Eco-friendly synthesis route of silver nanoparticle: A review

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Abstract. Nanotechnology is concerned with the production and use of nano-sized materials. In the development of nanotechnology, the synthesis of metal nanoparticles is a reliable and environmentally friendly step. At the present time, the use of the biosynthesis method in the development of metal nanoparticles has been developed as an alternative synthesis route, removing the limitations of traditional synthesis methods such as physical and chemical methods. In the biosynthesis process, researchers are facing challenges to synthesize stable and geometrically controlled Silver Nanoparticles (AgNPs). In the past few years, the plant-mediated synthesis method has proved to be important in the development of stable, low-cost and environment-friendly AgNPs and has been described by many researchers. In the past decade, silver nanoparticles (AgNPs) are the most studied and used nanoparticles due to their unique properties. In this review, we have discussed the eco-friendly synthesis route for the development of AgNPs and its application in various fields.

Keywords. Nanotechnology; biosynthesis method; metal nanoparticles; Silver Nanoparticles (AgNPs)

1. Introduction
Nanoscience is a new interdisciplinary and interesting subject that relies on the properties of nano-size objects. In the last few years, nanomaterials have attracted much attention in the field of science and technology. Researchers, through their research, have proved usefulness of nanomaterials in various fields such as healthcare, catalysis, chemical industry, biomedical, cosmetics, pharmaceutical-gene delivery, optics, health, mechanics, electronics, energy science, food and feed, environment, space industry, etc[1–6]. According to a previous study, nanotechnology is capable of addressing each of the challenges in various fields of science and engineering [7]. The word “nano” indicates the range in nanolevel, i.e. 10⁻⁹. The prefix “nano” is taken from the Greek language, whose meaning is “extremely small”[8]. So, the material whose physical dimension is in the range of scale 0.1 nm to 100 nm is called nano materials or nano crystalline materials. Becoming more specific the range is determined by parameter (h), which is called “Average minimum diameter of particle”. The particle will be nano particle if -

\[10^{-9} \text{ meter} < h < 10^{-8} \text{ meter}\]

So the most curial thing in nano science is measuring the size of the particle, that whether the particle size is coming in a range of nano scale or micro scale, which is generally determined by electron microscopy technique such as SEM and TEM. The wide applicability of nanoparticles is its size, structure, optical, chemical and physical properties. For example, many microorganisms have a size range in the nano meter scale, so if we will have antibacterial in the nano-size range, then it will be more...
effective on bacteria. The other examples are plasmonic characteristics of gold and silver nanoparticles are being used in bio-physical sciences and bio medical sciences[9], précised target subjected medicine delivery and diagnosis of disease by in vivo and in vitro techniques [10]. In the present review paper, we have focused on silver nanoparticles (AgNPs) which are considered to be one of the most potent antimicrobial agents. According to some recent studies, over the past decade AgNPs have been successful in detecting antibacterial and antifungal activity [11,12].

Silver is a tender, white, shiny transition metal with high electrical and thermal conductivity [13]. Silver has gained immense popularity in research institutes and in the medical field due to its medical benefits. It has been used in many forms since ancient times such as coins, utensils, solutions, foams, stitches, ointments, and lotions, etc. Silver is used as a therapeutic agent in a wide variety of medicines [13]. In recent years, silver nanoparticles have attracted special attention of the research society due to their physical, chemical and biological properties. Which are responsible for catalytic activity and bactericidal effects. As per literature, researchers found applications of AgNPs particles in nanobiotechnological research. Silver nanoparticles are used as antimicrobial agents for wound dressing creams and anticancer agents [13–16].

Various methods of manufacturing metallic nanoparticles are prevalent, in which chemical and physical manufacturing methods are popular. The above mentioned methods synthesized pure and well defined nanoparticles, but the chemical methods have several disadvantages because chemically synthesized nanoparticles are toxic, energy consuming, expensive, and not suitable for biological applications [16–19]. The synthesis of metal nanoparticles has gained more popularity in the last two-three decades. Over the past few years, it has been known that the properties and potential applications of nanoparticles vary with the phases, sizes, and morphology of these particles. Thus, the controlled synthesis of nanomaterials with novel morphology has attracted much attention.

This review presents a brief overview of the development of AgNPs that are synthesized by the biological synthesis route. In this review article, we have discussed the conditions governing the formation of nanoparticles, biosynthesis mechanisms, size/shape, and homogeneity of particles. In addition, we have discussed the properties and possible applications of silver nanoparticles. In the end of this study, future research on silver nanoparticles is discussed.

2. Research Trends
In the past decade, the popularity and importance of research on AgNPs has been increased. As per literature, in the first 20 decades researchers are focused for the preparation and characterization of AgNPs with chemical approaches. Physical and biological methodologies were additionally proposed due to their protected and green nature. There are a large number of explores and uses of green plant gum in the drug, cosmetic and food formulations and industries. Today, numerous works are focused on biological strategies and applications for a few purposes.

