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Review Article

# A REVIEW ON ECO-FRIENDLY SYNTHESIS OF SILVER NANOPARTICLES FROM PLANTS OF FIVE DIFFERENT FAMILIES AND ITS APPLICATION IN MEDICINAL FIELD

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## ABSTRACT

Metallic nanoparticles have wide applications in industrial and also in medicinal field. In this review a green synthesis of silver nanoparticles was reported from five different plant families namely Euphorbiaceae, Bignoniaceae, Rhamnaceae, Fabaceae and Apocynaceae. In all the researches, to prepare silver nanoparticles, a stock solution of silver nitrate was bio-reduced by mixing with aqueous plant extracts. Synthesized silver nanoparticles were characterized by UV-Vis Spectroscopy, FT-IR, EDAX, XRD, DLS, SEM and TEM analysis. Visual characterization was confirmed by observing the formation of deep brown colour from colourless silver nitrate solution due to Surface Plasmon Resonance (SPR). UV-Vis spectrum showed the characteristic absorption maxima in the wavelength range 400-460 nm. FT-IR studies showed the presence of different phytochemicals which were responsible for bio-reduction and capping. In all the reports the XRD study showed the face centre cubic (fcc) crystalline form of the synthesized nanoparticles. The SEM and TEM studies revealed the spherical morphology and sized range in between 10-90 nm. The formed AgNPs had good antimicrobial activity against different Gram positive, Gram negative bacteria and some pathogenic fungus like *Klebsiella pneumonia, Escherichia coli, Bacillus subtilis*, *Aspergillus niger* etc. Again AgNPs also exhibited cytotoxic and wound healing activity.

**Keywords:** Silver Nanoparticles, Nanotechnology, Bio-reduction, Antimicrobial, Wound Healing, SEM analysis.

## 1. INTRODUCTION

The field of nanotechnology covers the vast areas of basic sciences and biological sciences. This technology was guided by the size of the particles which varies from 1 nm to 100 nm. Metallic nanoparticles differ in their physical and chemical properties for e.g. melting points, mechanical strength, magnetic strength etc. from the bulk one. This change in properties with size variation makes it to a new emerging disruptive technology, which is quite different from sustaining technologies. These nanosized particles have wide range applications as sensors, semiconductor, catalyst, antimicrobial agents etc due to its large area to volume ratio [1, 2]. The discoveries and developments associated with nano-particles (nanotechnology) are summarized in Table 1. Now a day's many methods and approaches have been reported for the synthesis of nanoparticles by using chemical, physical, photochemical and biological routes. The synthesis of metal nanoparticles using bio inspired, eco friendly greener methods is one of the most attractive aspects of current nano science and nanotechnology. The object of this review is detailed discussion on synthesis and characterization of silver nanoparticles from five different plant families and its applications in medicinal field.

## 2. SYNTHESIS OF NANOPARTICLES BY PHYSICAL AND CHEMICAL METHODS

Two approaches are followed to synthesize nano-particles. One is top down in which external force is applied to form smaller particles and another one is bottom-up to produce various size nonmaterial by self assembly from fine molecular distributions in liquid or vapour phase (Fig. 1). Followings are the procedure used for the synthesis of nanoparticles.

### 2.1. Gas Condensation

Gas condensation was the first technique used to synthesize Nano crystalline metals and alloys. In this technique, a metallic or inorganic material is vaporized using thermal evaporation sources such as a Joule heated refractory crucibles, electron beam evaporation devices, in an atmosphere of 1-50 m bar. It is usually called 'inert gas evaporation'. This method was reported by the

group of researchers [3]. Increased pressure or increased molecular weight of the inert gas leads to an increase in the mean particle size. This so-called Inert Gas Condensation method is already used on a commercial scale for a wide range of materials.

**Table 1: Discoveries and Developments of nanotechnology**

| Sl No. | Year | Name of person associated with Discoveries and Developments of nanotechnology | Discoveries and Developments |
|---|---|---|---|
| 1 | 2000 | President Clinton | Launched the National Nanotechnology Initiative (NNI) to coordinate Federal R & D efforts and promote U.S. competitiveness in nanotechnology. |
| 2 | 2003<br><br>2003 | Naomi Halas, Jennifer West, Rebekah Drezek, and Renata Pasqualin | Congress enacted the 21st Century Nanotechnology Research and Development Act (P.L. 108-153).<br>Developed gold nanoshells, which when "tuned" in size to absorb near-infrared light, serve as a platform for the integrated discovery, diagnosis, and treatment of breast cancer without invasive biopsies, surgery, or systemically destructive radiation or chemotherapy. |
| 3 | 2004 | Suny Albany | The European Commission adopted the Communication "Towards a European Strategy for Nanotechnology," COM(2004):<br>Britain's Royal Society and the Royal Academy of Engineering published Nanoscience and Nanotechnologies: Opportunities and Uncertainties<br>Launched the first college-level education program in nanotechnology in the United States, the College of Nanoscale Science and Engineering. |
| 4 | 2005 | Erik Winfree and Paul Rothemund | Developed theories for DNA-based computation and "algorithmic self-assembly" |
| 5 | 2006 | James Tour and colleagues | Built a nanoscale car made of oligo(phenylene ethynylene) with alkynyl axles and four spherical C60 fullerene (buckyball) wheels. |
| 6 | 2007 | Angela Belcher and colleagues | Built a lithium-ion battery with a common type of virus that is nonharmful to humans |
| 7 | 2008 | | The first official NNI Strategy for Nanotechnology-Related Environmental, Health, and Safety (EHS) Research |
| 8 | 2009-2010 | Nadrian Seeman and colleagues | Created several DNA-like robotic nanoscale assembly devices. |
| 9 | 2010 | | IBM used a silicon tip measuring only a few nanometers at its apex (similar to the tips used in atomic force microscopes) to chisel away material from a substrate to create a complete nanoscale 3D relief map of the world one-one-thousandth the size of a grain of salt-in 2 minutes and 23 seconds. |
| 10 | 2011 | | The NSET Subcommittee updated both the NNI Strategic Plan and the NNI Environmental, Health, and Safety Research Strategy. |
| 11 | 2012 | | The NNI launched two more Nanotechnology Signature Initiatives (NSIs)--Nanosensors and the Nanotechnology |

