Green nanotechnology: a review on green synthesis of silver nanoparticles — an ecofriendly approach

Background: Nanotechnology explores a variety of promising approaches in the area of material sciences on a molecular level, and silver nanoparticles (AgNPs) are of leading interest in the present scenario. This review is a comprehensive contribution in the field of green synthesis, characterization, and biological activities of AgNPs using different biological sources.

Methods: Biosynthesis of AgNPs can be accomplished by physical, chemical, and green synthesis; however, synthesis via biological precursors has shown remarkable outcomes. In available reported data, these entities are used as reducing agents where the synthesized NPs are characterized by ultraviolet-visible and Fourier-transform infrared spectra and X-ray diffraction, scanning electron microscopy, and transmission electron microscopy.

Results: Modulation of metals to a nanoscale drastically changes their chemical, physical, and optical properties, and is exploited further via antibacterial, antifungal, anticancer, antioxidant, and cardioprotective activities. Results showed excellent growth inhibition of the microorganism.

Conclusion: Novel outcomes of green synthesis in the field of nanotechnology are appreciable where the synthesis and design of NPs have proven potential outcomes in diverse fields. The study of green synthesis can be extended to conduct the in silico and in vitro research to confirm these findings.

Keywords: green synthesis, plant mediated synthesis, silver bioactivity, microorganism

Introduction

Nanotechnology offers fields with effective applications, ranging from traditional chemical techniques to medicinal and environmental technologies. AgNPs have emerged with leading contributions in diverse applications, such as drug delivery,31 ointments, nanomedicine,37 chemical sensing,41 data storage,47 cell biology,54 agriculture, cosmetics,60 textiles,17 the food industry, photocatalytic organic dye-degradation activity,64 antioxidants,66 and antimicrobial agents.68

Despite the contradictions reported on the toxicity of AgNPs,69 its role as a disinfectant and antimicrobial agent has been given considerable appreciation. The available documented data33,74 and the interest of the community in this field prompted us to work on plant-mediated green synthesis and biological activities of AgNPs.

Different types of nanoparticles

Some distinctive reported forms of nanoparticles (NPs) are core–shell NPs,76 photochromic polymer NPs,78 polymer-coated magnetite NPs,80 inorganic NPs, AgNPs,
CuNPs, AuNPs, PtNPs, PdNPs, SiNPs, and NiNPs, while others are metal oxide and metal dioxide NPs, such as ZnONPs, CuO NPs, FeO, MgONPs, TiO2 NPs, CeO2 NPs, and ZrO2 NPs. Each of these has an exclusive set of characteristics and applications, and can be synthesized by either conventional or unconventional methods. An extensive classification of NPs is provided in Figure 1.

Figure 1 Different approaches to nanomaterial (NM) classification. Abbreviation: NPs, nanoparticles.
Nanoparticle synthesis

Comprehensive approaches available for NP synthesis are bottom-up and top-down. The latter approach is immoderate and steady, whereas the former involves self-assembly of atomic-size particles to grow nanosize particles. This can be achieved by physical and chemical means, as summarized in Table 1. However, ecofriendly green syntheses are economical, and proliferate and trigger stable NP formation, as shown in Figure 2.

Green approach (biological/conventional methods)

The surging popularity of green methods has triggered synthesis of AgNPs using different sources, like bacteria, fungi, algae, and plants, resulting in large-scale production with less contamination. Green synthesis is an ecofriendly and bio-compatible process, generally accomplished by using a capping agent/stabilizer (to control size and prevent agglomeration), plant extracts, yeast, or bacteria.

Green synthesis using plant extracts

In contrast to microorganisms, plants have been exhaustively used, as apparent from Table 2. This is because plant phytochemicals show greater reduction and stabilization. Eugenia jambolana leaf extract was used to synthesize AgNPs that indicated the presence of alkaloids, flavonoids, saponins, and sugar compounds. Bark extract of Saraca asoca indicated the presence of hydroxylamine and carboxyl groups. AgNPs using leaves of Rhynchotchemum ellipticum were synthesized, and the results indicated the presence of polyphenols, flavonoids, alkaloids, terpenoids, carboxylates, and steroids. Hesperidin was used to form AgNPs of 20–40 nm. Phenolic compounds of pyrogallol and oleic acid were reported to be essential for the reduction of silver salt to form NPs. Pepper-leaf extract acts as a reducing and capping agent in the formation of AgNPs of 5–60 nm. Fruit extracts of Malus domestica acted as a reducing agent. Similarly, Vitis vinifera, Andean blackberry, Adansonia digitata, Solanum nigrum, Nitraria schoberi or multiple fruit peels have also been reported for AgNP synthesis. Combinations of plant extracts have also been reported. Some other reductants used for AgNO₃ are polysaccharide, soluble starch, natural rubber, tarmac, cinnamon, stem-derived callus of green apple, red apple, egg white, lemon grass, coffee, black

Table 1 Chemical and physical synthesis of AgNPs

| Type | Reducing agent | Characterization | Biological activities | Reference |
|------|----------------|------------------|----------------------|-----------|
| Chitosan-loaded AgNPs | Polysaccharide chitosan | TEM, FTIR, XRD, DSC, TGA | Antibacterial | 114 |
| PVP-coated AgNPs | Sodium borohydride | UV-vis, TEM, EDS, DLS, FFFF | NANA | 115 |
| AgNPs | Ascorbic acid | UV-vis, EFTEM | Antibacterial | 116 |
| AgNPs | Hydrazine, D-glucose | UV-vis, TEM | Antibacterial | 117 |
| Polydiallyldimethylammonium chloride_ and poly-methacrylic acid–caped AgNPs | Methacrylic acid polymers | UV-vis, reflectance spectrophotometry | Antimicrobial | 118 |

Abbreviations: NPs, nanoparticles; TEM, transmission electron microscopy; FTIR, Fourier-transform infrared; XRD, X-ray diffraction; DSC, differential scanning calorimetry; TGA, thermogravimetric analysis; UV-vis, ultraviolet-visible (spectroscopy); EDS, energy-dispersive spectroscopy; DLS, dynamic light scattering; FF-F, flow field-flow fractionation; EFTEM, energy-filtered TEM; NA, not applicable.
Table 2 Plant-mediated synthesis of AgNPs

| Plant (Family)-Local Name | Part       | Characterization       | Phytoconstituents Present in plant | Size of AgNPs                  | Shape of AgNPs | Reference |
|---------------------------|------------|------------------------|-----------------------------------|-------------------------------|----------------|-----------|
| Acacia nilotica (Fabaceae) — babul | Pod       | UV-vis, HRTEM, FTIR, DLS, EDS, XRD, ζ-potential | Gallic acid, ellagic acid, epicatechin, rutin | HRTEM (20–30 nm) | Distorted spherical | 151       |
| Ocimum sanctum (Lamiaceae) — tulsi | Fresh leaf | UV-vis, TEM, XRD, FTIR | Alkaloids, glycosides, tannins, saponins, aromatic compounds | TEM (3–20 nm, average 9.5 nm) | Spherical | 152       |
| Citrullus colocynthis (Cucurbitaceae) — bitter apple | Fresh leaf | UV-vis, FTIR, AFM | NA | AFM (31 nm) | Spherical | 153       |
| Coccinia grandis (Cucurbitaceae) — ivy gourd | Fresh leaf | UV-vis, HRTEM, SEM, XRD, FTIR, TGA, EDS | Triterpenoids, alkaloids, tannin | TEM (20–30 nm) | Spherical | 154       |
| Pterocarpus santalinus (Fabaceae) — sandalwood | Fresh leaf | UV-vis, SEM, XRD, FTIR, TEM, AFM, EDX | NA | SEM (20–50 nm, average 20 nm), AFM (41 nm) | Spherical | 155       |
| Coleus aromaticus (Lamiaceae) — borage | Fresh leaf | UV-vis, XRD, FTIR, EDAX | Carvacrol, caryophyllene, patchouline, flavonoids | SEM (40–50 nm) | Spherical | 156       |
| Jatropha curcas (Euphorbiaceae) — physic nut | Seed      | UV-vis, HRTEM, XRD | NA | HRTEM (1.550 nm) at 10^{-3} M and 30–50 nm at 10^{-2} M | Spherical (at 10^{-3} M), unevenly shaped (at 10^{-2} M) | 157       |
| Melia dubia (Meliaceae) — malai vembu | Fresh leaf | UV-vis, TEM, SEM-EDS, XRD | Alkaloids, carbohydrates, glycosides, phenolic compounds, tannins, gums, mucilages | XRD (average 7.3 nm) | Irregular, but mostly spherical | 158       |
| Capsicum annum (Solanaceae) — peppers | Fresh leaf | UV-vis, TEM, FTIR, SAED, XRD, XPS, CV, DPV | Proteins/enzymes, polysaccharides, amino acids, vitamins | TEM (10±2 nm at 5 hours) | Spherical | 159       |
| Annona squamosa (Annonaceae) — sweetsops | Young leaf | UV-vis, XRD, TEM, FTIR, EDS, ζ-potential | Glycoside, alkaloids, saponins, flavonoids, tannins phenolic compounds, phytosterols | TEM (20–100 nm) | Spherical | 160       |
| Camellia sinensis (Theaceae) — tea | Dried leaf | XRD, TEM, FTIR | NA | Debye–Scherrer equation (3.42 nm), TEM (2–10 nm, average 4.06 nm) | Spherical | 161       |