3. Synthesis of Silver Nanoparticles
There are various methods available to synthesis nanoparticle [16,20,21]. The function of biological synthesis of AgNPs utilizing microorganisms such as plants, fungi and bacteria is reported in various research papers. The literature suggests that the depletion of metal compounds in developed nanoparticles results in a decrease in their antioxidant properties. As we have known from old studies that different methods of AgNPs synthesis are prevalent but the microbe mediated synthesis method is not able to achieve industrial feasibility because this method requires very complex environment and conditions for their maintenance. The utilization of plant extracts in the synthesis of silver NPs will be easier and more effective than microorganisms. Currently, biosynthesis is most popular synthesis route for the development of NPs. In the past, the biosynthesis method has attracted a lot of attention by its simplicity, attractiveness, eco-friendly, and fast synthesis of nanoparticles with diverse morphology. Sometimes, it is difficult to maintain microbial cultures of materials by the biological synthesis process, so various plant materials and their extracts are used to simplify this process.
Currently, the synthesis of metallic nanoparticles is done by physical, chemical and biological methods. Physical and chemical methods are commonly used in the synthesis of nanoparticles. But in the present circumstances, synthesis of AgNPs by green synthesis is easy and low costive which meets the demand of the research community as well as being friendly with the environment. In this review, the biosynthesis method in the synthesis of AgNPs has attracted special attention from researchers due to its unique properties (eg, optical, antimicrobial, and electrical properties due to its size and shape).

### 3.1 Physical Method

As per literature, two physical methods are important: Evaporation-condensation and laser ablation, these are prominent in the synthesis of nanoparticles. Metal bulk materials can be synthesized by AgNPs by laser ablation method. The NPs synthesized by the laser ablation method depend on various factors that determine the ablation effectiveness and characteristics of the synthesized nano silver particle. Laser ablation is currently one of the most unique and effective physical methods. The major feature of this method is that it forms pure and clean metal nanoparticles without using chemical reagents.

### 3.2 Chemical Method

The chemical method is the most commonly used method in the synthesis of NPs, with the synthesis of AgNPs using organic and inorganic agents. Various chemical methods are prevalent in the synthesis of NPs such as chemical reduction, micro emulsion method, and micro synthesis method. Chemical methods use hazardous toxic chemicals, which have high risk in use and are never environmentally friendly. This becomes the reason to develop the environmental friendly processes through green synthesis and other biological approaches.

### 3.3 Green / Biosynthesis

Currently, development of NPs via biosynthesis approach shows their excellent characteristics such as eco-friendly behaviour, low cost, easy synthesis route, and excellent performance compared to physical and chemical synthesis method. This method relies on plant extracts and is completely free of toxic chemicals [22–24].

Basic rules for the synthesis of the nanoparticle includes the following steps. In the first step of this process, the plant or part of the plant (sample) is collected, after which the sample is thoroughly washed two or three times with the help of distilled water so that the dirt present in the sample is cleaned. Then, clean and fresh plant sources are dried for one to two week in dark and powdering it with blender. Now for preparing the broth of the plant, about 10 grams of dried powder is boiled with 100 mL of deionized distilled water. The obtained solution is then completely filtered until an insoluble material appears in the broth. After this, filtrate is collected and AgNO$_3$ solution is added to it at 1mM concentration. In addition, the shaking of the incubator is added to the mixture, which changes the color of the mixture to pure Ag$^+$ ions and reduces Ag0 ions. Subsequently, the nanoparticles of the obtained solution are monitored at regular intervals by UV-spectra to identify specific absorption properties. The obtained nanoparticles are studied with the help of various characterization techniques and potential applications of nanoparticles are presented.

According to earlier studies, green synthesis gained more popularity by using plant extracts due to its exceptional properties such as fast processing, eco-friendliness behavior, non-pathogenic, etc. Many biomolecules and plant extracts with medicinal values are used to synthesis of silver nanoparticles, which are also environmentally suitable. There are many plants established which helps in the manufacture of silver nanoparticles and some of them is listed in the table below [Table 1]. Different part of plants are used to synthesize the metal nanoparticles such as leaf, root, stem, seed, fruit, flower etc.
Table 1. List of plants and their parts used in the synthesis of AgNPs and their sizes [24]