| | | | |
|---|---|---|---|
| | | | Knowledge Infrastructure (NKI)--bringing the total to five NSIs. |
| 12 | 2013 | | The NNI starts the next round of Strategic Planning, starting with the Stakeholder Workshop. |
| 13 | 2014 | | The NNI releases the updated 2014 Strategic Plan. The NNI releases the 2014 Progress Review on the Coordinated Implementation of the NNI 2011 Environmental, Health, and Safety Research Strategy. |
| 14 | 2016 | Jean-Pierre Sauvage, Sir J. Fraser Stoddart and Bernard L. Feringa | Nobel Prize in Chemistry for the design and synthesis of molecular machines |
| 15 | 2017 | Rainer Weiss, Barry C. Barish, and Kip S. Thorne | For decisive contributions to the LIGO detector and the observation of gravitational waves |
| 16 | 2018 | Oran D., Rodriques S.G., Gao R., Asano S., Skylar-Scott M.A., Chen F., Tillberg P.W., Marblestone A.H., Boyden E.S. | 3D nanofabrication by volumetric deposition and controlled shrinkage of patterned scaffolds |
| 17 | 2019 | The Hong Kong University of Science and Technology | Spider-Web-Inspired Stretchable Graphene Woven Fabric for Highly Sensitive, Transparent, Wearable Strain Sensors") |
| 18 | 2020 | Nicole Steinmetz | COVID-19 Vaccine Frontrunners and Their Nanotechnology Design |

*(https://www.nano.gov/timeline &https://www.nanowerk.com/spotlight)*

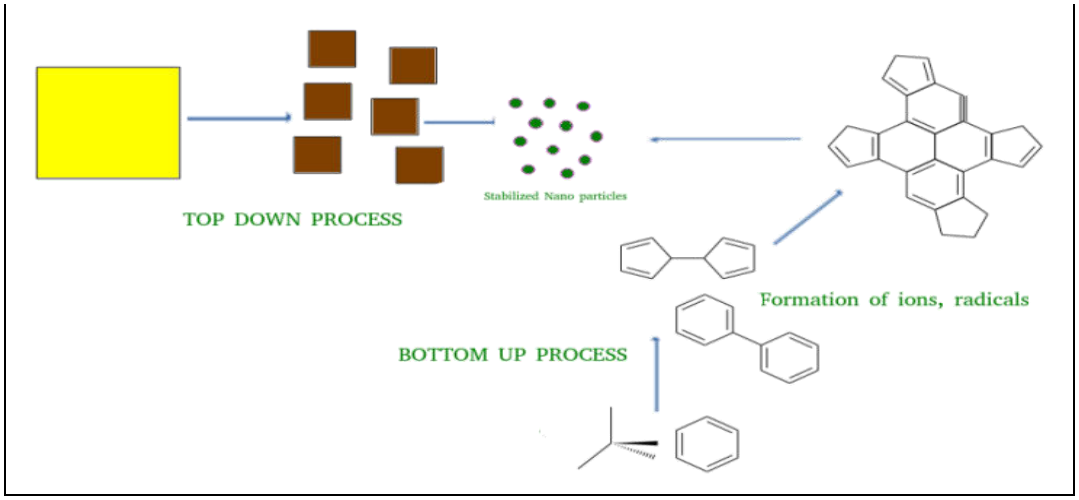


**Fig. 1: Top down and Bottom up process for synthesizing nonmaterial**

### 2.2. Vacuum Deposition and Vaporization

Before proceeding to the other methods, it is important to understand the terms vacuum deposition and vaporization or vacuum evaporation. In vacuum deposition process, elements, alloys or compounds are vaporized and deposited in a vacuum. The vaporization source is the one that vaporizes materials by thermal processes.CVD is a well known process in which a solid is deposited on a heated surface via a chemical reaction from the vapor or gas phase [4].

### 2.3. Chemical Vapor Deposition (CVD) and Chemical Vapor Condensation (CVC)

CVD is a well known process in which a solid is deposited on a heated surface via a chemical reaction from the vapor or gas phase. CVC reaction requires activation energy to proceed. This energy can be provided by several methods. In thermal CVD the reaction is activated by a high temperature above 900°C. A typical apparatus comprises of gas supply system, deposition chamber and an exhaust system. In

plasma CVD, the reaction is activated by plasma at temperatures between 300°C and 700°C [4].

### 2.4. Mechanical Attrition

Mechanical attrition produces its nanostructures not by cluster assembly but by the structural decomposition of coarser grained structures as a result of plastic deformation. The ball milling and rod milling techniques belong to the mechanical alloying process which has received much attention as a powerful tool for the fabrication of several advanced materials. Mechanical alloying is a unique process, which can be carried out at room temperature [5].

### 2.5. Chemical Precipitation

In this strategy the size is control by arrested precipitation technique. The basic trick has been to synthesize and study the nano material in situ *i.e.* in the same liquid medium avoiding the physical changes and aggregation of tiny crystallites. Thermal coagulation and Oswald ripening were controlled by double layer repulsion of crystallites using non-aqueous solvents at lower temperatures for synthesis [6].

### 2.6. Sol-Gel Techniques

In addition to techniques mentioned above, the sol-gel processing techniques have also been extensively used. Colloidal particles are much larger than normal molecules or nanoparticles. However, upon mixing with liquid colloids appear bulky whereas the nano sized molecules always look clear. It involves the evolution of networks through the formation of colloidal suspension (sol) and gelatin to form a network in continuous liquid phase (gel) [7].

## 3. GREEN SYNTHESIS OF NANOPARTICLES

Green synthesis is a very efficient way to synthesize nanoparticles. It is basically a bottom up approach but here expensive, toxic chemical reducing agents were replaced by green eco-friendly extract where reduction and stabilization occurs by the help of natural components, like phytochemicals, microorganisms etc. The biological reduction of metal precursors to synthesize nanosized material is eco-friendly, budget friendly [8, 9], higly stable [10] and can be used for production in bulk [11]. Green synthesized nano-particles are free from toxic chemicals so it can be used as carrier of drug for better result in health related problems. Green nano-biotechnology is a very good alternative for synthesizing hazardous chemical free nano materials by using biological extracts e.g. phytochemicals, microorganisms etc. with the help of various biotechnological tools [12-15]. The green synthesized nanoparticles are 20 times more effective antimicrobial agents' compare to chemically synthesized nanoparticles [16]. Such increase in effectiveness is due to the presence of various natural stabilizing agents in biological extracts [17]. Due to high surface energy of nano particles, it prefers to aggregate to get stable morphology. The role of stabilizers is to make them disperse in solution so that they can not aggregate [18]. The use of plant extracts to synthesize nanomaterials is a very good choice because of the presence of different phytochemicals like polyphenol, flavonoids, carbo-hydrtaes etc as a good reducing and stabilizing agents [19]. Presence of such stabilizer regulates the growth and also inhibits the coagulation or aggregation process [20]. Flavonoids for e.g. flavonols, chalcones, flavones etc. are polyphenolic compounds which can chelate and reduce the metal ions ($Ag^{+}$, $Cu^{2+}$ etc.) to nanoparticles. Again different monosaccharides and polysachharides can reduce the metal ions to nano particles by the help of their free aldehyde group [21].