(Continued)
| Plant (Family)-Local Name | Part          | Characterization          | Phytoconstituents Present in plant | Size of AgNPs                                                                 | Shape of AgNPs | Reference |
|--------------------------|---------------|---------------------------|-----------------------------------|------------------------------------------------------------------------------|----------------|-----------|
| Citrus sinensis (Rutaceae) — orange | Peel extract | UV-vis, TEM, FESEM, FTIR, XRD, EDAX | Vitamin C, flavonoids, acids, volatile oils XDS (33±3 nm at 25°C, 8±2 nm at 60°C), HRTEM (35±2 nm) | Spherical | 38        |
| Lantana camara (Verbenaceae) — wild/red sage | Fresh leaf | UV-vis, TEM, FESEM, FTIR, XRD, XPS, AFM, SAED | Phenolics, flavonoids, terpenoids, alkaloids, lipids, proteins, carbohydrates FESEM (34 nm), AFM (17–31 nm), TEM (14–27 nm), XRD (11–24 nm), SAED (~14 nm) | Spherical | 162       |
| Coriandrum sativum (Apiaceae) — coriander | Fresh leaf | UV-vis, TEM, FTIR, XRD, Z-scan techniques | Carotene, thiamine, riboflavin, niacin, oxalic acid, sodium TEM (8–75 nm, average 26 nm) | Spherical | 163       |
| Aloe vera (Asphodelaceae) — first-aid plant | Fresh leaf | UV-vis, TEM, FTIR, AFM, NIR absorption spectroscopy | NA | TEM (1.5±4.2 nm) | Spherical | 164       |
| Memecylon edule (Melastomataceae) — delek bangas | Shade-dried leaf | UV-vis, TEM, SEM, FTIR, EDAX | Triterpines, tannins, flavonoids, saponin | TEM (50–90 nm) | Square | 165       |
| Hibiscus rosa-sinensis (Malvaceae) — rose mallow | Leaf | UV-vis, TEM, FTIR, XRD, SAED | Proteins, vitamin C, organic acids (essentially malic acid), flavonoids, anthocyanins TEM (average size 13 nm), Scherrer equation (13 nm) | Spherical | 166       |
| Cinnamomum camphora (Lauraceae) — camphorwood | Fresh leaf | UV-vis, TEM, SEM, XRD, AFM | NA | TEM (55–80 nm, average diameter 64.8 nm) | Quasispherical | 55        |
| Piper longum (Piperaceae) — pipli | Dried fruit powder | UV-vis, SEM, FTIR, DLS | Piperidine, alkaloids, tannins, dihydros-tigmosterol, sesamim, terpenines DLS (15–200 nm, average 46 nm) | Spherical | 167       |
| Sesbania grandiflora (Fabaceae) — hummingbird tree | Fresh leaf | UV-vis, FE-TEM, FTIR, XRD, SAED | Carboxylic compounds, flavonoids, terpenoids, polyphenols TEM (10–50 nm, average 24.1 nm), XRD (18.52 nm) | Spherical | 168       |
| Moringa oleifera (Moringaceae) — drumstick tree | Fresh stem bark | UV-vis, TEM, HRSEM, FTIR, DLS, AFM | Phenols, β-sitosterol, caffeoylquinic acid, quercetin, kaempferol HRTEM (average size 40 nm), DLS (38 nm), SEM (40 nm) | Spherical and pentagonal | 169       |
| Origanum vulgare (Lamiaceae) — oregano | Leaves | UV-vis, FESEM, FTIR, XRD, DLS, ζ-potential | NA | FESEM (63–85 nm), Scherrer formula (65 nm), DLS (136±10.09 nm) | Spherical | 170       |

(Continued)
| Plant (Family)-Local Name | Part | Characterization | Phytoconstituents Present in plant | Size of AgNPs | Shape of AgNPs | Reference |
|---------------------------|------|------------------|----------------------------------|-------------|---------------|-----------|
| Vitex negundo (Lamiaceae) — Chinese chaste tree | Fresh leaf | UV-vis, TEM, FESEM, FTIR, XRD, EDX | Alkaloids, glycosides, flavonoids, phenolic compounds, reducing sugars, resin tannins | TEM (5–47 nm) | Spherical | 171 |
| Tephrosia tinctoria (Fabaceae) — alu pila | Shade dried stem extract | UV-vis, TEM, SEM, FTIR | Phenol, flavonoids | TEM (73 nm) | Spherical | 172 |
| Mimusops elengi (Sapotaceae) — Spanish cherry | Seed | UV-vis, TEM, FTIR, XRD, HPLC | Ascorbic acid, gallic acid, pyrogallol, resorcinol | TEM (1.28–30.48 nm) | Spherical | 173 |
| Alternanthera dentate (Amaranthaceae) — Joseph's coat | Leaf | FTIR, TEM, SEM, XRD | NA | SEM (50–100 nm) | Spherical | 174 |
| Sesuvium portulacastrum (Aizoaceae) — salt marsh | Leaf | UV-vis, TEM, FTIR, XRD | NA | TEM (5–20 nm) | Spherical | 175 |
| Dalbergia spinosa (Faboideae) — liana | Shade-dried leaf | UV-vis, TEM, FTIR, DLS | Flavonoids, isoflavonoids, neoflavonoids, steroids, terpenoids | TEM (18±4 nm) | Spherical | 176 |
| Sambucus nigra (Adoxaceae) — European black elderberry | Frozen fruit | UV-vis, FTIR, XRD, ζ-potential | Polyphenol anthocyanins | TEM (20–80 nm) | Spherical | 177 |
| Millingtonia hortensis (Bignoniaceae) — neem | Dried leaf | NA | NA | 2–8 nm | NA | 178 |
| Syzygium cumini (Myrtaceae) — jamun | Air-dried seed | UV-vis, SEM, XRD, FTIR, DLS, ζ-potential, HPLC | Gallic acid, p-coumaric acid, quercetin, 3,4-dihydroxybenzoic acid | SEM (40–100 nm), average 43.02 nm, Z-average 43±1.25 | Irregular spherical contour | 179 |
| Mukia maderaspatana (Cucurbitaceae) — Madras pea pumpkin | Fresh leaf | UV-vis, FESEM, FTIR, XRD, ART | NA | FESEM (13–34 nm), Debye–Scherrer formula (64 nm) | Spherical | 180 |
| Nelumbo nucifera (Nelumbonaceae) — sacred lotus | Fresh leaf | UV-vis, TEM, SEM, FTIR, XRD | Betulinic acid, steroidal pentacyclic triterpenoid, procyanidins | TEM (25–80 nm, average 45 nm), SEM (25–80 nm) | Spherical (TEM), triangular (SEM) | 181 |
Biosynthesis using microorganisms

Bacteria-mediated synthesis of AgNPs

Microorganisms like fungi, bacteria, and yeast are of huge interest for NP synthesis; however, the process is threatened by culture contamination, lengthy procedures, and less control over NP size. NPs formed by microorganisms can be classified into distinct categories, depending upon the location where they are synthesized. Otari et al synthesized AgNPs intracellularly using Actinobacteria Rhodococcus sp. NCIM 2891. Kannan et al biosynthesized AgNPs extracellularly. Table 3 provides some illustrative examples of the synthesis of AgNPs using different bacterial strains.

Alga-mediated synthesis of AgNPs

A diverse group of aquatic microorganisms, algae have been used substantially and reported to synthesize AgNPs. They vary in size, from microscopic (picoplankton) to macroscopic (Rhodophyta). AgNPs were synthesized using microalgae Chaetoceros calcitrans, C. salina, Isochrysis galbana, and Tetraselmis gracilis. Cystophora moniliformis marine algae were used by Prasad et al as a reducing and stabilizing agent to synthesize AgNPs. Table 4 illustrates some examples of the micro and macro-algae used for AgNPs synthesis.

Fungus-mediated synthesis of AgNPs

Extracellular synthesis of AgNPs using fungi is also a viable alternative, because of their economical large-scale production. Fungal strains are chosen over bacterial species, because of their better tolerance and metal-bioaccumulation property. Table 5 gives some of the fungal strains used for AgNP synthesis.

Synthesis from miscellaneous sources

Nanotechnology has placed DNA on a recent drive to be used as a reducing agent. Strong affinity of DNA bases for silver make it a template stabilizer. AgNPs were synthesized on DNA strands and found to be possibly located at N7 guanine and phosphate. Another attempt
Figure 3 Plant mediated synthesis of AgNPs.
| Reducing agent: bacterial strain                                                                 | Characterization                                                                 | Size                                                                 | Shape          | Gram+/ Gram− | Reference |
|------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------|----------------|---------------|-----------|
| *Serratia nematodiphila*                                                                        | UV-vis, SEM, EDS                                                              | SEM (65–70 nm)                                                       | Spherical      | Gram+         | 186       |
| *Bacillus stearothermophilus*                                                                   | UV-vis, TEM, FTIR, DLS                                                       | TEM (9.96–22.7 nm, average 14±4 nm)                                  | Spherical      | Gram+         | 187       |
| *Bacillus* strain CS1 I                                                                         | UV-vis, TEM                                                                  | TEM (42–92 nm)                                                       | NA             | Gram+         | 188       |
| Exopolysaccharide-producing strain *Leuconostoc lactis*                                         | UV-vis, TEM, SEM, AFM, XRD, TGA-DTA, Raman spectroscopy                      | TEM (30–200 nm, average 35 nm), AFM (average 30 nm)                  | Spherical      | Gram+         | 189       |
| *Escherichia coli*                                                                              | NA                                                                           | TEM (20–30 nm)                                                       | More or less spherical | Gram−         | 190       |
| *Streptomyces hygroscopicus*                                                                    | UV-vis, TEM, EDXA, FE XRD, BioAFM                                            | NA                                                                   | NA             | Gram+         | 191       |
| *Pediococcus pentosaceus*, *Enterococcus faecium*, *Lactococcus garvieae*                     | UV-vis, TEM, EDS                                                             | TEM (28.2–122 nm, average 52.5 nm)                                  | NA             | Gram+         | 192       |
| *Bacillus cereus*, *B. subtilis*, *Escherichia coli*, *Enterobacter cloacae*, *Klebsiella pneumonia*, *Lactobacillus acidophilus*, *Staphylococcus aureus*, *Pseudomonas aeruginosa* | NA                                                                           | TEM (10–50 nm)                                                       | Quasispherical | Gram+         | 193       |
| *Morganella morganii* RMA2                                                                       | UV, TEM, XRD, SAED                                                           | TEM (10–50 nm)                                                       | Quasispherical | Gram+         | 194       |
| *Escherichia coli*                                                                              | UV, FTIR, XRD                                                                | TEM (average 50 nm)                                                  | Spherical      | Gram+         | 195       |
| *Pseudomonas antarctica*, *P. proteolytica*, *P. mendica*, *Arthrobacter kerguelensis*, *A. gangotiensis*, *Bacillus indicus*, *B. cecembensis* | UV, TEM, AFM                                                                 | TEM (6.1±2.8 nm), AFM (4.6–13.3 nm)                                  | Spherical      | Gram+         | 196       |
| *Staphylococcus aureus*                                                                         | UV, AFM                                                                      | AFM (160–180 nm)                                                     | Irregular      | Gram+         | 197       |
| *Bacillus brevis* (NCIM 2533)                                                                    | UV-vis, SEM, FTIR, AFM, TLC                                                  | SEM (22–60 nm, average 41 nm), AFM (average 68 nm)                  | Spherical      | Gram+         | 198       |

Abbreviations: NPs, nanoparticles; UV-vis, ultraviolet-visible (spectroscopy); TEM, transmission electron microscopy; SEM, scanning electron microscopy; FESEM, field-emission SEM; HRSEM, high-resolution TEM; XRD, X-ray diffraction; FTIR, Fourier-transform infrared (spectroscopy); AFM, atomic force microscopy; HPLC, high-performance liquid chromatography; DLS, dynamic light scattering; EDX, energy-dispersive X-ray (spectroscopy); EDAX, ED X-ray analysis; SAED, selected-area electron diffraction; TGA, thermogravimetric analysis; NA, not available; TLC, thin-layer chromatography.
was made with calf-thymus DNA to synthesize AgNPs.\(^{218}\) Similarly, silver-binding peptides were identified and selected using a combinatorial approach for NP synthesis.\(^{219}\)

### Bioactivities

#### Antibacterial activity of AgNPs

As a broad-spectrum antibiotic, silver is highly toxic to bacteria. It has been of great interest for the past couple of years, due to its wide spectrum of pharmacological activities, with applications in the fields of agriculture, textiles, and especially medicine. Some attributed contributions are given in Table 6.