| Reference | Plant                        | Used Part      | Average size |
|-----------|------------------------------|----------------|--------------|
| [25]      | Medicago sativa              | Leaves         | 2-3nm        |
| [26]      | Pseudocydonia sinensis       | Fruit          | 15-20nm      |
| [27]      | Morinda citrifolia           | Root           | 30-35nm      |
| [28]      | Pungamia pinnata, Hemidesmus indicus, | Leaves | 24-55nm |
|           | Syzygium cumini              |                |              |
| [29]      | Murraya koenigii             | Leaves         | 40-80nm      |
| [30]      | Saraca indica                | Flower         | 18-22nm      |
| [31]      | Salicornia brachiata         | Shoot          | 30-40nm      |
| [32]      | Terminalia chebula           | Fruit          | 25nm         |
| [33]      | Viola serpens                | Leaves         | 80-90nm      |
| [34]      | Rosmarinus officinalis       | Leaves         | 14-42nm      |
| [35]      | Ocimum tenuiflorum           | Leaves         | 7-15nm       |
| [36]      | Olive                        | Leaves         | 20–25 nm     |
| [37]      | Ammannia baccifera           | Leaves         | 10–30 nm     |
| [38]      | Hibiscus cannabinus          | Leaves         | 9 nm         |
| [39]      | Vitex negundo                | Leaves         | 5–47 nm      |
| [40]      | Podophyllum hexandrum        | Leaves         | 14 nm        |
| [41]      | Ficus religiosa              | Leaves         | 5–35 nm      |
| [42]      | Piper pedicellatum           | Leaves         | 2–35 nm      |
| [43]      | Moringa oleifera             | Flower         | 14nm         |
| [44]      | Solanum torvum               | Fruit          | 5-10nm       |
| [45]      | Artocarpus heterophyllus     | Seed           | 10nm         |
| [46]      | Andrographis paniculata      | Leaves         | 13–17 nm     |
| [47]      | Crataegus douglasii          | Fruit          | 29nm         |
| [48]      | Tithonia diversifolia        | Leaves         | 25nm         |
| [49]      | Brucea javanica              | Peel           | 38nm         |
| [50]      | Ixora coccinea               | Leaves         | 13–57 nm     |
| [51]      | Artemisia nilagirica         | Leaves         | 70–90 nm     |
| [52]      | Cucumis melo                 | Fruit          | 13-25nm      |
| [53]      | Leucas aspera                | Barks          | 29–45 nm     |
| [54]      | Phyllanthus emblica          | Fruit          | 188nm        |
| [55]      | Sesbania grandiflora         | Leaves         | 22 nm        |
4. Mechanism of AgNPs Synthesis
Reducing the silver metal ion solution and a biological agent is important for making AgNPs by green synthesis. According to previous studies, there is no need to add capping and stabilizing agents from outside in this method because the agents present in the cells or reducing agents of other components act as stabilizing and capping agents. Synthesis of AgNP is carried out very easily by biological entities, its main reason being the presence of a large number of organic chemicals such as carbohydrates, fats, proteins, enzymes and coenzymes. Which are able to donate electrons to meet the deficiency of Ag⁺ ions and convert to Ag⁰. The active ingredient responsible for meeting the deficiency of Ag⁺ ions can be identified based on the organism/extract used. For the formation of AgNPs, electron can be obtained from dehydrogenation of acids and alcohols in hydrophytes, keto to enol conversions in mesophytes or both mechanisms in xerophytes plants [66]. As per literature, microbial cellular and extracellular oxidoreductase enzymes can execute their reduction process in the same way. Figure 1 represents pathway for synthesis of silver nanoparticles.

![Silver nanoparticle synthesis pathway](image)

Figure 1. Synthesis Mechanism of AgNPs [67]

5. Application
5.1 Anti-microbial activity
Studies has found that silver nanoparticle has both gram negative and gram positive bacteria as well as fungi. AgNPs formed from Solanum trilobatum inhibit bacterial growth in the pathogen. Maximum prohibition percentage can be found against Escherichia coli, Klebsiella planticola, Klebsiella pneumoniae and Streptococcus. The antibacterial could be clarified by various means and mechanism. The anti-bacterial result of silver nanoparticle can be found from Garcinia mangostana leaf extract in contrary to E. coli and staphylococcus aureus has boosted mechanism of bacterial effect and damaging effect on some polymeric subunits of the membrane[68]. Silver nanoparticles bind to the surface bacterial cell membrane by acting with sulphur-containing proteins, which disrupt cell membrane penetration and respiratory functions leading to cell death. Thus interaction of silver nanoparticle with compound containing the thiol from respiratory enzyme cell could prevent the respiration of the bacteria. The anti-bacterial cell of silver nanoparticle not only interact with the membrane but also penetrate the bacteria. Silver nanoparticle rush into the bacterial cell and condense the DNA so that DNA and cell duplication can be prevented [69].
Study has also narrates that the surface available for interaction can mitigate the binding of the particles to the microorganism. Generally compared with large particles small nanoparticles have a large surface area for the bacteria. For example the stronger bacterial effect of silver nanoparticles contains drastic amount of olea extract and this further justify the extremely large surface area of small nanoparticles. A change in the chemical composition of the bacterial cell wall also suggests that varying degrees of antibacterial activity of AgNPs from Avicen alba leaves gram-positive and gram-negative bacteria [70].