## 4. CHARACTERIZATION OF SILVER NANO-PARTICLES

Formation of stable silver nanoparticles was confirmed and characterized by using different techniques. It is very important to characterize silver nanoparticles for its application to different biological and chemical field. Initial characterization of silver nanoparticles (Ag-Np) was performed by using UV-Vis spectroscopy. Once Ag-Np is formed, it showed an absorption peak in the wavelength region of 420-460 nm due to surface plasmon resonance. Fourier transform infrared spectroscopy (FTIR) was used to find out the presence of functional groups which are involved in reduction and stabilization of silver nanoparticles. Formation of silver nanoparticles using *S. torvum* leaf extract was characterized by using FTIR which shows peaks at 1648, 1535, 1450 and 1019 $cm^{-1}$ and it was found that the peak at 1450$cm^{-1}$ (-COO-) for carboxylate ions was one of the stabilizing factor for the silver nanoparticles. Other techniques such as powder X-ray diffractometry (XRD), dynamic light scattering (DLS), transmission and scanning electron microscopy (TEM, SEM), atomic force microscopy (AFM) were also used for Ag-Np characterization [22-24].

The wavelength of X-rays is on the atomic scale, so powder X-ray diffractometry technique was used to

find out the crystalline nature of the particles. Dynamic light scattering helps to find out the hydrodynamic diameter of the nanoparticles and provides information on the aggregation state of the Ag-Np in solution. SEM and TEM were used to find out the morphology and size of the particles and it was found that in most of the cases the shape of silver nanoparticles is spherical. Atomic Force Microscope (AFM) offers visualization and help to analyze the Ag-Np in three dimensional structures. So by using AFM one can measure the volume of Ag-Np.

## 5. APPLICATION OF SILVER NANO-PARTICLES

Silver nanoparticles are very effective agent to destroy microorganism. Many researchers are working in this field and from their reports it was found that silver nanoparticles play an important role to inhibit the growth of bacteria, specially the growth of gram negative bacteria. Silver nanoparticles work by interacting with the bacterial cell membrane and can also penetrate the cell of the bacteria although the exact mechanisms of antimicrobial activity by silver nano-particles are still not well known. But according to the studies of some researchers, $Ag^+$ ions form complex with nucleosides or may undergo electrostatic interactions with negatively charge bacterial cell to destroy it [25-28]. In case of silver nanoparticles (AgNP) these silver ions can come from can come from ionizing the surface of a solid piece of silver. Antibacterial activities of the silver nanoparticles were determined by the well dilution (cup plate method), broth dilution (MIC: Minimum Inhibitory Concentration) assay and MBC (Minimal Bactericidal Concentration) assay (in triplicate set). Different bacterial strain like *E. coli*, *Staphylococcus aureus*, *Bacillus subtilis* were used as inoculant and grown at 37°C to get OD 0.6 at 600 nm. Lowest concentration, which inhibited any visual growth, was considered to be MIC with respect to various reference antibiotics for e.g. tetracycline (TET), streptomycin (STP), ampicillin (AMP). Various factors like type of microorganisms, temperature, pH and $AgNO_3$ concentration are the controlling factors for antimicrobial activity by silver nanoparticles [29]. Among all the above mentioned factors, the concentration of AgNP is the key factor as with increasing concentration there is increase in antimicrobial activity. This is due to increase in effective surface area of smaller size AgNP for interaction with the microbes [30].

Apart from antimicrobial activity, silver nanoparticles have wide applications in different fields like food industry, cosmetic industry, textile industry etc. Silver nanoparticles show greater catalytic property for many chemical reactions for e.g. in the area of dye reduction and their removal [31, 32]. Silver nanoparticles were also used as a biosensor like other nanoparticles. The size and shape of nano materials makes them efficient biosensor as they have most of their constituent atoms located at or near their surface and their physicochemical properties are totally different from the bulk scale. The fundamental principle for coloured based biosensor is the Surface Plasmon Resonance (SPR) spectroscopy [33].

Silver nanoparticles can also act as good antioxidant agent. Antioxidants protect cells against the damaging effects of reactive oxygen species otherwise called, free radicals which results in oxidative stress leading to cellular damage [34]. Free radicals are highly reactive and can damage the healthy cells by lose their structure and function [35]. Free radicals were previously reported as being capable of damaging a lot of cellular components such as proteins, lipids and DNA [36]. Antioxidant blocks the chain reaction of free radical by supplying the hydrogen ion. According to Haes and Van Duyne, 2002 silver nanoparticles synthesized from aqueous extract of *P. longum* fruit showed *in vitro* effective antioxidant power [37]. Also from the report of another group of scientists, the biosynthesized silver nanoparticles showed powerful antioxidant activity [38].

## 6. PLANT MEDIATED SYNTHESIS OF SILVER NANOPARTICLES

Plant mediated green synthesis of silver nanoparticles is a very efficient, quick, economical and environment friendly process comparable to chemical process as there is no use of harmful chemical like sodium borohydride. The natural reducing agents and stabilizer from plant sources are the key agents for synthesizing silver nanoparticles. Different portions of plants are used to prepare extracts for the synthesis of these nanoparticles (Fig. 2). Different group of researchers had extensive works on silver nanoparticles synthesis, characterization and its applications. The syntheses of Ag-NP from plants of five different plant families and its characterization and application are discussed briefly in this review (Table 2).