#### Antifungal activity of AgNPs

Resistant pathogenic activities of bacteria and fungi have increased invasive infections at an alarming rate. Ultimately, the subsequent need is to find more potent antifungal agents. Table 7 provides some examples from the literature that have reported antifungal properties of green synthesized AgNPs.

### Anticancer activity of AgNPs

The paramount need of today is the synthesis of effective anticancer treatment, as cardiovascular at the top most; cancer is the second most leading cause of human dysphoria. Therefore the synthesis of anticancer agents is of utmost necessity. AgNPs also possess substantial anticancer activities,\(^{239}\) as shown in Table 8.

### Anti-inflammatory activity of AgNPs

AgNPs of 20–80 nm were synthesized using *Sambucus nigra* (blackberry) extract. The NPs were characterized using ultraviolet-visible and Fourier-transform infrared spectroscopy.

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### Table 4 Alga-mediated synthesis of AgNPs

| Reducing agent: alga strain | Characterization | Size | Shape | Algae type | Macro/microalgae | Reference |
|----------------------------|-----------------|------|-------|------------|-----------------|-----------|
| *Sargassum wightii* Greville | UV, TEM, XRD, FTIR | TEM (8–27 nm) | Spherical | Brown | Macroalgae | 201 |
| *Caulerpa racemosa* | UV, TEM, FTIR, XRD | TEM (10 nm) | Spherical | Green | Microalgae | 202 |
| Polysaccharide extracted from algae: *Pterocladia capillacea*, *Jania rubins*, *Ulva fasciata*, *Colpomenia sinusa* | UV, TEM, FTIR | TEM (7, 12, and 20 nm for *U. fasciata*, *P. capillacea*, *J. rubins*, and *C. sinusa*, respectively) | Spherical | Red and green | Macroalgae | 203 |
| *Chaetomorpha linum* | UV-vis, SEM, FTIR | SEM (3–44 nm, average ~30 nm) | Varied | Green | Microalgae | 204 |
| *Chaetoceros calctran*, *Chlorella salina*, *Isochrysis galbana*, *Tetraselmis gracilis* | UV, SEM | SEM (53.1–73.9 nm) | NA | Green | Microalgae | 199 |
| *Gelidium amansii* | UV-vis, SEM, FTIR | SEM (27–54 nm) | Spherical | Red | Macroalgae | 205 |

Abbreviations: NPs, nanoparticles; UV-vis, ultraviolet-visible (spectroscopy); TEM, transmission electron microscopy; SEM, scanning electron microscopy; XRD, X-ray diffraction; FTIR, Fourier-transform infrared (spectroscopy).

### Table 5 Fungus-mediated synthesis of AgNPs

| Fungal species used | Characterization | Size | Shape | Reference |
|---------------------|-----------------|------|-------|-----------|
| *Fusarium oxysporum* | UV-vis, TEM, FTIR | TEM (5–50 nm) | Spherical and few triangular | 206 |
| *Verticillium* | UV-vis, TEM, SEM, EDX | TEM (25–12 nm) | Spherical | 207 |
| *Aspergillus fumigatus* | UV-vis, TEM, XRD | TEM (5–25 nm) | Spherical and triangular | 208 |
| *Penicillium fellutanum* | UV-vis, TEM | TEM (5–25 nm) | Spherical | 209 |
| *Aspergillus flavus* | UV-vis, TEM, FTIR, XRD | TEM (8.92±1.61 nm) | NA | 210 |
| *Fusarium semitectum* | UV-vis, TEM, FTIR, XRD | TEM (10–60 nm) | Spherical | 211 |
| *Alternaria alternata* | UV-vis, TEM, SEM, FTIR, EDX | SEM (20–60 nm, average 32.5 nm) | Spherical | 212 |
| *Rhizopus stolonifer* | UV-vis, TEM, SEM, FTIR, AFM | TEM (3 and 20 nm) | Spherical | 213 |
| *Phanerochaete chrysosporium* | UV-vis, TEM, FTIR, AFM, TLC | TEM (34–90 nm) | Spherical and oval | 214 |

Abbreviations: NPs, nanoparticles; UV-vis, ultraviolet-visible (spectroscopy); TEM, transmission electron microscopy; SEM, scanning electron microscopy; EDX, energy-dispersive X-ray (spectroscopy); XRD, X-ray diffraction; FTIR, Fourier-transform infrared (spectroscopy); AFM, atomic force microscopy; TLC, thin-layer chromatography.
| Biological entity                  | Testmicroorganism                                                                 | Method                                      | Reference |
|-----------------------------------|------------------------------------------------------------------------------------|---------------------------------------------|-----------|
| Citrullus colocynthis             | E. coli                                                                           | Agar diffusion method                       | 153       |
| Pterocarpus santalinus            | E. coli                                                                           | NA                                          | 154       |
| Madhuca longifolia flower extract | Bacillus cereus, Staphylococcus saprophyticus, E. coli, Salmonella typhimurium     | Agar well diffusion method                  | 153       |
| Aspergillus clavatus fungus       | E. coli, Pseudomonas aeruginosa                                                   | NA                                          | 220       |
| Chenopodium murale leaf extract   | E. coli                                                                           | Cup–plate agar-diffusion method             | 221       |
| Iresine herbstii leaf extract     | Staphylococcus aureus, Enterococcus faecalis, E. coli                            | Agar-diffusion method                       | 222       |
| Beetroot                          | E. coli, P. aeruginosa, Staphylococcus, Streptococcus                            | NA                                          | 223       |
| Dioscorea bulbifera plant         | St. aureus, E. faecalis, E. coli                                                 | Disk diffusion method                       | 224       |
| Rosa indica flower petals         | E. coli, P. aeruginosa, Staphylococcus, Streptococcus                            | Agar well diffusion method                  | 225       |
| Ocimum tenuiflorum plant          | NA                                                                                 | Agar well diffusion method                  | 226       |
| Cassia fistula fruit extract      | E. coli, Klebsiella pneumonia                                                     | Disk diffusion method                       | 227       |
| Chitosan polymer                  | S. aureus                                                                         | Parallel-streak method, colony-counting method | 154       |
| Chitosan polymer                  | E. coli (ATCC 25922), S. aureus (ATCC 6538)                                       | Agar disk diffusion method                  | 228       |
| Oxidized AgNPs                    | E. coli                                                                           | Cup–plate agar-diffusion method             | 229       |
| Gallic acid                       | E. coli                                                                           | Microdilution method                       | 230       |
| AgNPs                             | E. coli, Vibrio cholerae, P. aeruginosa, Salmonella typhi                           | Agar diffusion method                       | 73        |

**Abbreviations:** NPs, nanoparticles; NA, not available.
Table 7 Antifungal properties of AgNPs

| Biological entity used for reduction | Fungal species used as test organism | Characterization | Reference |
|-------------------------------------|-------------------------------------|------------------|-----------|
| Green and black tea leaves          | Aspergillus flavus, A. parasiticus  | UV-vis, SEM, FTIR, EDX | 231       |
| Waste dried grass                   | Fusarium solani, Rhizoctonia solani | UV-vis, TEM, XRD   | 232       |
| Dodonaea viscosa and Hyptis suaveolens leaf extracts | Candida albicans (ATCC 90028), C. glabrata (MTCC 3019), C. tropicalis (MTCC 184), clinical isolate (MTCC 11,802) | FTIR, SEM, XRD, DLS, ζ-potential | 233       |
| Cysteine and maltose                | C. albicans (ATCC 10231), C. parapsilosis (ATCC 22019) | UV-vis, TEM, SEM, DLS | 234       |
| Lignin                              | A. niger                           | UV-vis, TEM, SEM, EDS, XRD | 235       |
| Cyanobacterium Nostoc strain HKAR2 cell extract | A. niger, Trichoderma harzianum | UV-vis, TEM, SAED, SEM, FTIR, XRD, ζ-potential | 236       |
| Bergenia ciliate plant extract      | A. fumigatus (FCBP 66), F. solani (FCBP 0291), A. niger (FCBP 0198), A. flavus (FCBP 0064) | UV-vis, SEM, FTIR | 237       |
| Trifolium resupinatum seed extract  | Neofusicoccum parvum, R. solani   | UV-vis, TEM FTIR, XRD | 238       |

Abbreviations: NPs, nanoparticles; UV-vis, ultraviolet-visible (spectroscopy); TEM, transmission electron microscopy; SEM, scanning electron microscopy; XRD, X-ray diffraction; FTIR, Fourier-transform infrared (spectroscopy); DLS, dynamic light scattering; EDX, energy-dispersive X-ray (spectroscopy); EDAX, ED X-ray analysis; SAED, selected-area electron diffraction.

Table 8 Anticancer property of AgNPs

| Biological entity used for reduction | Cancer cells under study | Characterization | Reference |
|-------------------------------------|--------------------------|------------------|-----------|
| Cleome viscosa fruit extract        | Lung (A549) and ovarian (PA1) cancer cell lines | UV-vis, TEM, SEM, FESEM, EDAX, FTIR, XRD | 240       |
| Annona muricata leaf extract        | Human fibroblasts isolated from dermis | UV-vis, TEM, XRD, DLS, ζ-potential | 239       |
| N,N,N-trimethyl chitosan chloride and polyelectrolyte complex | Colon cancer cell lines (HCT116) and Mammalian cell lines (African green monkey kidney cell lines (VERO cells) | HRTEM, FESEM, FTIR, EDX, XRD, 1H NMR | 241       |
| Rheum Rhabarbarum fresh stem extract | Cervical carcinoma HeLa cell line | UV-vis, SEM, TEM, FTIR, EDX, TGA, XRD, ζ-potential | 242       |
| Matricaria chamomilla               | A549 lung cancer cells     | UV-vis, TEM, FESEM, FTIR, XRD EDS, DLS | 243       |
| Zataria multiflora leaf extract     | Cervical carcinoma cells (HeLa cell line) | UV-vis, TEM, FTIR, EDS, DLS, ζ-potential | 96        |
| Phoenix dactylifera hairy-root extract | Human breast cancer (MCF7 cell line) | UV-vis, TEM, FTIR, XRD, FESEM, EDAX, Nanophox spectra analysis, PCCS | 244       |

Abbreviations: NPs, nanoparticles; UV-vis, ultraviolet-visible (spectroscopy); TEM, transmission electron microscopy; SEM, scanning electron microscopy; FESBM, field-emission SEM; HRTEM, high-resolution TEM; XRD, X-ray diffraction; FTIR, Fourier-transform infrared (spectroscopy); AFM, atomic force microscopy; HPLC, high-performance liquid chromatography; DLS, dynamic light scattering; EDX, energy-dispersive X-ray (spectroscopy); EDAX, ED X-ray analysis; TGA, thermogravimetric analysis; PCCS.
spectroscopy and X-ray diffraction, and further investigations were carried out for anti-inflammatory effects, both in vitro and in vivo, against Wister rats.177