5.2 Anti-oxidant activity
The antioxidant activity of silver nanoparticle gained from Chenopodium murale extracts and 5 mM AgNO3 by the DPPH scavenging and β-carotene bleaching assays [71]. The result showed significance in difference between the antioxidant values of the plant aqueous extract and silver nanoparticles due to the higher total phenolic content and total flavonoids content in the case of nanoparticle. Study shows in Rosmarinus sp and Z. multiflora nanoparticles has highest antioxidants and reduction capacity wherein lower antioxidant and reduction capacity found in C. tinctorius nanoparticles [72]. Further the relation between antioxidant and reduction capacity demonstrate that the plant with high antioxidant activity have high reducing capacity and high silver nanoparticles synthesis.

5.3 Drug Delivery to targeted site
Due to smaller size of nano particle drug carrier can bypass barrier of blood brain and epithelial junction of skin that can easily impede drug delivery at set target site [73]. As result of their high surface area to volume ratio, improved pharmacokinetics and bio distribution of therapeutic agents’ nano carrier gives preferential accumulation at targeted site. Which improve the solubility of hydrophobic compound and render them for parenteral administration [74,75]. Ensuring the drug delivery to their target site at right time to achieve maximum therapeutic effect is key issue in the design and development of novel drug delivery system. The silver nanoparticle (AgNP) could transfer through blood tissue to reach the target cell/site. Silver nanoparticle have been widely used in novel therapeutic agent. As characteristics listed above it has further uses in anti-bacterial, anti-fungal, anti-viral and anti-inflammatory agent.

5.4 Antibacterial Agent
Compared to their bulk counterpart at nano scale level it is gaining greater importance. The nano size changes the chemical, physical and optical properties of the metal which showed for antibacterial activity. It has observed that aqueous silver ion get exposed to filtrate T. Viride were reduced in solution, further this leads to formation of extreme stable AgNPs with size of 4-50nm[76]. This nanoparticle further evaluate for increase in antimicrobial activities with various antibiotics gram negative and gram positive bacteria. Due to presence of AgNP the antibacterial activities of ampicillin, kanamycin, erythromycin and chloramphenicol were increased [77]. To develop new antimicrobial agent the combination of antibiotics with AgNPs has better antimicrobial effects and provided helpful insight.

5.5. Water treatment
Nano technology has become an alternative to treat water effectively. Silver nanoparticle is very ideal to prevent water or treat water from disinfection. Due to the dimension and strength of silver nanoparticle cellulose nano- and microfibers have been investigated for water treatment. These different membranes were investigated for nanofiltration, microfiltration, ultrafiltration, membrane distillation, and haemodialysis. Beside membranes the nano particle used to coat beads, ceramic filters and paper filters [78,79]. In the study for microbial inactivation the silver nanoparticles coating were used to develop column filtration.

6. Conclusion and future outlook
In the present review, the properties and application of a wide range of silver nanoparticles AgNPs synthesized by the biological synthesis route are discussed. As per literature, various types of silver nanoparticles have been synthesized through green routes. Various microorganisms have also been
widely used with plants in the synthesis of AgNPs. A variety of characterization methods and techniques are used to successfully synthesis and confirmation of AgNPs. Various review and research articles gives emphasis on biosynthesis process of silver nanoparticles via natural and chemical ways. Mainly in this review we are trying to capture eco-friendly ways to synthesis the silver nanoparticles along with some other ways so as to draw conclusion for most effective way to approach and explore the field of nanotechnology. Synthesising nano particles via eco-friendly or environmental friendly route is significant in the field nano technology. In field of nanotechnology things are manipulated in such a way that material can possess unique properties at atomic level. Synthesis of silver nanoparticle can beneficial in various means such as the products would be safe at competitive cost (ecomonical), energy efficient and waste would be lesser. AgNPs can be synthesis by chemical and physical method which are quiet expensive and contain toxic substances which in turn in bio synthesis process via fungi has lower toxicity and eco-friendly behaviour[80]. AgNPs has commercial widespread application due to its various properties such as high electrical conductivity, optical properties, and effective antibacterial activities and fungi could be easily culture in larger scale and have advantage over microorganism such as high tolerance against harsh environment. From all these studies we concluded that green synthesized AgNPs serve as simple and cost-effective methods for the development of nanomedicine to control infection. Also inhibits the release of active toxins for environmental protection. AgNPs are more effective antimicrobial agents than other salts due to their wide applications, in particular, it also establishes better contact with microorganism. The above reports clearly indicate that extensive studies have been conducted to understand the effects and toxicity levels of AgNPs. The full potential for development and applications of AgNPs is still being explored.