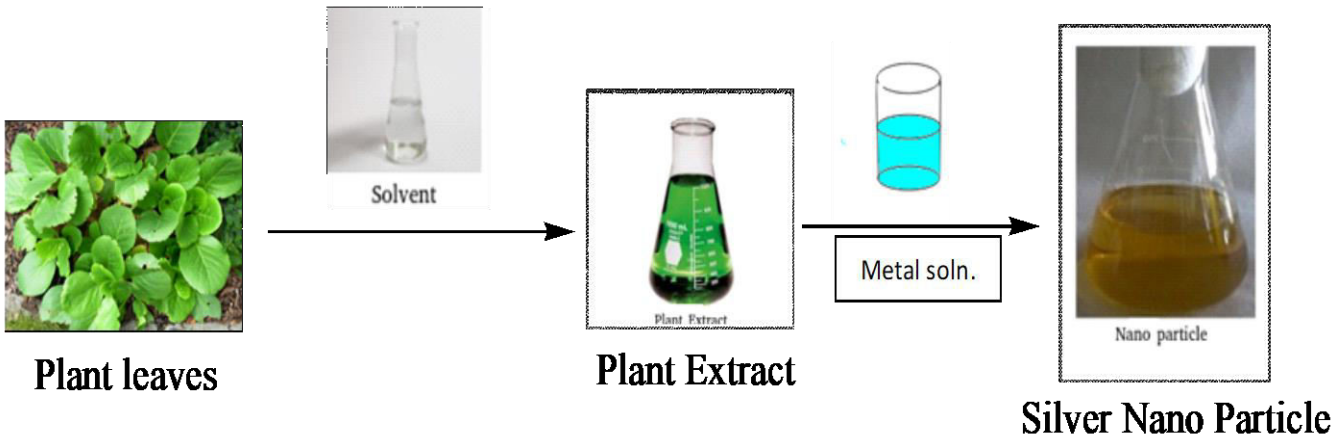


**Fig. 2: Schematic diagram represents the formation of nano particles form plant extracts**

**Table 2: Plant mediated synthesis and applications of silver nanoparticles by different researchers from five different families**

| Family: Euphorbiaceae | | | | | | |
|---|---|---|---|---|---|---|
| **Sl No.** | **Plants under investigation** | **Plant's part** | **Characterization Techniques of Ag-Np** | **Size and shape of Ag-Np** | **Application of Ag-Np** | **Ref.** |
| 1 | *Euphorbia hirta* | Leaves | UV-VIS, SEM | 40-50 nm and Spherical shape | Antibacterial activity | [39] |
| 2 | *Securinega leucopyrus* | leaves and fruits | UV-VIS, FTIR, SEM,TEM | 11-20 nm and spherical to oval | Antibacterial activity | [40] |
| 3 | *Euphorbia Tirucalli* | Stem | UV-VIS, FTIR, FE SEM, XRD | Avg. Size 24 nm and Spherical shape | Antimicrobial activity | [41] |
| 4 | *Euphorbia amygdaloides* | Whole plant | UV-VIS, SEM, XRD | 7-20 nm and Spherical shape | Antibacterial activity | [42] |
| 5 | *Euphorbia antiquorum L* | Latex | UV-VIS, FTIR, SEM, TEM, EDAX, XRD | 10-50 nm and Spherical shape | Antimicrobial activity and cytotoxic activity | [43] |
| 6 | *Euphorbia milii* | Leaves | UV-VIS, FTIR, SEM,TEM | 20-50 nm and Spherical shape | Antibacterial activity | [44] |
| **Family: Bignoniaceae** | | | | | | |
| **Sl No.** | **Plants under investigation** | **Plant's part** | **Characterization Techniques of Ag-Np** | **Size and shape of Ag-Np** | **Application of Ag-Np** | **Ref.** |
| **1** | *Tecoma Stans (L.)* | Leaves | UV-VIS, FTIR, SEM, XRD, EDX,TEM | 5-30 nm and Spherical shape | No report | [45] |
| **2** | *Millingtonia Hortensis* | Flower | UV-VIS, FTIR, SEM, XRD, EDX | 10-40 nm, spherical and rod in shape | Antibacterial activity | [46] |
| **3** | *Stenolobium stans L.* | Flower | UV-VIS, FTIR, SEM, DLS | 7.8-45.3 nm, spherical and cuboid in shape | No report | [47] |
| **4** | *Tecomella undulata* | Leaves | UV-VIS, SEM, EDX, AFM, DLS | 32-46 nm and Spherical shape | No report | [48] |
| **5** | *Tecoma capensis* | Leaves | UV-VIS,FTIR,SEM, XRD | 23-47 nm and Spherical shape | Antibacterial activity | [49] |
| **6** | *Tabebuia argentea* | Flower | UV-VIS, FTIR, SEM, XRD | 20-30 nm and Spherical shape | Antibacterial activity | [50] |

| Family: Rhamnaceae | | | | | | |
|---|---|---|---|---|---|---|
| **Sl No.** | **Plants under investigation** | **Plant's part** | **Characterization Techniques of Ag-Np** | **Size and shape of Ag-Np** | **Application of Ag-Np** | **Ref.** |
| 1 | *Ziziphus jujuba* | Leaves | UV-VIS, XRD, FT-IR, TEM, DLS and Zeta potential. | 20-30 nm | Antimicrobial activity and catalytic activity | [51] |
| 2 | *Zizyphus xylopyrus* | Bark | UV-VIS, SEM, EDX | 60-70 nm, spherical | No report | [52] |
| 3 | *Ziziphus spina-christi* | Leaves | UV-VIS, FE-SEM, XRD | 30-70nm | Antibacterial activity | [53] |
| 4 | *Ventilago Maderaspatana* | Leaves | UV-VIS, FTIR, SEM | spherical | No report | [54] |
| 5 | *Ziziphus Nummularia* | Leaves | UV-VIS, SEM, SPR, TEM | 200 nm, Spherical | Antibacterial activity and Antioxidant activity | [55] |
| 6 | *Ziziphus mauritiana* | Leaves | UV-VIS, FTIR, SEM, | 15-35 nm, Spherical | Antibacterial activity | [56] |
| **Family: Fabaceae** | | | | | | |
| **Sl No.** | **Plants under investigation** | **Plant's part** | **Characterization Techniques of Ag-Np** | **Size and shape of Ag-Np** | **Application of Ag-Np** | **Ref.** |
| **1** | *Acacia concinna* | Fruit | UV-VIS, FTIR, TEM | 10-35 nm, Spherical | Antibacterial activity | [57] |
| **2** | *Mimosa Pudica* | Root | UV-VIS, FTIR, SEM, TEM, EDAX, XRD | ~35 nm, Spherical | Antibacterial Activity and Electro-chemical Detection of Dopamine | [58] |
| **3** | *Pongamia pinnata* | Bark | UV-VIS, SEM, TEM, XRD | 5-15 nm and 22-25 nm, Spherical | Antimicrobial activity | [59] |
| **4** | *Erythrina suberosa (Roxb.)* | Leaves | UV-VIS, FTIR, DLS, TEM | 15-34 nm, Spherical | Antimicrobial activity and Cytotoxic Activity | [60] |
| **5** | *Clitoria ternatea* | Leaves | UV-VIS, FTIR, XRD | 13.74 nm | Antibacterial and antifungal activity | [61] |
| **6** | *Pterodon emarginatus* | Leaves | UV-VIS, FTIR, DLS, TEM, MALDI-TOF, XRD | 28-38 nm, Spherical | No report | [62] |
| **Family: Apocynaceae** | | | | | | |
| **Sl No.** | **Plants under investigation** | **Plant's part** | **Characterization Techniques of Ag-Np** | **Size and shape of Ag-Np** | **Application of Ag-Np** | **Ref.** |
| 1 | *Adenium obesum* | Leaves | UV-VIS, AFM, cyclic Votametry | 75.2 and 55.7 nm | Antibacterial activity | [63] |
| 2 | *Allamanda cathartica L.* | Leaves | UV-VIS, SEM, TEM, EDAX, AFM | 19-40 nm, Spherical | Antimicrobial activity | [64] |
| 3 | *Catharanthus roseus* | Leaves | UV-VIS, XRD, FTIR, AFM | 10-88 nm | Antioxidant, Antimicrobial and wound healing activity | [65] |
| 4 | *Plumeria rubra* | Flower | UV-VIS, TEM | 20-80 nm, spherical and irregular | Antimicrobial activity | [66] |
| 5 | *Cynanchum viminale* | Whole plant | UV-VIS, SEM, EDAX | ~ 60-68 nm (agglomerated) | No report | [67] |
| 6 | *Cynanchum sarcomedium* | Whole plant | UV-VIS, SEM, EDAX | ~ 60-85 nm, Spherical | No report | [67] |