**Antiviral activity of AgNPs**

Multidimensional biological activities of AgNPs provide significant antiviral potentiality. HEPES buffer was used to synthesize NPs of 5–20 nm. Postinfection antiviral activity of AgNPs was evaluated using Hut/CCR5 cells using ELISA. AgNPs inhibited HIV1 retrovirus 17%–187% more than the reverse-transcriptase inhibitor azidothymidine triphosphate245. Polysulfone-incorporated AgNPs manifested antiviral and antibacterial activity. This was attributed to the release of sufficient silver ions from the membrane, acting as an antiviral agent.246

**Cardioprotection**

The medicinal herb neem (*Millingtonia hortensis*) has been used to synthesize AgNPs, and showed significant cardioprotective properties in rats.178

**Wound dressing**

Anotechnology has contributed significantly in the area of wound healing, as healing is attributed to increased anti-inflammatory and antimicrobial activity. A cotton fabric treated with NPs of size 22 nm exhibited potent healing power.247 Another advance in this area was made with the impregnation of AgNPs into bacterial cellulose for antimicrobial wound dressing. *Acetobacter xylinum* (strain TISTR 975) was used to produce bacterial cellulose, which was immersed in silver nitrate solution. It was effective against both Gram-positive and Gram-negative bacteria.248 The performance of a polymer is increased by the introduction of inorganic NPs. In this regard, polyurethane solution containing silver ions was reduced by dimethylformamide using electrospinning. Collagen was introduced to increase its hydrophilicity. This collagen sponge incorporating AgNPs had enhanced wound-healing ability in an animal model.249 Most recently, Jacob et al biosynthesized nanoengineered tissue impregnated with AgNPs, which significantly prevented borne bacterial growth on the surface of tissue and could help in controlling health-associated infections.250

**Conclusion**

Nature has its own coaching manners of synthesizing miniaturized functional materials. Increasing awareness of green chemistry and the benefit of synthesis of AgNPs using plant extracts can be ascribed to the fact that it is ecofriendly, low in cost, and provides maximum protection to human health. Green synthesized AgNPs have unmatched significance in the field of nanotechnology. AgNPs cover a wide spectrum of significant pharmacological activities, and the cost-effectiveness provides an alternative to local drugs. Besides plant-mediated green synthesis, special emphasis has also been placed on the diverse bioassays exhibited by AgNPs. This review will help researchers to develop novel AgNP-based drugs using green technology.

**Author contributions**

All authors contributed to data analysis, drafting or revising the article, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

**Disclosure**

The authors report no conflicts of interest in this work.

**References**

1. Prasad R, Swamy VS. Antibacterial activity of silver nanoparticles synthesized by bark extract of Syzygium cumini. *J Nanopart. 2013;*2013:6. doi:10.1155/2013/431218
2. Isaac R, Sakhivvel G, Murthy C. Green synthesis of gold and silver nanoparticles using *Averrhoa bilimbi* fruit extract. *J Nanotechnol. 2013;*2013:6. doi:10.1155/2013/906592
3. Jagtap UB, Bapat VA. Green synthesis of silver nanoparticles using Artocarpus heterophyllus Lam. seed extract and its antibacterial activity. *Ind Crops Prod. 2013;*46:132–137.
4. Phanjom P, Borthakur M, Das R, Dey S, Bhuyan T. Green synthesis of silver nanoparticles using leaf extract of Amaranthus viridis. *Int J Nanotechnol Appl. 2012;*6:53–59.
5. Ghoireishi SM, Behpour M, Khayatkashani M. Green synthesis of silver and gold nanoparticles using Rosa damascena and its primary application in electrochemistry. *Phys E. 2011;*44(1):97–104.
6. Suresh G, Gunasekar PH, Kokila D, et al. Green synthesis of silver nanoparticles using Delphinium denudatum root extract exhibits antibacterial and mosquito larvicidal activities. *Spectrochim Acta A. 2014;127:61–66.
7. Santoshkumar T, Rahuman AA, Bagavan A, et al. Evaluation of stem aqueous extract and synthesized silver nanoparticles using *Cissus quadrangularis* against Hippobosca maculata and Rhipicephalus (Boophilus) microplus. *Exp Parasitol. 2012;*122(2):156–165.
8. Heydari R, Rashidipour M. Green synthesis of silver nanoparticles using extract of oak fruit hull (Jaft): synthesis and in vitro cytotoxic effect on MCF-7 cells. *Int J Breast Cancer. 2015;*2015:6.
9. Rajeshkumar S. Synthesis of silver nanoparticles using fresh bark of Pongamia pinnata and characterization of its antibacterial activity against gram positive and gram negative pathogens. *Resour-Effic Technol. 2016;*2(1):30–35. doi:10.1016/j.refff.2016.06.003
10. Song JY, Kim BS. Biological synthesis of bimetallic Au/Ag nanoparticles using *Persimmon* (Diopyros kaki) leaf extract. *Korean J Chem Eng. 2008;*25(4):808–811. doi:10.1007/s11814-008-0133-7.
21. Baghiizadeh A, Ranjbar S, Gupta VK, et al. Green synthesis of silver nanoparticles using seed extract of Calendula officinalis in liquid phase. J Mol Liq. 2015;207:159–163. doi:10.1016/j.molliq.2015.03.029

22. Rivera-Rangel RD, González-Muñoz MP, Avila-Rodríguez M, Razo-Lazcano TA, Solans C. Green synthesis of silver nanoparticles in oil-in-water microemulsion and nano-emulsion using geranium leaf aqueous extract as a reducing agent. Colloids Surf A. 2018;536:60–67. doi:10.1016/j.colsurfa.2017.07.051

23. Baskaran C, Ratha Bai V. Green synthesis of silver nanoparticles using sallflower flower: structural characterization, and its antibacterial activity on applied wool fabric. J Inorg Organomet Polym Mater. 2018;28(6):2525–2532. doi:10.1007/s10904-018-0925-5

24. Karthiga P. Preparation of silver nanoparticles by Garcinia mangostana stem extract and investigation of the antimicrobial properties. Biotechnol Res Innovation. 2018;2(1):30–36. doi:10.1016/j.birion.2017.11.001

25. Baskaran C, Ratha Bai V. Green synthesis of silver nanoparticles using Coleus forskholii roots extract and its antimicrobial activity against Bacteria and Fungus. Int J Drug Dev Res. 2013;5(1):1–10.

26. Swamy MK, Akhtar MS, Mohanty SK, Sinmiah UK. Synthesis and characterization of silver nanoparticles using fruit extract of Momordica cymbalaria and assessment of their in vitro antimicrobial, antioxidant and cytotoxicity activities. Spectrochim Acta A. 2015;151:939–944.

27. Saliem AH, Ibrahim OM, Salih SI. Biosynthesis of silver nanoparticles using cinnamon zeylanicum plants bark extract. Kafa J Vet Med Sci. 2016;7(1):51-63.

28. Nazeruddin G, Prasad N, Prasad S, Shaikh Y, Waghmare S, Adhyapak P. Coirandrum sativum seed extract assisted in situ green synthesis of silver nanoparticle and its anti-microbial activity. Ind Crops Prod. 2014;60:212–216.

29. Selvakumar P, Sithara R, Viveka K, Sivashanmugam P. Green synthesis of silver nanoparticles using leaf extract of Acrylaca hispida and its application in blood compatibility. J Photochem Photobiol B. 2018;182:52–61.

30. Bharathi D, Kalaiselvam P, Atmaram V, Anbu S. Biogenic synthesis of silver nanoparticles from aqueous flower extract of Bougainvillea specabilis and their antibacterial activity. J Med Plants. 2016;4:248–252.

31. Sreeelakshmy V, Deepa M, Mridula P. Green synthesis of silver nanoparticles from glycyrrhiza glabra root extract for the treatment of gastric ulcer. J Dev Drugs. 2016;5(2):152.

32. Tamilesvari R, Haniff Nisha M, Jesurani S, et al. Synthesis of silver nanoparticles using the vegetable extract of raphanus sativus (Radish) and assessment of their antibacterial activity. Int J Adv Technol Sci Eng. 2015;3(5):207–212.

33. Basi S, Samanta HS, Ganguly J. Green synthesis and swelling behavior of Ag-nanocomposite semi-IPN hydrogels and their drug delivery using Dolichos biflorus Lam. Soft Mater. 2018;16(1):7–19.

34. Irvani S, Zolfaghari B. Green synthesis of silver nanoparticles using Pinus eldarica bark extract. Biomed Res Int. 2013;2013:5.

35. Gavade SM, Nikam G, Dhabre B, Sabale S, Tashmankar B, Mulik G. Green synthesis of silver nanoparticles by using carambola fruit extract and its antimicrobial activity. Adv Nat Sci. 2015;6(4):045015.

36. Mitral AK, Kaler A, Banerjee UC. Free Radical Scavenging and Antioxidant Activity of Silver Nanoparticles Synthesized from Flower Extract of Rhododendron dauricum. Nano Biomed Eng. 2012;4(3):118–124.

37. Upadhyay P, Mishra SK, Purohit S, Dubey G, Singh Chauhan B, Srirkshina S. Antioxidant, antimicrobial and cytotoxic potential of silver nanoparticles synthesized using flavonoid rich alcoholic leaves extract of Reinwardtia indica. Drug Chem Toxicol. 2018;42(1):1–11.

38. Rajagopal T, Jemimah LAA, Ponnmanikanp C, Ayyanar M. Synthesis of silver nanoparticles using Catharanthus roseus root extract and its larvicidal effects. J Environ Biol. 2015;36(6):1283.

39. Carabineiro S. Applications of gold nanoparticles in nanomedicine: recent advances in vaccines. Molecules. 2017;22(5):857.

40. Kaviya S, Santhanakalmhi J, Viswathanathan B, Mathumury J, Srinivasan K. Biosynthesis of silver nanoparticles using Citrus sinensis peel extract and its antibacterial activity. Spectrochim Acta A. 2011;79(3):594–598.

41. Roy K. ‘Green’synthesis of Silver Nanoparticles by Using Grape (Vitis Vinifera) Fruit Extract: Characterization of the Particles & Study of Antibacterial Activity, 2012.

42. Nayak D, Ashe S, Rauta PR, Kumari M, Nayak B. Bark extract mediated green synthesis of silver nanoparticles: evaluation of antimicrobial activity and antiproliferative response against osteosarcoma. Mater Sci Eng C. 2016;58:44–52.

43. Roy K, Biswas S, Banerjee PC. Synthesis of Silver nanoparticles by using grape (Vitis vinifera) fruit extract; characterization of the particles and study of antibacterial activity. Research Journal of Pharmaceutical, Biological and Chemical Sciences. 2013;4(1):1271–1278.

44. Singh J, Dhalwai AS. Novel green synthesis and characterization of the antioxidant activity of silver nanoparticles prepared from nepeta leucophylla root extract. Anat Lett. 2018;52(2):1–18.

