To explain the mechanism of antibacterial activity of AgNPs, several theories have been proposed. A few theories include alteration of permeability of cell membrane [46], release of lipopolysaccharides and membrane proteins [47], generation of free radicals responsible for the damage of membrane [48] and dissipation of the proton motive force resulting in the collapse of the membrane potential [49] but the exact mechanism has not been fully deciphered [50].

Fig 7: Antibacterial activity of synthesized AgNPs against (A) *Bacillus subtilis* (B) *Escherichia coli* (C) *Klebsiella pneumoniae* (D) *Streptococcus aureus*. (1) Ampicillin control (2) 5µl AgNPs (3) 10µl AgNPs (4) 15µl AgNPs (5) 20µl AgNPs.
Table I: Antibacterial activity of the synthesized silver nanoparticles against some human pathogens

<table>
<thead>
<tr>
<th>S.No</th>
<th>Bacterial strains</th>
<th>Ampicillin (10µg/10µl)</th>
<th>Zone of inhibition in mm for 5µl of AgNPs</th>
<th>Zone of inhibition in mm for 10µl of AgNPs</th>
<th>Zone of inhibition in mm for 15µl of AgNPs</th>
<th>Zone of inhibition in mm for 20µl of AgNPs</th>
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<tr>
<td>1</td>
<td><em>Bacillus subtilis</em></td>
<td>18</td>
<td>12</td>
<td>16</td>
<td>20</td>
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<tr>
<td>2</td>
<td><em>Escherichia coli</em></td>
<td>13</td>
<td>15</td>
<td>17</td>
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<td>18</td>
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<tr>
<td>3</td>
<td><em>Klebsiella pneumoniae</em></td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>16</td>
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<tr>
<td>4</td>
<td><em>Staphylococcus aureus</em></td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>16</td>
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Fig 8: Graph representing the Zone of Inhibition exhibited by synthesized AgNPs against some human pathogens

Catalytic activity

As silver is recognized to be an excellent catalyst for degradation of organic dyes, the green synthesized AgNPs from *Soymida febrifuga* aqueous leaf extract were used for degradation of Methylene blue [MB] dye. The reduction of Methylene blue to Leuco methylene blue [LMB] in the presence of sodium borohydride [NaBH₄] as a function of time has been investigated. The prominent band observed in UV-Visible absorption spectrum of Methylene blue at 663 nm corresponds to $n-\pi^*$ transition.⁵¹⁻⁵³ In a typical catalytic reaction, freshly prepared NaBH₄ [1 ml, 0.025M] solution, was added to MB [5ml, $0.167 \times 10^{-4}$M]. The MB showed an absorbance peak at 663 nm with a shoulder at 614nm, whose absorbance decreased in the presence of NaBH₄ as shown in Fig. 9A. The slow variation in the intensity of the absorption peak at 663 nm indicated the poor reaction rate in the reduction of MB to LMB by NaBH₄. Without catalyst, MB degradation took months together to be degraded, even in the presence of strong reducing agent like NaBH₄ indicating that our results are in agreement with earlier results reported.⁵¹ However, immediately after adding 50 µl of AgNPs to the reaction mixture, the
intensity of the absorbance band at 663 nm successively decreased with increasing reaction time as shown in Fig. 9B. The reduction reaction of MB by sodium borohydride in the presence of AgNPs was completed in less than 20 minutes. To exhibit potential catalytic activity, the redox potential of AgNPs should lie between the redox potential of donor $[\text{NaBH}_4]$ and the acceptor $[\text{MB}]$ system.\textsuperscript{[51, 55, 56]} The AgNPs act as an electron transfer mediator between MB and sodium borohydride by acting as a redox catalyst known as Electron relay effect.\textsuperscript{[57]}

Fig 9: Catalytic activity of AgNPs synthesized from aqueous leaf extract of \textit{Soymida febrifuga}. (A) UV-Visible spectra of reduction of MB by NaBH$_4$ at different time intervals (B) Reduction of MB by NaBH$_4$ using AgNPs synthesized from \textit{Soymida febrifuga} aqueous leaf extract as a catalyst at different time intervals

CONCLUSION

A simple, cost-effective and eco-friendly biosynthesis of AgNPs was developed using aqueous leaf extract of \textit{Soymida febrifuga}. Water-soluble organic compounds present in the...
plant material were mainly responsible for reducing Ag ions to nanosized Ag particles. The characterization studies which includes UV-Visible spectroscopy, Nanoparticle analyzer, SEM, TEM and FTIR explained that the AgNPs were spherical in shape with size ranging between 10-30nm and they were highly stable. XRD pattern confirmed the crystalline nature of the silver nanocrystals. Zeta potential studies demonstrated negative surface charge of the formed nanoparticles. These green synthesized AgNPs exhibited antibacterial activity against *Bacillus subtilis, Escherichia coli, Klebsiella pneumoniae* and *Staphylococcus aureus* strains. They have also shown significant catalytic activity in degradation of MB dye by sodium borohydride. The inexpensive and biosynthetic method developed can be used as substitute for the physical and chemical methods used for the synthesis of AgNPs. This method can be applied for more economical and environment-friendly large-scale productivity of AgNPs which can find many more applications in industry.

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