7. References

[1] Prasad R 2014 Synthesis of Silver Nanoparticles in Photosynthetic Plants 2014 J. Nanoparticles 1–8
[2] Priyadarshini E, Pradhan N, Sukla L B and Panda P K 2014 Controlled synthesis of gold nanoparticles using Aspergillus terreus f0 and its antibacterial potential against gram negative pathogenic bacteria J. Nanotechnol. 2014
[3] Zhang S, Zhang X, Jiang G, Zhu H, Guo S, Su D, Lu G and Sun S 2014 Tuning nanoparticle structure and surface strain for catalysis optimization J. Am. Chem. Soc. 136 7734–9
[4] Wang D, Xin H L, Howden R, Wang H, Yu Y, Muller D A, Disalvo F J and Abruaña H D 2013 Structurally ordered intermetallic platinum-cobalt core-shell nanoparticles with enhanced activity and stability as oxygen reduction electrocatalysts Nat. Mater. 12 81–7
[5] Fan Z and Zhang H 2016 Crystal phase-controlled synthesis, properties and applications of noble metal nanomaterials Chem. Soc. Rev. 45 63–82
[6] Balasooriya E R, Jayasinghe C D, Jayawardena U A, Ruwanthika R W D, De Silva R M and Udagama P V 2017 Honey Mediated Green Synthesis of Nanoparticles: New Era of Safe Nanotechnology J. Nanomater. 2017
[7] Wen W and Wu J M 2014 Nanomaterials via solution combustion synthesis: A step nearer to controllability RSC Adv. 4 58090–100
[8] Srivastava R 2012 Synthesis and characterization techniques of nanomaterials Int. J. Green Nanotechnol. Biomed. 4 17–27
[9] Jain P K, Huang X, El-Sayed I H and El-Sayed M A 2008 Noble metals on the nanoscale: Optical and photothermal properties and some applications in imaging, sensing, biology, and medicine Acc. Chem. Res. 41 1578–86
[10] Gajanan K and Tijare S N 2018 Applications of nanomaterials Mater. Today Proc. 5 1093–6
[11] Bryaskova R, Pencheva D, Nikolov S and Kantardjiev T 2011 Synthesis and comparative study on the antimicrobial activity of hybrid materials based on silver nanoparticles (AgNps) stabilized by polyvinylpyrrolidone (PVP) J. Chem. Biol. 4 185–91
[12] Jaffri S B and Ahmad K S 2018 Augmented photocatalytic, antibacterial and antifungal activity of prunosynthetic silver nanoparticles Antif. Cells, Nanomedicine Nanopartic. 46 127–37
[13] Tao G, Cai R, Wang Y, Liu L, Zuo H, Zhao P, Umar A, Mao C, Xia Q and He H 2019 Bioinspired design of AgNPs embedded silk sericin-based sponges for efficiently combating bacteria and promoting wound healing Mater. Des. 180
[14] Khattami M, Sharifi I, Nobre M A L, Zafarnia N and Afzalooonian M R 2018 Waste-grass-mediated green synthesis of silver nanoparticles and evaluation of their anticancer, antifungal and antibacterial activity Green Chem. Lett. Rev. 11 125–34
[15] Valsalam S, Agastian P, Arasu M V, Al-Dhabi N A, Ghilan A K M, Kaviyarasu K, Ravindran B, Chang S W and Arakiyardar S 2019 Rapid biosynthesis and characterization of silver nanoparticles from the leaf extract of Tropaeolum majus L. and its enhanced in-vitro antibacterial, antifungal, antioxidant and anticancer properties J. Photochem. Photobiol., B Biol. 191 65–74
[16] Zhang X F, Liu Z G, Shen W and Gurunathan S 2016 Silver nanoparticles: Synthesis, characterization, properties,
applications, and therapeutic approaches Int. J. Mol. Sci. 17
[17] Prabhu S and Poulou E K 2012 Silver nanoparticles: mechanism of antimicrobial Int. Nano Lett. 2 32–41
[18] Ahmed S, Ahmad M, Swami B L and Ikrum S 2016 A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise J. Adv. Res. 7 17–28
[19] Li X, Xu H, Chen Z S and Chen G 2011 Biosynthesis of nanoparticles by microorganisms and their applications J. Nanomater. 2011
[20] Saleh Ghadimi L, Arsalani N, Ahdadzadeh I, Hajalilou A and Abouzari-Loff E 2019 Effect of synthesis route on the electrochemical performance of CoMnFeO₃ nanoparticles as a novel supercapacitor electrode material Appl. Surf. Sci. 494 440–51
[21] Beyene H D, Werkneh A A, Bezabh H K and Ambaye T G 2017 Synthesis paradigm and applications of silver nanoparticles (AgNPs), a review Sustain. Mater. Technol. 13 18–23
[22] Beyene H D, Werkneh A A, Bezabh H K and Ambaye T G 2017 Synthesis paradigm and applications of silver nanoparticles (AgNPs), a review Sustain. Mater. Technol. 13 18–23
[23] Rasheed T, Bilal M, Iqbal H M N and Li C 2017 Green biosynthesis of silver nanoparticles using leaves extract of Artemisia vulgaris and their potential biomedical applications Colloids Surfaces B Biointerfaces 158 408–15
[24] Ismail M, Guif S, Khan M A and Khan M I 2018 Plant Mediated Green Synthesis of Anti-Microbial Silver Nanoparticles—A Review on Recent Trends Rev. Nano. Nanotechnol. 5 119–35