45. Mishra MP, Padhy RN. Antibacterial activity of green silver nanoparticles synthesized from Anogeissus acuminata against multidrug resistant urinary tract infecting bacteria in vitro and host-toxicity testing. J Appl Biomed. 2018;16(2):120–125.
44. Baharara J, Namvar F, Ramezani T, Hosseini N, Mohamad R. Green synthesis of silver nanoparticles using Achillea biebersteinii flower extract and its anti-angiogenic properties in the rat aortic ring model. Molecules. 2014;19(4):4624–4634.

45. Ahmad N, Sharma S, Rai R. Rapid green synthesis of silver and gold nanoparticles using peels of Punica granatum. Adv Mater Lett. 2012;3(5):376–380.

46. Mukunthan K, Balaji S. Cashew apple juice (Anacardium occidentale L.) speeds up the synthesis of silver nanoparticles. Int J Green Nanotechnol. 2012;4(2):71–79.

47. Kaur R, Singh J, Tripathi S. Incorporation of inorganic nanoparticles into an organic polymer matrix for data storage application. Current Appl Phys. 2017;17(5):756–762.

48. Raut Rajesh W, Lakakakula Jaya R, Kolekar Niranjan S, Mendhulkar Vijay D, Kashid Sahebrao B. Phytosynthesis of silver nanoparticle using Gliricidia sepium (Jacq.). Curr Nanosci. 2009;5(1):117–122.

49. Mata R, Nakkala JR, Sadras SR. Catalytic and biological activities of green silver nanoparticles synthesized from Plumeria alba (frangipani) flower extract. Mater Sci Eng C. 2015;51:216–225.

50. Benakshani F, Allafchian A, Jalali SAH. Green synthesis, characterization and antibacterial activity of silver nanoparticles from root extract of Lepidium draba weed. Green Chem Lett Rev. 2014;75:330–339.

51. Velayutham K, Rahuman AA, Rajakumar G, et al. Larvicidal activity of green synthesized silver nanoparticles using bark aqueous extract of Ficus racemosa against Culex quinquefasciatus and Culex gelidus. Asian Pac J Trop Med. 2013;6(2):95–101.

52. Kahrilas GA, Wally LM, Fredrick SJ, Hisky M, Prieto AL, Owens JE. Microwave-assisted green synthesis of silver nanoparticles using orange peel extract. ACS Sustainable Chem Eng. 2013;2(3):367–376.

53. Gao Y, Huang Q, Su Q, Liu R. Green synthesis of silver nanoparticles at room temperature using kiwifruit juice. Spectrosc Lett. 2014;47(10):790–795.

54. Abdal Dayem A, Hossain MK, Lee SB, et al. The role of reactive oxygen species (ROS) in the biological activities of metallic nanoparticles. Int J Mol Sci. 2017;18(1):120.

55. Huang J, Li Q, Sun D, et al. Biosynthesis of silver and gold nanoparticles by novel sundried Cinnamomum camphora leaf. Nanotechnology. 2007;18(10):105104.

56. Gogoi N, Babu PJ, Mahanta C, Bora U. Green synthesis and characterization of silver nanoparticles using alcoholic flower extract of Nyctanthes arbortristis and in vitro investigation of their antibacterial and cytotoxic activities. Mater Sci Eng C. 2015;46:463–469.

57. Kumar D, Kumar G, Agrawal V. Green synthesis of silver nanoparticles using Hollarithra antisynterciera (L.) Wall. bark extract and their larvicidal activity against dengue and filariasis vectors. Parasitol Res. 2018;117(2):377–389.

58. Bankar A, Joshi B, Kumar AR, Zinjarde S, Banana peel extract mediated novel route for the synthesis of silver nanoparticles. Colloids Surf A. 2010;368(1):58–63.

59. Ulag B, Turkdemir MH, Cicek A, Mete A. Role of irradiation in the green synthesis of silver nanoparticles mediated by fig (Ficus carica) leaf extract. Spectrochim Acta A. 2015;135:153–161.

60. Fukui H. Development of new cosmetics based on nanoparticles. In: Naito M, Yokoyama T, Hosokawa K, Nogi K, editors. Nanoparticle Technology Handbook. 3rd ed. Elsevier; 2018:845–877. ISBN: 978-0-444-64110-6

61. Sasikala A, Rao ML, Savithramma N, Prasad T. Synthesis of silver nanoparticles from stem bark of Cochlospermum religiosum (L.) Alston: an important medicinal plant and evaluation of their antimicrobial efficacy. Appl Nanosci. 2015;5(7):827–835.

62. Erosa MSD, Diaz MMC, Lazeano TAR, Rodriguez MA, Aguiler JAR, Del Pilar González-Muñoz M. Aqueous leaf extracts of Cnidoscolus chayamansa (Mayan chaya) cultivated in Yucatán México. Part II: for the phytomimetic synthesis of silver nanoparticles. Mater Sci Eng C. 2018;91:838–852.

63. Vijayan R, Joseph S, Mathew B. Green synthesis of silver nanoparticles using Nervalia zeylanica leaf extract and evaluation of their antioxidant, catalytic, and antimicrobial potentials. Part Sci Technol. 2018;36:1–11.

64. Fathima JB, Pugazhendi A, Oves M, Venis R. Synthesis of eco-friendly copper nanoparticles for augmentation of catalytic degradation of organic dyes. J Mol Liq. 2018;260:1–8.

65. Cruz D, Falé PL, Mourato A, Vaz PD, Serralheiro ML, Lino ARL. Preparation and physicochemical characterization of Ag nanoparticles biosynthesized by Lippia citroidora (Lemon Verbena). Colloids Surf B. 2010;81(1):67–73.

66. Sharma P, Bhatt D, Zaidi M, Saradhi PP, Khanna P, Arora S. Silver nanoparticle-mediated enhancement in growth and antioxidant status of Brassica juncea. Appl Biochem Biotechnol. 2012;167(8):2225–2233.

67. Ashokkumar S, Ravi S, Velmurugan S. Green synthesis of silver nanoparticles from Gloriosa superba L. leaf extract and their catalytic activity. Spectrochim Acta A Mol Biomol Spectrosc. 2013;115:388–392.

68. Zhang J, Si G, Zou J, Fan R, Guo A, Wei X. Antimicrobial Effects of Silver Nanoparticles Synthesized by Fatsia japonica Leaf Extracts for Preservation of Citrus Fruits. J Food Sci. 2017;82(8):1861–1866.

69. McGillicuddy E, Murray I, Kavanagh S, et al. Silver nanoparticles in the environment: sources, detection and ecotoxicology. Sci Total Environ. 2017;575:231–246.

70. Ashokkumar S, Ravi S, Kathiravan V, Velmurugan S. Synthesis, characterization and catalytic activity of silver nanoparticles using Tribulus terrestris leaf extract. Spectrochim Acta A Mol Biomol Spectrosc. 2014;121:88–93.

71. Kumar PSM, MubarakAli D, Saratale RG, et al. Synthesis of nanocobaloid gold particles for effective antimicrobial property against clinical human pathogens. Microb Pathog. 2017;113:68–73.

72. Philip D, Unni C, Aromal SA, Vidhu V. Murraya koenigii leaf extract of Nyctanthes arbortristis and in vitro investigation of their antibacterial and larvicidal activity against dengue and filariasis vectors. Spectrochim Acta A. 2011;78(2):899–904.

73. Morones JR, Elechiguerra JL, Camacho A, et al. The bactericidal effect of silver nanoparticles. Nanotechnology. 2005;16(10):2346.

74. Vijayan SR, Santhiyagu P, Ramasamy R, et al. Seaweeds: a resource for marine bionanotechnology. Enzyme Microb Technol. 2016;95:45–57.

75. Veerasamy R, Xint TZ, Gunasagaran S, et al. Biosynthesis of silver nanoparticles using mangosteen leaf extract and evaluation of their antimicrobial activities. J Saudi Chem Soc. 2011;15(2):113–120.

76. Chaudhuri RG, Paria S. Core/shell nanoparticles: classes, properties, synthesis mechanisms, characterization, and applications. Chem Rev. 2012;112(4):2373–2433.

77. Philip D, Mangifera indica leaf-assissted biosynthesis of well-dispersed silver nanoparticles. Spectrochim Acta A. 2011;78(1):327–331.

78. Zhu M-Q, Zhu L, Han J, Wu W, Hurst JK, Li AD. Spiropyran-based photochromic polymer nanoparticles with optically switchable luminescence. J Am Chem Soc. 2006;128(13):4303–4309.

79. Arunachalam KD, Annamalai SK, Hari S. One-step green synthesis and characterization of leaf extract-mediated biocompatible silver and gold nanoparticles from Memecylon umbellatum. Int J Nanomedicine. 2013;8(3):1307–1315.

80. Ulbrich K, Hola K, Subr V, Bakandritsos A, Tucek J, Zboril R. Targeted drug delivery with polymers and magnetic nanoparticles: covalent and noncovalent approaches, release control, and clinical studies. Chem Rev. 2016;116(9):5338–5431.
Ahmad et al.

81. Singh P, Kim YJ, Yang DC. A strategic approach for rapid synthesis of gold and silver nanoparticles by Panax ginseng leaves. *Artif Cells Nanomed Biotechnol*. 2016;44(8):1949–1957.

82. Dhole SM, Kulkarni NS. Investigation of in vitro and in vivo atifungal property of biologically synthesized copper nanoparticles (CuNP) against rhizoctonia solani a phytopathogen of soyaabean (Glycine max, L. Merrill). *Int J Eng Sci Generic Res*. 2018;4(5):17–30.

83. Wang C, Mathiyalagan R, Kim YJ, et al. Rapid green synthesis of silver and gold nanoparticles using Dendropanax morifolia leaf extract and their anticancer activities. *Int J Nanomedicine*. 2016;11:3691.

84. Payne JN, Waghwani HK, Connor MG, et al. Novel synthesis of kanamycin conjugated gold nanoparticles with potent antibacterial activity. *Front Microbiol*. 2016;7:607.

85. Hubbuch J. *Novel self patent gold nanoparticles for antineoplastic activity*: poster presented at: posters-at-capitol wisteren kenny university; march 3; 2016. United state of America. Available from:https://digitalcommons.murraystate.edu/postersatthecapitol/2016/WKU/10.

86. Kumar PV, Kala SMJ. Green Synthesis, Characterisation and Biological Activity of Platinum Nanoparticle Using Croton Caudatus Geisel Leaf Extract. *Int J Recent Res Aspects* (Special Issue:Conscientious Computing Technologies). 2018; 608-612.

87. Kouvaris P, Delimitis A, Zaspalis V, Papadopoulos D, Tsipas SA, Michalidis N. Green synthesis and characterization of silver nanoparticles produced using Arbutus unedo leaf extract. *Mater Lett*. 2012;76:18-20.