### 6.1. Euphorbiaceae family: Synthesis, Characterization and Application of Ag-NP

An efficient and cost effective synthesis of silver nanoparticles was reported by Elumalai et al., 2010 from the aqueous extract of leaves of *Euphorbia hirta*. Formation of silver nanoparticles was confirmed by appearance of dark-yellowish brown colour. Absorbance peak at 430 nm with peak broadening in UV-Vis spectrograph is the characteristic of silver nanoparticles. SEM analysis revealed a diameter range of

40-50 nm of silver nanoparticle with spherical shape. Agar well diffusion assay method was used to find out the antibacterial activity of the synthesized Ag nanoparticles. The toxicity of AgNP was maximum against *B. cereus* and *S.aureus* compare to other bacterial stain [39].

Manisha et al., 2013 reported the synthesis of silver nanoparticles using 1 mM $AgNO_3$ solution and the aqueous extracts of leaves and fruits of *Securinega leucopyrus* plant. FTIR spectra showed that carbonyl (-C=O), hydroxyl (-OH) and amine ($-NH_2$) groups are involved in formation of this silver nanoparticles. The formed AgNP was spherical to oval in shape and size range in between 11-20 nm was found by SEM and TEM analysis. These synthesized particles have also shown considerable anti bacterial activity against different human pathogens like *Pseudomonas aeruginosa, Bacillus subtilis, Klebsiella pneumonia* etc. [40].

Another study reported the synthesis of silver nanoparticles using the aqueous extract of stem of *E. Tirucalli* plant [41]. AgNP was characterized by different techniques like UV-VIS, FTIR, FE SEM, XRD. SEM analysis showed that synthesized silver nanoparticles were in spherical shape and average size of the particles was 24 nm. The green synthesized silver nanoparticles showed toxicity against human pathogens such as Gram positive bacteria *Staphylococcus aureus, Bacillus subtilis* and Gram negative bacteria *Pseudomonas aeruginosa* and *E. coli* [68-70]. The Gram negative bacterium *E. coli* showed maximum zone of inhibition as the cell wall of Gram negative bacteria composed of thinner peptidoglycan layer [71].

Plant mediated green synthesis of silver nanoparticles by peroxidise from *Euphorbia amygdaloides* of Euphorbiaceae family was reported by Cicek et al., 2015. Peroxidase enzyme was partially purified by ammonium sulphate precipitation of plant homogenate. The size of the AgNP was 7 to 20 nm and spherical in shape which was characterized by SEM and XRD studies. This research finding reported that room temperature, pH 6 and increasing concentration of silver nitrate favoured the synthesis of silver nanoparticles. The antibacterial affect of the synthesized AgNP was studied using the disc diffusion method against *Serratia marcescens, Yersinia pseudotuberculosis*, *Klebsiella pneumoniae, Staphylococcus aureus, Staphylococcus epidermidis, Streptococcus pyogenes, Pseudomonas aeruginosa, Salmonella typhimurium, Listeria monocytogenes*, and *Escherichia coli* O157:H7. The study showed that AgNPs are found to have highest antimicrobial activity against *Klebsiella pneumonia* (19.0 mm), *Yersinia pseudotuberculosis* (18.5mm), and *Salmonella typhimurium* (18.5 mm) [42].

A facile synthesis of well-dispersed spherical silver nanoparticles with size ranging from 10 to 50 nm from latex extract of *Euphorbia antiquorum L.* was reported by Rajkuberan et al., 2015. UV-Vis spectrum showed the Surface Plasmon Resonance (SPR) peak at 438 nm. FTIR analysis shows that phenolic constituents play a major role in reduction and stabilization of the nanoparticles and from XRD study it was observed that AgNPs were face centered cubic (fcc) crystalline in nature. The synthesized silver nanoparticles showed various activities like antimicrobial against different human pathogens, larvicidial activity against *Culex quinquefasciatus* and *Aedes aegypti (*IIIrd instar larvae*)* and anticancer activity against human cervical carcinoma cells (HeLa) [43].

The dried leaf extract of *Euphorbia milli* was mixed with 1 mM $AgNO_3$ in order to synthesize silver nanoparticles. The formation of AgNP was characterized by UV-Vis spectrophotometer, FTIR, SEM and TEM analysis. The UV-Vis absorption showed the absorption maxima ranged from 425 to 475 nm which is characteristics of AgNPs. FTIR analysis confirmed the presence of functional groups like carbonyl (-C=O), hydroxyl (-OH), amine ($-NH_2$) etc. and also the presence of reducing and capping agent in plant extract which are associated in formation of AgNP. SEM and TEM analysis characterization confirmed that synthesized AgNP were mostly spherical and sized range in between 20 to 50 nm. Silver nanoparticles synthesized from *E. milii* leaves exhibited good antibacterial activity against different Gram-positive and Gram-negative bacteria [44].