[25] Gardea-Torresdey J L, Gomez E, Peralta-Videa J R, Parsons J G, Trojan J and Jace-Yacaman M 2003 Alalfa sprouts: A natural source for the synthesis of silver nanoparticles Langmuir 19 1357–61
[26] Nagajothy C P, Sreekanth T V M and Lee K D 2012 AgNPs: Green synthesis, characterization, antimicrobial, and cytotoxicity studies of melanin and aqueous extracts of pseudocoydina sinensis (Chinese quince) fruit Synth. React. Inorganic, Met. Nano-Metal Chem. 42 1339–44
[27] Suman T Y, Radhika Rajasree S R, Kanchana A and Elizabeth S B 2013 Biosynthesis, characterization and cytotoxic effect of plant mediated silver nanoparticles using Morinda citrifolia root extract Colloids Surfaces B Biointerfaces 106 74–8
[28] Pandu K K, Achary V M M, Krishnaveni R, Padhi B K, Sarangi S N, Sahu S N and Panda B B 2011 In vitro biosynthesis and genotoxicity bioassay of silver nanoparticles using plants Toxicol. Vitr. 25 1097–105
[29] Bonde S R, Rathod D P, Ingle A P, Ade R B, Gade A K and Rai M K 2012 Murraya koenigii mediated synthesis of silver nanoparticles and its activity against three human pathogenic bacteria Nanosci. Methods 1 25–36
[30] Vidhu V K and Philip D 2014 Spectroscopic, microscopic and catalytic properties of silver nanoparticles synthesized using Saraca indica flower Spectrochim. Acta - Part A Mol. Biomol. Spectrosc. 117 102–8
[31] Seralathan J, Stevenson P, Subramaniam S, Raghavan R, Pemaiah B, Sivasubramanian A and Veerappan A 2014 Spectroscopy investigation on chemo-catalytic, free radical scavenging and bactericidal properties of biogenic silver nanoparticles synthesized using Salicornia brachiata aqueous extract Spectrochim. Acta - Part A Mol. Biomol. Spectrosc. 118 349–55
[32] Edison T J J and Sethuraman M G 2012 Instant Green synthesis of silver nanoparticles using Terminalia chebula fruit extract and evaluation of their catalytic activity on reduction of methylene blue Process Biochem. 47 1351–7
[33] Kumar A, Muzzumdar R S and Dhewa T 2016 Biological synthesis of silver nanoparticles by using Viola serpens extract Asian Pacific J. Trop. Dis. 6 223–6
[34] Das J and Velusamy P 2013 Antibacterial effects of biosynthesized silver nanoparticles using aqueous leaf extract of Rosmarinus officinalis L. Mater. Res. Bull. 48 4531–7
[35] Vignesh V, Felix Anbarasi K, Karthikkeyen S, Sathiyaranayanan G, Subramaniam P and Thirumurugan R 2013 A superficial phyto-assisted synthesis of silver nanoparticles and their assessment on hematological and biochemical parameters in Labeo rohita (Hamilton, 1822) Colloids Surfaces A Physicochem. Eng. Asp. 439 184–92
[36] Khalil M M H, Ismail E H, El-Baghdady K Z and Mohamed D 2014 Green synthesis of silver nanoparticles using olive leaf extract and its antibacterial activity Arab. J. Chem. 7 1131–9
[37] Suman T Y, Elumalai D, Kaleena P K and Rajasree R S R 2013 GC-MS analysis of bioactive components and synthesis of silver nanoparticle using Ammannia baccifera aerial extract and its larvicidal activity against malaria and filariasis vectors Ind. Crops Prod. 47 239–45
[38] Bindhu M R and Umadevi M 2013 Synthesis of monodisperse silver nanoparticles using Hibiscus cannabinus leaf extract and its antimicrobial activity Spectrochim. Acta - Part A Mol. Biomol. Spectrosc. 101 184–90
[39] Prabhu D, Arulvasu C, Babu G, Manikandan R and Srinivasan P 2013 Biologically synthesized green silver nanoparticles from leaf extract of Vitex negundo L. induce growth-inhibitory effect on human colon cancer cell line HCT15 Process Biochem. 48 317–24
[40] Jeyaraj M, Rajesh M, Arun R, Murukali D, Sathishkumar G, Sivanandhan G, Dev G K, Manickavasagam M, Premkumar K, Thajuddin N and Ganapathi A 2013 An investigation on the cytotoxicity and caspase-mediated apoptotic effect of biologically synthesized silver nanoparticles using Podophyllum hexandrum on human cervical carcinoma cells Colloids Surfaces B Biointerfaces 102 708–17
[41] Antony J J, Sithika M A A, Joseph T A, Suryakala U, Sankarganesh A, Siva D, Kalaiselvi S and Achiraman S 2013 In vivo antitumor activity of biosynthesized silver nanoparticles using Ficus religiosa as a nanofactory in DAL induced mice model Colloids Surfaces B Biointerfaces 108 185–90
[42] Tamuly C, Hazarika M, Borah S C, Das M R and Boruah M P 2013 In situ biosynthesis of Ag, Au and bimetallic
nanoparticles using Piper pedicellatum CDC. Green chemistry approach Colloids Surf. B 102:627–34.