88. Malaei R, Farhadi K, Forough M, Hajizadeh S. Green Biological Fabrication and Characterization of Highly Monodisperse Palladium Nanoparticles Using Pistacia Atlantica Fruit Broth. *J Nanostruct*. 2018;8(4):47–54.

89. Liong M, Lu J, Tamanoi F, Zink JI, Nel A. Mesoporous silica nanoparticles for biomedical applications. Google Patents; 2018.

90. Keshwarwani J, Yoon KY, Hwang J, Rai M. Photofabrication of silver nanoparticles by leaf extract of Datura metel: hypothetical mechanism involved in synthesis. *J BiomanoSci*. 2009;3(1):39–44.

91. Woodard A, Xu L, Barragan AA, Nava G, Wong BM, Mangolini L. On the non-thermal plasma synthesis of nickel nanoparticles. *J Mater Chem*. 2018;28(3):1246-1248.

92. Zayed MF, Elaia WH, Shabaka A. Malva parviflora extract assisted green synthesis of silver nanoparticles. *Spectrochim Acta A*. 2012;98:423–428.

93. Karuppiah M, Rajmohan R. Green synthesis of gold nanoparticles using *Ixora coccinea* leaves extract. *Mater Lett*. 2013;97:141–143.

94. Raja A, Ashokkumar S, Marthandan RP, et al. Eco-friendly preparation of zinc oxide nanoparticles using Tabernaemontana divaricata and its photocatalytic and antimicrobial activity. *J Photochem Photobiol B*. 2018;181:53–58.

95. Uozumi Y, Kim K. Synthesis of Imidazo [1, 2-a] pyrimidines by A3-Coupling on CuO Nanoparticles. *Synfacts*. 2018;14(08):0883.

96. Baharara J, Ramezani T, Hosseini N, Mousavi M. Silver Nanoparticles Synthesized Coating with Zataria Multiflora Leaves Extract Induced Apoptosis in HeLa Cells Through p53 Activation. *Ipr*. 2018;17(2):627.

97. Muthukumar H, Mohammed SN, Chandrasekar N, Sekar AD, Pugazhendhi A, Matheswaran M. Effect of iron doped Zinc oxide nanoparticles coating in the anode on current generation in microbial electrochemical cells. *Int J Hydrogen Energy*. 2018.

98. Yakop F, Abd Ghafar SA, Yong YK, et al. Silver nanoparticles Clinacanthus Nutans leaves extract induced apoptosis towards oral squamous cell carcinoma cell lines. *Artif Cells Nanomed Biotechnol*. 2018;1–9.

99. Fard SE, Tavfizi F, Torbati MB. Silver nanoparticles biosynthesised-using Centella asiatica leaf extract: apoptosis induction in MCF-7 breast cancer cell line. *IET Nanobiotechnol*. 2018;12(7):994–1002. doi:10.1049/iet-nbt.2018.5069

100. Pugazhendhi A, Prabhu R, Muruganathan K, Shanmuganathan R, Natarajan S. Anticancer, antimicrobial and photocatalytic activities of green synthesized magnesium oxide nanoparticles (MgONPs) using aqueous extract of Sargassum wightii. *J Photochem Photobiol B*. 2019;190:86–97. doi:10.1016/j.jphotobiol.2018.11.014

101. Jha AK, Prasad K. Green synthesis of silver nanoparticles using Cynas leaf. *Int J Green Nanotechnol*. 2010;12(12):P110–P117. doi:10.1080/19340871003684572

102. Gautam SP, Saxena G, Singh V, Yadav AK, Bharagava RN, Thapa KB. Green synthesis of TiO2 nanoparticles using leaf extract of Jatropha curcas L. for photocatalytic degradation of tannery wastewater. *Chem Eng J*. 2018;336:386–396. doi:10.1016/j.cej.2017.12.029

103. Siubalan N, Ramkumar VS, Pugazhendhi A, et al. ROS-mediated cytotoxic activity of ZnO and CeO2 nanoparticles synthesized using the Rubia cordifolia L. leaf extract on MG-63 human osteosarcoma cell lines. *Environ Sci Pollut Res*. 2017;25(11):10482–10492.

104. Fathima JB, Pugazhendhi A, Venis R. Synthesis and characterization of ZnO2 nanoparticles-antimicrobial activity and their prospective role in dental care. *Microb Pathog*. 2017;110:245–251. doi:10.1016/j.micpath.2017.06.039

105. Larson JK, Carvan MJ, Hutz RJ. Engineered nanomaterials: an emerging class of novel endocrine disruptors. *Biol Reprod*. 2014;91(1):20. doi:10.1095/biolreprod.114.121434

106. Jeevanandam J, Barhoum A, Chan YS, Dufresne A, Danquah MK. Review on nanoparticles and nanomaterials: history, sources, toxicity and regulations. *Beilstein J Nanotechnol*. 2018;9(1):1050–1074. doi:10.3762/bjnano.9.98

107. Pachapur V, Brar SK, Verma M, Surampalli RY. Nanomaterials in the Environment: In: Nano-Ecotoxicology of Natural and Engineered Nanomaterials for Animals and Humans. American society of civil engineering library. 2015:421-437.

108. Khan I, Saeed K, Khan I. Nanoparticles: properties, applications and toxicities. *Arabian J Chem*. 2017. doi:10.1016/j.arabjc.2017.05.011

109. Ranjit K, Baquee AA. Nanoparticle: an overview of preparation, characterization and application. *Int. Res. J. Pharm.*. 2013;4(4):47–57.

110. Bhatia S. Natural Polymer Drug Delivery Systems: Nanoparticles, Plants, and Algae. Springer International Publishing. HolderSpringer International Publishing. Switzerland. 2016:133-93.

111. Sanjay SS, Pendye AC. A brief manifestation of nanotechnology. In: Ashutosh Kumar Shakula, editor. EMR/ESR/EPF Spectroscopy for Characterization of Nanomaterials. Springer; 2017:47–63.

112. Arole V, Munde S. Fabrication of Nanomaterials by Top-down and Bottom-up Approaches- An overview. *J Adv Appl Sci Technol*. 2014;1(2):89–93.

113. Thakkar KN, Mhatre SS, Parikh RY. Biological synthesis of metallic nanoparticles. *Nanomedicine*. 2010;6(2):257–262. doi:10.1016/j.nano.2009.07.002

114. Ali SW, Rajendran S, Joshi M. Synthesis and characterization of chitosan and silver loaded chitosan nanoparticles for bioactive polyester. *Carbohydr Polym*. 2011;83(2):438–446. doi:10.1016/j.carbpol.2010.08.004

115. Tejamaya M, RöMer I, Merrier RC, Lead JR. Stability of metallic nanoparticles. *Frontiers in Nanotechnology*. 2018;10(1):1–9.

116. Pal S, Tak YK, Song JM. Does the antibacterial activity of silver nanoparticles depend on the shape of the nanoparticle? A study of the gram-negative bacterium Escherichia coli. *Appl Environ Microbiol*. 2007;73(6):1712–1720. doi:10.1128/AEM.02218-06
1. Shirvastava S, Bera T, Roy A, Singh G, Ramachandrarao P, Dash D. Characterization of enhanced antibacterial effects of novel silver nanoparticles. Nanotechnology. 2007;18(22):225103. doi:10.1088/0957-4484/18/49/495102

2. Dubas ST, Kumigadzudzana P, Potiyaraj P. Layer-by-layer deposition of antimicrobial silver nanoparticles on textile fibers. Colloids Surf A. 2006;289(1):105–109. doi:10.1016/j.colsurfa.2006.04.012

3. Ahmad S, Ahmad M, Swami BL, Ikram S. A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: a green expertise. J Adv Res. 2016;7(1):17–28. doi:10.1016/j.jare.2015.02.007

4. Raveendran P, Fu J, Wallen SL. Completely “green” synthesis and stabilization of metal nanoparticles. J Am Chem Soc. 2003;125(46):13940–13941. doi:10.1021/ja029267j

5. Daphne J, Francis A, Mohanty R, Ojha N, Das N. New Synthesis of Antibacterial Silver Nanoparticles using Yeast Isolates and its Characterization. Res J Pharm Technol. 2018;11(1):83–92. doi:10.9598/0974-360X.2018.00016.1

6. Mohamad NAN, Arham NA, Jai J, Hadi A. Plant Extract as Reducing Agent in Synthesis of Metallic Nanoparticles: A Review. Advanced Materials Research. 2014;832: 350–355.

7. Soman A, Firouz J, Bharathi V, et al. Phytochemical screening of silver nanoparticles extract of Eugenia jambolana using Fourier infrared spectroscopy. Int J Res Pharm Sci. 2017;8(3):383–387.

8. Banerjee P, Nath D. A phytochemical approach to synthesize silver nanoparticles for non-toxic biomedical application and study on their antibacterial efficacy. Nanosci Technol. 2015;2(1):1–14.

9. Hazarika D, Phukan A, Saikia E, Chetia B. Phytochemical screening and synthesis of silver nanoparticles using leaf extract of Rynchotococcus ellipticum. Int J Pharm Sci. 2014;6(1):672–674.

10. Stephen A, Seethalakshmi S. Phytochemical synthesis and preliminary characterization of silver nanoparticles using hesperidin. J Nanosci. 2013;13(5):5. doi:10.1155/2013/125654

11. Martinez-Bennett D, Silva-Granados A, Correa-Torres S, Herrera A. Chromatographic analysis of phytochemicals components present in mangifera indica leaves for the synthesis of silver nanoparticles by AgNO3 reduction. Paper presented at: Journal of Physics: Conference Series Vol. 687; 2016.

12. Mallikarjuna K, Sushma NJ, Narasimha G, Manoj L, Raju BDP. Phytochemical fabrication and characterization of silver nanoparticles by using Pepper leaf broth. Arabian J Chem. 2014;7(6):1099–1103. doi:10.1016/j.arabjc.2012.04.001

13. Kumar B, Smita K, Cumbal L, Debut A. Green synthesis of silver nanoparticles by using Pepper leaf broth. Saudi J Biol Sci. 2017;24(1):45–50. doi:10.1016/j.sjbs.2015.09.006

14. Kumar CMK, Yugandhar P, Savithramma N. Biological synthesis of silver nanoparticles from Adansonia digitata L. fruit pulp extract, characterization, and its antimicrobial properties. J Intercell Ethnopharmacol. 2016;5(1):79. doi:10.5455/jic.2016.06.012

15. Malakozhundan B, Vijayakumaran S, Vaseeharan B, et al. Two potential uses for silver nanoparticles coated with Solanum nigrum unripe fruit extract: biofilm inhibition and photodegradation of dye effluent. Microb Pathog. 2017;111:316–324. doi:10.1016/j.micpath.2017.08.039

16. Rad MS, Rad JS, Heshmati GA, Miri A, Sen DJ. Biological synthesis of gold and silver nanoparticles by Nitraria schoberi fruits. Open J Adv Drug Delivery. 2013;1(2):174–179.