### 6.2. Bignoniaceae family: Synthesis, Characterization and Application of Ag-NP

Arunkumar et al., 2013 reported the synthesis of spherical shape AgNP of sized between 5-30 nm from the leaf broth of *Tecoma stans* (Family: Bignoniaceae). The synthesized silver nanoparticles were preliminary confirmed by observing the Surface Plasmon Resonance (SPR) vibrations between 390 nm and 450nm with the $\lambda_{max}$ at 430 nm. By comparing the FTIR spectra after and before the reaction, they reported that different phytochemicals were responsible for reducing silver nitrate to form silver nanoparticles. From Atomic absorption spectroscopy analysis showed the yield of silver nanoparticles was 1.40 mg of silver nanoparticles from per gram of dry leaves [45].

Another efficient method of synthesis of silver nano-

particles was reported by Gnanajobitha et al., 2013 from Bignoniaceae plant family. AgNP was synthesized by incubating 1mM $AgNO_3$ solution with aqueous extract of flowers of *Millingtonia Hortensis*. UV-Vis spectrum showed strong surface plasmon resonance band positioned at 460 nm which is characteristics of AgNP. Presence of strong absorption bands about at 3313.48, 3195.83, 1670.24, 1400.22, 1193.85, 1118.64, 651.89, 601.75 $cm^{-1}$ were indicative of different functional groups like Alkyne ≡ C–H , alcohols & phenols (O-H), Carbonyl C=O, alkanes (C-H), alcohols etc. which acted as reducing and capping agent. SEM analysis study showed that presence of 10-40 nm sized spherical and rod shaped silver nanoparticles. The synthesized AgNP had shown strong antibacterial activity against *B. subtilis* and *K. planticola* [46].

Another eco-friendly synthesis of silver nanoparticles was reported from aqueous floral extract of Stenolobium stans of Bignoniaceae family. The UV-visible spectrum showed $\lambda_{max}$ at 455 nm of the reduced silver nitrate solution. The bio-reduction of $Ag^+$ ion by phenolic compounds present in the extract was confirmed through FTIR. The presence of silver was recorded through EDS and SEM study recorded the size of the AgNP in the range 7.8 to 45.3 nm. The average size range of 28.51 nm was analyzed by the zeta particle analyzer [47].

The dried leaf extract of *Tecomella undulate* was used to synthesize 32-46 nm and spherical shape AgNP from 1mM $AgNO_3$ solution. The UV-Vis spectrum shows the peak near 430 nm and which remain unaltered with different interval of time indicting the stability and uniformity of silver nanoparticles synthesis. The DLS pattern of the synthesized nanoparticles showed two peaks at 5.8 nm (5%) and 77.48 nm (95%). The high negative zeta potential value (-16.0 mV) indicates that synthesized AgNP are highly stable due to electrostatic repulsive force. The sizes of the nanoparticles were measured through scanning electron microscopy and the purity was confirmed by electron dispersive X-ray spectroscopy (EDS) [48].

Green synthesis of silver nanoparticles by bio-reduction method from leaves extracts of *Tecoma capensis* was reported by Vinay and Chandrasekhar, 2017. The synthesized AgNPs was characterized by some well known techniques including UV-Vis, FTIR, XRD & SEM. Broad UV-Vis spectrum at 382nm confirmed the synthesis of AgNPs. FTIR analysis showed absorbance bands at 3279 $cm^{-1}$, 2912 $cm^{-1}$, 1642 $cm^{-1}$, 1060 $cm^{-1}$, 758 $cm^{-1}$ and 540 $cm^{-1}$ respectively for alcohol O-H, alkane C-H, imine C=N, primary alcohol C-O and halo compound C-I. These functional groups are involved in the bio reduction of $Ag^+$ to AgNP. The spherical morphology along with size range 23 to 47 nm and average diameter of 31.9 nm were ascertained by SEM analysis [49].

The spherical shape silver nanoparticles of an average size 22.87 nm were synthesized from *Tabebuia argentea* is a genus of flowering plants in the family Bignoniaceae. A brown colour solution was formed which had Surface plasmon resonance (SPR) peak at 340 nm in UV-Vis spectrum. Absorbance bands on FT-IR analysis were observed at 3,701, 3380, 2925, 3333, 1618, 1387, 1070, and 601 $cm^{-1}$. The antibacterial assay was performed by standard well diffusion method against different bacterial pathogens *like Pseudomonas aeruginosa, Klebsiella aerogenes, Staphylococus aureus* and *E-coli*. The synthesized Ag NPs showed significant toxicity against the gram-positive and gram-negative bacteria [50].

### 6.3. Rhmnaceae family: Synthesis, Characterization and Application of Ag-NP

Gavade et al., 2014 reported an eco-friendly synthesis of silver nanoparticles from leaf extracts of *Ziziphus jujuba*. There was appearance of AgNP characteristic Surface plasmon resonance (SPR) absorption band at $\lambda_{max}$ 434 nm in UV-Vis spectrum. FT-IR analysis reported the presence of different phytochemicals which were involved in bio-reduction of silver ion and capping of AgNP. The formed nanoparticles were face centered cubic (fcc) crystalline in nature and sized range in between 20 to 30 nm. DLS study reported the hydrodynamic size of 28 nm and high negative Zeta potential of -26.4 mV indicated the stability of AgNPs in colloidal state. The formed AgNPs not only showed catalytic activity for the reduction of methylene blue and 4-Nitrophenol but also showed toxicity against *E. coli* [51].

Another efficient biosynthesis of silver nanoparticles from bark extracts of *Zizyphus xylopyrus* was reported by Maria et al., 2015. At pH 11 bio-reductions of $Ag^+$ ion is maximum. Surface plasmon resonance absorbance peaks in the range 413-420 nm in UV-Visible spectrum confirming the formation of silver nanoparticles. Capping of AgNPs by the phytochemicals was suggested by EDX analysis. SEM study revealed that the formed AgNPs were spherical and sized range between 60 to 70nm [52].