[43] Bindhu M R, Sathe V and Umadevi M 2013 Synthesis, characterization and SERS activity of biosynthesized silver nanoparticles Spectroch. Acta - Part A Mol. Biomol. Spectrosc. 115:409–15.

[44] Ramamurthy C H, Padma M, mariya samadaman I D, Mareeswaran R, Suyavaran A, Kumar M S, Premkumar K and Thirunavukkarasu C 2013 The extra cellular synthesis of gold and silvernano particles and their free radical scavenging and antibacterial properties Colloids Surf. B 102: 808–15.

[45] Jagtap U B and Bapat V A 2013 Green synthesis of silver nanoparticles using Artocarpus heterophyllus Lam. seed extract and its antibacterial activity Ind. Crops Prod. 46:132–7.

[46] Suryakalaa U, Antony J J, Suganya S, Siva D, Sukirtha R, Kamalakannan S, Pichiaih P B T and Achiraman S 2013 Hepatocurative activity of biosynthesized silver nanoparticles fabricated using Andrographis paniculata Colloids Surf. B 102:189–94.

[47] Ghaffari-Moghadam M and Hadi-Dabanlou R 2014 Plant mediated green synthesis and antibacterial activity of silver nanoparticles using Crataegus douglasii fruit extract J. Ind. Eng. Chem. 20:739–44.

[48] Tran T T T, Vu T T H and Nguyen T T H 2013 Biosynthesis of silver nanoparticles using Tithonia diversifolia leaf extract and their antimicrobial activity Mater. Lett. 105:220–3.

[49] Yudha S S, Notriawan D, Angasa E, Eka Suharto T, Hendri J and Nishina Y 2013 Green synthesis of silver nanoparticles using aqueous rings extract of Brueca javanica (L.) Merr at ambient temperature Mater. Lett. 97:181–3.

[50] Karuppiah M and Rajmohan R 2013 Green synthesis of silver nanoparticles using Ixora coccinea leaves extract Mater. Lett. 97:141–3.

[51] Vijayakumar M, Priya K, Nancy F T, Noorilah A and Ahmed A B A 2013 Biosynthesis, characterisation and anti-bacterial effect of plant-mediated silver nanoparticles using Artemisia nilagirica Ind. Crops Prod. 41:235–40.

[52] Gul S, Ismail M, Khan M I, Khan S B, Asiri A M, Rahman I U, Khan M A and Kamboh M A 2016 Novel synthesis of silver nanoparticles using melon aqueous extract and evaluation of their feeding deterrent activity against housefly Musca domestica Asian Pacific J. Trop. Dis. 6:311–6.

[53] Antony J J, Nivedtheetha M, Siva D, Pradeepha G, Kokilavani P, Kalaiselvi S, Sankargasam A, Balasundaram A, Masilamani V and Achiraman S 2013 Antimicrobial activity of Leucas aspera engineered silver nanoparticles against Aeromonas hydrophila in infected Catla catla Colloids Surf. B 109:20–4.

[54] Rosarin F S, Arulmozhi V, Nagarajan S and Mirunalini S 2013 Anti proliferative effect of silver nanoparticles using amla on Hep2 cell line Asian Pac. J. Trop. Med. 6:1–10.

[55] Jeyaraj M, Sathishkumar G, Sivanandhan G, MubarakAli D, Rajesh M, Arun R, Kapildev G, Manickavasagam M, Thajuddin N, Premkumar K and Ganapathi A 2013 Biogenic silver nanoparticles for cancer treatment: An experimental report Colloids Surf. B 106:86–92.

[56] Zhang Y, Cheng X, Zhang Y, Xue X and Fu Y 2013 Biosynthesis of silver nanoparticles at room temperature using aqueous aloe leaf extract and antibacterial properties Colloids Surf. A Physicochem. Eng. Asp. 423:63–8.

[57] Annamalai A, Christina V L P, Christina V and Lakshmi P T V 2014 Green synthesis and characterisation of Ag NPs using aqueous extract of Phyllanthus maderaspatensis I. J. Exp. Nanosci. 9:113–9.

[58] Krishnaraj C, Jagan E G, Rajasekar S, Selvakumar P, Kalaiselvi S, Sankarganesh A, Balasundaram A, Masilamani V and Achiraman S 2013 Antimicrobial activity of Leucas aspera engineered silver nanoparticles against Aeromonas hydrophila infected Catla catla Colloids Surf. B 109:20–4.

[59] Dabanlou R 2014 Plant mediated green synthesis and antibacterial activity of silver nanoparticles using Albizia adianthifolia leaf Mater. Lett. 87:97–105.

[60] Suraj R, Sivakumar G and Abdul Rahuman A 2011 Larvicidal activity of synthesized silver nanoparticles using Eclipta prostrata leaf extract against filariasis and malaria vectors Acta Trop. 118:196–203.