17. Naganathan K, Thirunavukkarasu S. Green way genesis of silver nanoparticles using multiple fruit peel wastes and its antimicrobial, anti-oxidant and anti-tumor cell line studies. Paper presented at 2nd International Conference on Mining, Material and Metallurgical Engineering: IOP Conference Series: Materials Science and Engineering191; 2017. doi:10.1088/1757-899X/191/1/012009

18. Song JY, Kim BS. Rapid biological synthesis of silver nanoparticles using plant leaf extracts. Bioprocess Biosyst Eng. 2009;32(1):79. doi:10.1007/s00449-008-0224-6

19. Huang H, Yang X. Synthesis of polysaccharide-stabilized gold and silver nanoparticles: a green method. Carbohydr Res. 2004;339(15):2627–2631. doi:10.1016/j.carres.2004.08.005

20. Vigneshwaran N, Nachane R, Balasubramanya R, Varadarajan P. A novel one-pot ‘green’ synthesis of stable silver nanoparticles using soluble starch. Carbohydr Res. 2006;341(12):2012–2018. doi:10.1016/j.carres.2006.04.042

21. Guidelli EJ, Ramos AP, Zaniquelli MED, Baffa O. Green synthesis of colloidal silver nanoparticles using natural rubber latex extracted from Hevea brasiliensis. Spectrochim Acta A. 2011;82(1):140–145. doi:10.1016/j.saa.2011.07.024

22. Shamel K, Ahmad MB, Zamanian A, et al. Green biosynthesis of silver nanoparticles using Curcuma longa tuber powder. Int J Nanomedicine. 2012;7:5603. doi:10.2147/IJN.S30631

23. Umoren S, Oboh I, Gasem Z. Green synthesis and characterization of silver nanoparticles using red apple (Malus domestica) fruit extract at room temperature. J Mater Environ Sci. 2014;5:907–914.

24. Lu R, Yang D, Cui D, Wang Z, Guo L. Egg white-mediated green synthesis of silver nanoparticles with excellent biocompatibility and enhanced radiation effects on cancer cells. Int J Nanomed. 2012;7:2101. doi:10.2147/IJN.S30631

25. Massurkar SA, Chaudhari PR, Shidore VB, Kamble SP. Rapid biosynthesis of silver nanoparticles using Cymbopogan citratus (lemongrass) and its antimicrobial activity. Nano-Micro Lett. 2011;3(3):189–194. doi:10.1007/BF03355671

26. Nanagouda NM, Varma RS. Green synthesis of silver and palladium nanoparticles at room temperature using coffee and tea extract. Green Chem. 2008;10(8):859–862. doi:10.1039/b804703k

27. Begum NA, Mondal S, Basu S, Laskar RA, Mandal D. Biogenic synthesis of Au and Ag nanoparticles using aqueous solutions of Black Tea leaf extracts. Colloids Surf B. 2009;71(1):113–118. doi:10.1016/j.colsurfb.2009.01.012

28. Pande N, Jaspal DK, Ambekar J. Ecofriendly synthesis and applications of silver nanoparticles. J Chem Pharm Res. 2014;6(9):403–410.

29. Awad AM, Salem NM, Abdene AO. Green synthesis of silver nanoparticles using carbob leaf extract and its antibacterial activity. Int J Ind Chem. 2013;4(1):29. doi:10.1186/2228-5547-4-29

30. Sulaiman GM, Mohammed WH, Marzoog TR, Al-Amyeri AAA, Kadhum AAH, Mohamad AB. Green synthesis, antimicrobial and cytotoxic effects of silver nanoparticles using Eucalyptus chapmaniana leaves extract. Bioprocess Biosyst Eng. 2018;41(6):63. doi:10.1007/s00449-016-1696-0

31. Mousavi B, Tafvizi F, Zaker Bostanabad S. Green synthesis of silver nanoparticles using Artemisia turcomanica leaf extract and the study of anti-cancer effect and apoptosis induction on gastric cancer cell line (AGS). Artif Cells Nanomed Biotechnol. 2018;46(11):1–12. doi:10.1080/21691401.2018.1430697

32. Kumara V, Verma S, Choudhury S, Tyagid M, Chatterjee M, Varjarya PS. Biocompatible silver nanoparticles from vegetable waste: its characterization and bio-efficacy. Int J Nano Mat Sci. 2015;4(1):70–86.

33. Sathishkumar M, Sneha K, Won S, Cho C-W, Kim S, Yun Y-S. Cinnamon zeylanicum bark extract and powder mediated green synthesis of metallic nanoparticles using natural rubber latex and the study of the anti-cancer effect and apoptosis induction on gastric cancer cell line (AGS). Artif Cells Nanomed Biotechnol. 2018;46(11):1–12. doi:10.1080/21691401.2018.1430697

34. Ojha S. Green Synthesis of Metallic Nanoparticles Using Leaf Extract of Selected Silkworm Host Plants and Their Applications. Indian institute of technology Guwahati. Department of Biosciences and Bioengineering; 2018.
Ahmad et al. | International Journal of Nanomedicine 2019:14

151. Jebakumar Immanuel Edison TN, Sethuraman MG. Electrocatlytic reduction of benzyl chloride by green synthesized silver nanoparticles using pod extract of Acacia nilotica. ACS Sustainable Chem Eng. 2013;1(10):1326–1332. doi:10.1021/sc4001725

152. Mallikarjuna K, Narasimha G, Dillip G, et al. Green synthesis of silver nanoparticles using Ocimum leaf extract and their characterization. Dig J Nanomater Biostruct. 2011;6(1):181–186.

153. Satyavani K, Ramanathan T, Gurudeeban S. Plant mediated synthesis of biomedical silver nanoparticles by using leaf extract of Citrullus colocynthis. Res J Nanosci Nanotechnol. 2011;1(2):95–101. doi:10.3923/jinn.2011.95.101

154. Arunachalam R, Dhanasingh S, Kalimuthu B, Uthirappan M, Rose C, Mandal AB. Phyto-synthesis of silver nanoparticles using Coccinia grandis leaf extract and their application in the photocatalytic degradation. Colloids Surf B. 2012;94:226–230. doi:10.1016/j.colsurfb.2012.01.040

155. Gopinath K, Gowri S, Arumugam A. Phyto-synthesis of silver nanoparticles using Pterocarpus santalinus leaf extract and their antibacterial properties. J Nanostruct Chem. 2013;3(1):68. doi:10.1186/2193-8865-3-68

156. Vanaja M, Annadurai G. Coleus aromaticus leaf extract mediated synthesis of silver nanoparticles and its bactericidal activity. Appl. Nanosci. 2013;3(3):217–223. doi:10.1007/s13204-012-0121-9

157. Bar H, Bhui DK, Sahoo GP, Sarkar P, Pyne S, Misra A. Green reduction of benzyl chloride by green synthesized silver nanoparticles by using pod extract of Acacia nilotica. Mater Lett. 2010;64(1):181–184. doi:10.1016/j.matlet.2009.11.081

158. Mallikarjuna K, Balasubramanyam K, Narasimha G, Kim H. Phyto-synthesis and antibacterial studies of bio-based silver nanoparticles using Sesbania grandiflora (Avisa) leaf tea extract. Mater Res Express. 2018;5(1):015054. doi:10.1088/2053-1591/aa67d

159. Vasanth K, Ilango K, MohanKumar R, Agrawal A, Dubey GP. Anticancer activity of Moringa oleifera mediated silver nanoparticles on human cervical carcinoma cells by apoptosis induction. Colloids Surf B. 2014;117:354–359. doi:10.1016/j.colsurfb.2014.02.052

160. Sankar R, Karthik A, Prabu A, Karthik S, Shivashangari KS, Ravikumar V. Origanum vulgare mediated biosynthesis of silver nanoparticles for its antibacterial and anticancer activity. Colloids Surf B. 2013;108:80–84. doi:10.1016/j.colsurfb.2013.02.033

161. Prabhuj D, Arulvasu C, Babu G, Manikanandar R, Srinivasan P. 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. 2013;48(2):317–324. doi:10.1016/j.procbio.2012.12.013

162. Rajaram K, Aiswarya D, Sureshkumar P. Green synthesis of silver nanoparticle using Tephrosia tinctoria and its anti-diabetic activity. Mater Lett. 2015;138:251–254. doi:10.1016/j.matlet.2014.10.017

163. Kumar HAK, Mandal BK, Kumar KM, et al. Antimicrobial and antioxidant activities of Mimusops elengi seed extract mediated isotropic silver nanoparticles. Spectrochim Acta A. 2014;130:13–18. doi:10.1016/j.saa.2014.03.024

164. Kumar DA, Palanchamy V, Roopan SM. Green synthesis of silver nanoparticles using Alternanthera dentata leaf extract at room temperature and their antimicrobial activity. Spectrochim Acta A. 2014;127:168–171. doi:10.1016/j.saa.2014.02.058

165. Nabiakh B, Kandasamy K, Raj A, Alkunhi NM. Synthesis of antimicrobial silver nanoparticles by callus and leaf extracts from saltmarsh plant, Sesuvium portulastrum L. Colloids Surf B. 2010;79(2):468–493. doi:10.1016/j.colsurfb.2010.05.018

166. Muniyappan N, Nagarajan N. Green synthesis of silver nanoparticles with Dalbergia spinnosa leaves and their applications in biological and catalytic activities. Process Biochem. 2014;49(6):1054–1061. doi:10.1016/j.procbio.2014.03.015

167. David L, Moldovan B, Vulea A, et al. Green synthesis, characterization and anti-inflammatory activity of silver nanoparticles using European black elderberry fruits extract. Colloids Surf B. 2014;122:767–777. doi:10.1016/j.colsurfb.2014.08.018

168. Savitha R, Saraswathi U. A study on the preventive effect of silver nano particles synthesized from millingtonia hortensis in isooproterenol induced cardiac toxicity in male wistar rats. World J Pharm Technol. 2016;5(8):1442–1450.