In this study silver nanoparticles were synthesized using aqueous *Ziziphus spina-Christi* leaves extract. Appearance

of reddish brown colour solution indicates the bio reduction of $Ag^+$ ion to silver nanoparticles. This was further confirmed by noticing the surface plasmon resonance (SPR) absorption peak at wavelength around 442 nm. Morphology study by FESEM analysis reported that the particle sizes located in the range of 30-70 nm. The results of XRD study clearly indicated that the formed AgNP was face centered cubic (fcc) crystalline in nature. The growth inhibitory effect of AgNP was performed against different micro-organism. The result showed that AgNP was very effective against gram positive and gram-negative bacteria and *K. pneumoniae* was the most sensitive organism [53].

This work reported an eco-friendly synthesis of silver nanoparticles using leaf extract of *Ventilago maderaspatana* from Rhamnaceae family. Appearance of dark brown colour and absorbance maxima at 431 nm confirmed the bio-reduction of $Ag^+$ to form silver nanoparticles. The IR bands at 3437.27, 2366.57, 2079.87, 1637.47, 1367.12, 1225.41, 1015.75 and 672.27 $cm^{-1}$ suggested the presence of different phytochemicals which were acting as reducing agents. SEM analysis revealed that the formed AgNPs are spherical in shape [54].

This is another rapid biogenic approach for the synthesis of silver nanoparticles from aqueous leaf extract of *Ziziphus nummularia*. Formation of intense yellow solution and absorption band at 438 nm indicated the presence of silver nanoparticles. According to the SEM analysis, formed AgNPs were spherical and size was 200 nm. Silver nanoparticles showed antibacterial activity against *Streptococcus mutans* & *Staphylococcus aureus*. Apart from that it had an antioxidant activity against DPPH [55].

Asimuddin et al., 2020 reported the green synthesis of silver nanoparticles from aqueous solution of *Ziziphus mauritiana* leaves extract. Absorption band at 413 nm indicates the presence of silver nanoparticles. According to this report optimum temperature and time for the synthesis of good quality AgNP were 65°C and 15 minutes respectively. From TEM analysis data it was assumed that particles are of spherical shape with small size ranging from 3-20 nm. Elemental composition analysis by EDX method indicated the presence of Ag as major element in the sample. Formed AgNPs showed antibacterial activity against different gram positive and gram negative bacteria like *S. aureus, B. subtilus*, *P. aeruginosa* and *E. coli* but it was more selective against a gram positive, *S. aureus,* bacterial strain [56].

### 6.4. Fabaceae family: Synthesis, Characterization and Application of Ag-NP

A group of researcher reported green and economic friendly synthesis of silver nanoparticles from *Acacia concinna* fruit extract of Fabaceae family [57]. A silver nitrate solution of 4 mmol $L^{-1}$ concentration was prepared to bio reduce by phytochemicals. Bio-reduction to form AgNPs was ascertained by observing dark brown colour in aqueous solution and SPR absorbance peak at 450 nm in UV-Vis spectrum. It was evident from TEM study that particle size ranged from 10 nm to 35 and the average size estimated was 18 nm. The antibacterial activity of AgNPs was analyzed against *Escherichia coli* by Agar Well Diffusion Method. It showed very good toxicity as the nanoparticles had larger surface area for interactions [57].

This study reported the green synthesis of silver nanoparticles from the root extract of *Mimosa Pudica* plant of Fabaceae family. The dark brown colour solution showed an absorbance band at about 430 nm wavelength to confirm the formation of AgNPs. Absorption band at 3314.24, 2128.46, 1636.26 and 583.23 $cm^{-1}$ in FTIR spectrum indicate the presence of different functional groups which were responsible for bio-reduction of $Ag^+$ ion. Also the capping of the AgNPs by proteins indicated by the broadening of amide I band at 1636.26 $cm^{-1}$. The TEM analysis reported that the formed AgNPs are spherical in shape and average diameter was approximately 35 nm. SEM study also supported that speherical morphology of nanoparticles. The diffraction peaks at $2\theta$ = 38.28°, 44.33°, 64.33° and 78.53° in XRD study supported Face Centered Cubic (FCC) structure of AgNPs. The synthesized AgNPs were toxic against microorganisms like organisms like *Escherichia coli*, *Bacillus subtilis* and *Pseudomonas aeruginosa* but toxicity is high for *Escherichia coli*, *Bacillus subtilis*. Again Cyclic Voltammetry (CV) experiment showed the excellent conductivity of AgNPs which was used to prepare electrochemical sensor for detection of Dopamine [58].

Another simple, efficient and less toxic method of synthesis of silver nanoparticles from fresh bark of *Pongamia pinnata* was reported by Rajeshkumar, 2016. Preliminary visual identification was the appearance of dark brown colour solution of silver nitrate after 10 minutes incubation with the plant extract. Surface Plasmon Resonance (SPR) absorbance peak at 420 nm in UV-Vis spectrum confirm the formation of AgNPs. Elemental analysis by EDAX was performed to confirm the formation of metallic silver nanoparticles in the

reaction mixture. SEM analysis revealed that the synthesized silver nanoparticles were predominantly spherical in shape. The small sized AgNPs ranged from 5 to 15 nm and large sized ranged from 22 to 55 nm were observed in the TEM image. There was formation of some undefined shapes with slight aggregation due to the presence of phytochemicals like phenolic amides, piperine, polysaccharides and other reducing sugars [72, 73]. The synthesized silver nanoparticles showed maximum antimicrobial activity against *K. planticola* (Gram negative bacterium) compared to *S. aureus* (Gram positive bacterium) [59].

Mohanta et al., 2017 reported the green synthesis of silver nanoparticles from Leaf Extract of *Erythrina suberosa* (Roxb.). Just like other studies they also reported dark brown coloration of silver nitrate solution after addition of plant extract and also $\lambda_{max}$ at 428 nm in UV-Vis spectrum. In FT-IR spectrum appearance of strong absorption band 3740 $cm^{-1}$ indicates the presence reducing polyphenolic compounds. The average hydrodynamic size by DLS study of synthesized AgNPs was ~73 nm. The negative Zeta potential value of -15.8 mV was indicative to explain its stability in solution. The TEM image showed spherical shaped silver nanoparticles having diameter range 15-34 nm. Anti-microbial activity of synthesized AgNPs by agar-cup method showed zone of inhibition against *P. aeruginosa*, *S. aureus, C. kruseii* and *T. mentagrophytes*. The nanoparticles showed Cytotoxic activity against A-431 Carcinoma osteosarcoma cell line. Apart from that it also exhibited wound healing capacity for BJ-5Ta cells [60].