[61] Ankanwar B, Damle C, Ahmad A and Sastry M 2005 Biosynthesis of gold and silver nanoparticles using Emblica Officinalis fruit extract, their phase transfer and transmetallation in an organic solution J. Nanosci. Nanotechnol. 5:1665–71.

[62] Babu S A and Prabu H G 2011 Synthesis of AgNPs using the extract of Cataltopsis procera flower at room temperature Mater. Lett. 65:1675–7.

[63] Banerjee J and Narendhirakannan R T 2011 Biosynthesis of silver nanoparticles from Syzygium cumini (L.) seed extract and their evaluation in vitro antioxidant activities Dig. J. Nanomater. Biointerfaces 6:961–8.

[64] Dwivedi A D and Gopal K 2010 Biosynthesis of silver and gold nanoparticles using Chenopodium album leaf extract Colloids Surf. A Physicochem. Eng. Asp. 369:27–33.

[65] Gengan R M, Anand K, Phulukdaree A and Chuturgoon A 2013 A549 lung cell line activity of biosynthesized silver nanoparticles using Albizia adianthifolia leaf Colloids Surf. B 105:87–91.

[66] Dabanlou R, Sivakumar G and Abdul Rahuman A 2011 Larvicidal activity of synthesized silver nanoparticles using Eclipta prostrata leaf extract against filariasis and malaria vectors Acta Trop. 33:1596–203.

[67] Ankanwar B, Damle C, Ahmad A and Sastry M 2005 Biosynthesis of gold and silver nanoparticles using Emblica Officinalis fruit extract, their phase transfer and transmetallation in an organic solution J. Nanosci. Nanotechnol. 5:1665–71.
[69] Qing Y, Cheng L, Li R, Liu G, Zhang Y, Tang X, Wang J, Liu H and Qin Y 2018 Potential antibacterial mechanism of silver nanoparticles and the optimization of orthopedic implants by advanced modification technologies Int. J. Nanomedicine 13 3311–27
[70] Dakal T C, Kumar A, Majumdar R S and Yadav V 2016 Mechanistic basis of antimicrobial actions of silver nanoparticles Front. Microbiol. 7 1–17
[71] Abdel-Aziz M S, Shaheen M S, El-Nekeety A A and Abdel-Wahhab M A 2014 Antioxidant and antibacterial activity of silver nanoparticles biosynthesized using Chenopodium murale leaf extract J. Saudi Chem. Soc. 18 356–63
[72] Goodarzi V, Zamani H, Bajuli L and Moradshahi A 2014 Evaluation of antioxidant potential and reduction capacity of some plant extracts in silver nanoparticles’ synthesis. Mol. Biol. Res. Commun. 3 165–74
[73] Rizvi S A A and Saleh A M 2018 Applications of nanoparticle systems in drug delivery technology Saudi Pharm. J. 26 64–70
[74] Patra J K, Das G, Fraceto L F, Campos E V R, Rodriguez-Torres M D P, Acosta-Torres L S, Diaz-Torres L A, Grillo R, Swamy M K, Sharma S, Habtemariam S and Shin H S 2018 Nano based drug delivery systems: Recent developments and future prospects 10 Technology 1007 Nanotechnology 03 Chemical Sciences 0306 Physical Chemistry (incl. Structural) 03 Chemical Sciences 0303 Macromolecular and Materials Chemistry 11 Medical and He J. Nanobiotechnology 16 1–33
[75] Din F ud, W, Aman A, Ullah I, Qureshi O S, Mustapha O, Shaﬁque S and Zeb A 2017 Effective use of nanocarriers as drug delivery systems for the treatment of selected tumors Int. J. Nanomedicine 12 7291–309
[76] Fayaz A M, Balaji K, Girilal M, Yadav R, Kalaichelvan P T and Venketesan R 2010 Biogenic synthesis of silver nanoparticles and their synergistic effect with antibiotics: a study against gram-positive and gram-negative bacteria Nanomedicine Nanotechnology, Biol. Med. 6 103–9
[77] Franci G, Falanga A, Galdiero S, Palomba L, Rai M, Morelli G and Galdiero M 2015 Silver nanoparticles as potential antibacterial agents Molecules 20 8856–74
[78] Wang Z, Wu A, Ciacchi L C and Wei G 2018 Recent advances in Nanoporous Membranes for Water Purification Nanomaterials 8
[79] Shepard Z J, Lux E M and Oyandedel-Craver V A 2020 Performance of silver nanoparticle-impregnated ovoid ceramic water filters Environ. Sci. Nano 7 1772–80
[80] Syed A, Saraswati S, Kundu G C and Ahmad A 2013 Biological synthesis of silver nanoparticles using the fungus Humicola sp. And evaluation of their cytotoxicity using normal and cancer cell lines Spectrochim. Acta - Part A Mol. Biomol. Spectrosc. 114 144–7

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