For the synthesis of silver nanoparticles Nigam and Singh, 2018 mixed *Clitoria ternatea* plant extract with 1mM $AgNO_3$ solution. Silver nitrate solution was turned to deep brown and showed broad absorption band in 400 to 450 nm wavelength range. FTIR spectrum showed different absorption bands for carbonyl, -NH, -OH functional groups which acted as a reducing agent and also capping agent. XRD (X-RAY Diffraction) Analysis reported the size of AgNP to 135.0 Å. Silver nanoparticles showed antibacterial activity against *Staphylococcus aureus, Mycobacterium luteus* and *Klebsiella pneumonia* and antifungal activity against *Colletotrichum, Aspergillus niger* and *Candida albicans* [61].

Another green synthesis of silver nanoparticles was reported from aqueous extracts of *Pterodon emarginatus* leaves by Oliveira et al., 2019. Its formation was confirmed by observing spectral bands around the wavelength of 400-425 nm in UV-Vis spectrum. Colloidal stability and surface zeta potential were analysed by DLS and result showed that formed AgNPs were stable even after 5 months of production. The TEM images showed that the formed nanoparticles of summer and winter season were round in shape with dry diameters of 33.20±4.85 nm and 28.10±6.20 nm. The qualitative analyses of the FTIR reported the presence of different phytochemicals which reduced the $Ag^+$ ion to Ag°. Again molecular profiles assessed by MALDI-TOF mass spectrometry helped us to understand the complete profile of season wise abundance of phytochemicals associated to form silver nanoparticles. XRD data also helped to understand the crystalline nature of formed silver nanoparticles [62].

### 6.5. Apocynaceae family: Synthesis, Characterization and Application of Ag-NP

Biosynthesis of silver nanoparticles from leaf extract of *Adenium obesum* of Apocynaceae family was reported by Li et al., 2013. UV-Vis absorption maximum in the range 440-460 nm and appearance of dark brown solution were the indication of formation of silver nanoparticles. AFM study reported the existence of nanostructures with the average size range of 55.7nm to 75.2nm. Cyclic voltametry showed good conductance value of AgNPs. Silver nanoparticles synthesized from silver nitrate using 5% leaf extract showed good antibacterial activity against *Escherichia coli* [63].

Another rapid eco-friendly synthesis of silver nanoparticles was reported from the aqueous leaf extract of *Allamanda cathartica*. Within 10 minutes of incubation of 1mM $AgNO_3$ with plant extract there was appearance of signatory brown colour due to surface Plasmon resonance of AgNPs. Broad absorbance peak in the range 320-400 nm in UV-Vis spectrum indicated that the particles were polydispersed. The presence of elemental silver was also confirmed by EDAX analysis. SEM image showed spherical morphology with size ranged from 20 to 40 nm. The synthesized nanoparticles showed antimicrobial activity against different micro-organisms like *Klebsiella pneumonia, Escherichia coli, Bacillus subtilis*, *Aspergillus niger* etc [64].

Another efficient biosynthesis of silver nanoparticles (AgNPs) from *Catharanthus roseus* leaf extract was carried out by using silver nitrate solution [65]. Formation of silver nanoparticles was characterized by observing absorbance peak at 425 nm in UV-Vis spectrum. The FT-IR absorbance peak at 3434, 2024, 1624, and 1213 $cm^{-1}$ confirmed the role of different

phytochemicals as reducing and stabilizing agents. XRD patterns corresponding to (122), (111), (200), and (220), respectively were indicative of face-centered-cubic crystalline structure of synthesized silver nanoparticles. AFM study reported crystalline particles with grains sized 10-88nm in diameter with mean size of about 49 nm. The formed AgNPs of 300 μg $mL^{-1}$ concentration exhibited 82% antioxidant activity against DPPH. The smaller size of AgNPs exhibited better toxicity against different pathogens like *E. coli, C. koseri, K. pneumonia, P. aeruginosa, S. aureus* and *C. albicans* compare to larger $Ag^+$ ions. AgNP-treated wound in male albino mice was recovered greatly compare to untreated one. This wound healing capacity of AgNPs was due to promotion of reproduction and migration of keratinocytes [74] and boost up the repair of fibroblasts into myofibroblasts [75].

Mandal, 2018 reported a simplified and efficient synthesis of silver nanoparticles from *Plumeria rubra* flower extract. On bio-reduction of 0.25M $AgNO_3$ solution, appearance of dark brown colour solution which showed maximum absorption peak at 450 nm in UV-Vis spectrum. The TEM image showed that the shape of the nanoparticles was spherical and in the size ranged between 20-80 nm. The synthesized AgNPs showed toxicity in agar plate against *Bacillus sp.* and *E. coli* colonies [66].

A comparative study on synthesis of silver nanoparticles was performed for two plants *Cynanchum viminale* and *Cynanchum sarcomedium* of Apocynaceae family by Bhagyanathan and Thoppil, 2018. *C. viminale* produced deep brown colour solution whereas *C. sarcomedium* gave light brown solution from colourless silver nitrate solution. UV-Vis spectrum exhibited absorbance maxima 460 to 505 nm and 400 nm respectively for *C. viminale* and *C. sarcomedium*. These differences in colour and $\lambda_{max}$ are due to morphology, size and agglomeration formation in the surrounding media. EDAX analyses confirm the presence of elemental silver in AgNPs synthesized from both these plants. SEM images of *C. viminale* synthesized nanoparticles were spherical and size range distribution from ~60-68 nm whereas *C. sarcomedium* produced AgNPs in the size range between ~60-85 nm [67].

## 7. CONCLUSION

In this review different medicinal plants from five different plant families were chosen to report green synthesis of silver nanoparticles. Preparation of silver nanoparticles by using aqueous plant extracts was a very efficient, rapid, economical and eco-friendly process. It was noticed from different reports of FT-IR studies that plant secondary metabolites played an important role for bio-reduction of $Ag^+$ to silver nanoparticles and also acted as good stabilizing agents of the formed nanoparticles. So further investigation may be carried out to identify and isolate the particular bio molecules which were responsible for formation and capping of AgNPs. Again these synthesized silver nanoparticles were very effective to inhibit the growth of different pathogens and also had cytotoxic and wound healing activity. So these nanosized particles will be a great future in drug delivery system in medicinal field.

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### *Conflict of Interest*

The author declares that there is no conflict of interest in submission of this manuscript.

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