169. Atale N, Saxena S, Nirmala JG, Narendhirakann R, Mohanty S, Rani V. Synthesis and characterization of Syzygium cumini nanoparticles for its protective potential in high glucose-induced diabetic stress: a green approach. Appl Biochem Biotechnol. 2017;181(3):1140–1154. doi:10.1007/s12010-016-2274-6

170. Chitra G, Balasubramani R, Ramkumar R, Sowmiya R, Perumal A, Mukim M, MUKIM M. M. maderaspatana (Cucurbitaceae) extract-mediated synthesis of silver nanoparticles to control Culex quinquefasciatus and Aeles aegypti (Diptera: Culicidae). Parasitol Res. 2015;114(4):1407–1415. doi:10.1007/s00436-015-4320-7

171. Santhoshkumar T, Rahuman AA, Rajakumar G, et al. Synthesis of silver nanoparticles using Nelumbo nucifera leaf extract and its larvicidal activity against malaria and filariasis vectors. Parasitol Res. 2011;108(3):693–702. doi:10.1007/s00436-010-1915-4

172. Gnanadesigan M, Anand M, Ravikumar S, et al. Biosynthesis of silver nanoparticles by using mangrove plant extract and their potential mosquito larvicidal property. Asian Pac J Trop Med. 2011;4(10):799–803. doi:10.1016/S1995-7645(11)60197-1
183. Li X, Xu H, Ren Z-S, Chen G. Biosynthesis of nanoparticles by microorganisms and their applications. *J Nanomater*. 2011;2011:16. doi:10.1155/2011/270974

184. Otari S, Patil R, Ghosh S, Thorat N, Pawar S. Intracellular synthesis of silver nanoparticles by actinobacteria and its antimicrobial activity. *Spectrochim Acta A*. 2015;136:1175–1180. doi:10.1016/j.saa.2014.10.003

185. Kannan N, Subbalaxmi S. Green synthesis of silver nanoparticles using Bacillus subtilis IA751 and its antimicrobial activity. *Res J Nanosci Nanotechnol*. 2011;11(2):87–94. doi:10.3923/rjnn.2011.87.94

186. Malarkodi C, Rajeshkumar S, Paulkumar K, Gnanajobitha G, Vanaja M, Annadurai G. Biological synthesis of silver nanoparticles by using optimized biomass growth of Bacillus sp. *J Nanosci Nanotechnol*. 2013;3:26–32.

187. Hallol M. Studies on Bacterial Synthesis of Silver Nanoparticles Using Gamma Radiation and Their Activity against Some Pathogenic Microbes. Cairo (Egypt): Department of Microbiology and Immunology, Cairo University; 2013.

188. Das VL, Thomas R, Varghese RT, Soniya E, Mathew J, Radhakrishnan E. Extracellular synthesis of silver nanoparticles by the Bacillus strain CS 11 isolated from industrialized area. *J Biotech*. 2014;4(2):121–126. doi:10.1271/s13205-013-0130-8

189. Saravanan C, Rajesh R, Kaviarasanan T, Muthukumar K, Kavitha D, Shetty PH. Synthesis of silver nanoparticles using bacterial exopolysaccharide and its application for degradation of azo-dyes. *Biotechnol Rep*. 2017;15:33–40. doi:10.1016/j.btre.2017.02.006

190. Gándhi H, Khan S. Biological synthesis of silver nanoparticles and its antibacterial activity. *J Nanomed Nanotechnol*. 2016;7(2):366. doi:10.4172/2157-7439.1000366

191. Sadhasivam S, Shanmugam P, Yun K. Biosynthesis of silver nanoparticles by Streptomyces hygrosoripsis and its antimicrobial activity against medically important pathogenic microorganisms. *Colloids Surf B*. 2010;81(1):358–362. doi:10.1016/j.colsurfb.2010.07.036

192. Sintubin L, De Windt W, Dick J, et al. Lactic acid bacteria as reducing and capping agent for the fast and efficient production of silver nanoparticles. *Appl Microbiol Biotechnol*. 2009;84(4):741–749. doi:10.1007/s00253-009-1932-6

193. Shahverdi AR, Minaein S, Shahverdi HR, Jamalifar H, Nohi -A-A. Rapid synthesis of silver nanoparticles using culture supernatants of Enterobacteria: a novel biological approach. *Process Biochem*. 2007;42(5):919–923. doi:10.1016/j.procbio.2007.02.005

194. Parikh RY, Ramanathan R, Coloe PJ, et al. Genus-wide physicochemical evidence of extracellular crystalline silver nanoparticles biosynthesis by Morganella spp. *PLoS One*. 2011;6(6):e21401. doi:10.1371/journal.pone.0021401

195. Gurunathan S, Kalishwaralal K, Vaidyanathan R, et al. Biosynthesis, purification and characterization of silver nanoparticles using Escherichia coli. *Colloids Surf B*. 2009;74(1):328–335. doi:10.1016/j.colsurfb.2009.07.048

196. Shivaji S, Madhu S, Singh S. Extracellular synthesis of antibacterial silver nanoparticles using psychrophiles bacteria. *Process Biochem*. 2011;46(9):1800–1807. doi:10.1016/j.procbio.2011.06.008

197. Nanda A, Saravanan M. Biosynthesis of silver nanoparticles from Staphylococcus aureus and its antimicrobial activity against MRSA and MRSE. *Nanomedicine*. 2009;5(4):452–456. doi:10.1016/j.nano.2009.01.012

198. Saravanan M, Barik SK, MubarakAli D, Prakash P, Pugazhendi A. Synthesis of silver nanoparticles from Bacillus brevis (NCIM 2533) and their antibacterial activity against pathogenic bacteria. *Microb Pathog*. 2018;116:221–226. doi:10.1016/j.micpath.2018.01.038

199. Merin DD, Prakash S, Bhimva BV. Antibacterial screening of silver nanoparticles synthesized by marine micro algae. *Asian Pac J Trop Med*. 2010;3(10):797–799. doi:10.1016/S1995-7645(10)60191-5

200. Prasad TN, Kambala VSR, Naidu R. Phyconanotechnology: synthesis of silver nanoparticles using brown marine algae Cystophora moniliformis and their characterisation. *J Appl Phycol*. 2013;25(1):177–182. doi:10.1007/s10881-012-9585-x

201. Govindaraju K, Kiruthiga V, Kumar VG, Singaravelu G. Extracellular synthesis of silver nanoparticles by a marine alga, Sargassum wightii Grevigli and their antibacterial effects. *J Nanosci Nanotechnol*. 2009;9(9):5497–5501.

202. Kathiraven T, Sundaramanickam A, Shanmugam N, Balasubramanian T. Green synthesis of silver nanoparticles using marine algae Caulerpa racemosa and their antibacterial activity against some human pathogens. *Appl Nanosci*. 2015;5(4):499–504. doi:10.1007/s13204-014-0341-2

203. El-Rafie H, El-Rafie M, Zahran M. Green synthesis of silver nanoparticles using polysaccharides extracted from marine macro algae. *Carbohydr Polym*. 2013;96(2):403–410. doi:10.1016/j.carbpol.2013.03.071

204. Kannan RRR, Arumugam R, Ramya D, Manivannan K, Anantharanam P. Green synthesis of silver nanoparticles using marine macroalgae Chaetomorpha linum. *Appl Nanosci*. 2013;3(3):229–233. doi:10.1007/s13204-012-0125-5

205. Pugazhendi A, Prabakar D, Jacob JM, Karuppusamy I, Saratate RG. Synthesis and characterization of silver nanoparticles using Gelidium amansii and its antimicrobial property against various pathogenic bacteria. *Microb Pathog*. 2018;114:41–45. doi:10.1016/j.micpath.2017.11.013

206. Ahmad A, Mukherjee P, Senapati S, et al. Extracellular biosynthesis of silver nanoparticles using the fungus Fusarium oxysporum. *Colloids Surf B*. 2003;28(4):313–318. doi:10.1016/S0927-7755(02)00174-1

207. Mukherjee P, Ahmad A, Mandal D, et al. Fungus-mediated synthesis of silver nanoparticles and their immobilization in the mycelial matrix: a novel biological approach to nanoparticle synthesis. *Nan Lett*. 2001;1(10):515–519. doi:10.1021/nl01055274

208. Bhainsa KC, D’Souza S. Extracellular biosynthesis of silver nanoparticles using the fungus Aspergillus fumigatus. *Colloids Surf B*. 2006;47(2):160–164. doi:10.1016/j.colsurfb.2005.11.026

209. Kathiresan K, Manivannan S, Nabeel M, Dhivya B. Studies on silver nanoparticles synthesized by a marine fungus, Penicillium fellutanum isolated from coastal mangrove sediment. *Colloids Surf B*. 2009;71(1):133–137. doi:10.1016/j.colsurfb.2009.01.016

210. Vigneshwaran N, Ashtaputre N, Varadarajan P, Nachane R, Paraliak R, Balasubramanyan R. Biological synthesis of silver nanoparticles using marine macroalgae. *Aquat Procedia*. 2016;10:60191–5

211. Basavaraju S, Balaji S, Lagashetty A, Rajasab A, Venkataraman A. Extracellular biosynthesis of silver nanoparticles using the fungus Fusarium semitectum. *Mater Res Bull*. 2008;43(5):1164–1170. doi:10.1016/j.materresbull.2007.06.020

212. Gajbhiye M, Kesharwani J, Ingle A, Gade A, Rai M. Fungus-mediated synthesis of silver nanoparticles and their activity against pathogenic fungi in combination with fluconazole. *Nanomedicine*. 2009;5(4):382–386. doi:10.1016/j.nano.2009.06.005

213. Banu A, Rathod V, Ranganath E. Silver nanoparticle production by Rhizopus stolonifer and its antibacterial activity against extended spectrum β-lactamase producing (ESBL) strains of enterobacteriaceae. *Mater Res Bull*. 2011;46(9):1417–1423. doi:10.1016/j.materresbull.2011.05.008
214. Saravanan M, Arokijaraj S, Lakshmi T, Pugazhendhi A. Synthesis of silver nanoparticles from Phenerochaete chrysosporium (MTCC-787) and their antibacterial activity against human pathogenic bacteria. *Microb Pathog.* 2018;117:68–72. doi:10.1016/j.micpath.2018.02.008

215. Wei G, Zhou H, Liu Z, et al. One-step synthesis of silver nanoparticles, nanorods, and nanowires on the surface of DNA network. *J Phy Chem B.* 2005;109(18):8738–8743. doi:10.1021/jp043418a

216. Nithya B, Mishra H, Nampoori V. Synthesis of silver nanoparticles in DNA template and its influence on nonlinear optical properties. *Nanosci Nanotechnol.* 2012;2(4):99–103. doi:10.5923/j.nnn.20120204.02

217. Kasyanenko N, Varshavskii M, Ikonnikov E, et al. DNA modified with metal nanoparticles: preparation and characterization of ordered metal-DNA nanostructures in a solution and on a substrate. *J Nanomater.* 2016;2016:12. doi:10.1155/2016/3237250

218. Dai S, Zhang X, Li T, Du Z, Dang H. Preparation of silver nanoparticles on DNA templates. *Appl Surf Sci.* 2005;249(1–4):346–353. doi:10.1016/j.apsusc.2004.12.026

219. Naik RR, Stringer SJ, Agarwal G, Jones SE, Stone MO. Biomimetic synthesis and patterning of silver nanoparticles. *Nat Mater.* 2002;1(3):169. doi:10.1038/nmat758

220. Patil MP, Singh RD, Koli PB, et al. Antibacterial potential of silver nanoparticles synthesized using Madhuca longifolia flower extract as a green resource. *Microb Pathog.* 2018;121:184–189. doi:10.1016/j.micpath.2018.05.040

221. Verma VC, Khawar RN, Gange AC. Biosynthesis of antimicrobial silver nanoparticles by the endophytic fungus Aspergillus clavatus. *Nanomedicine.* 2010;5(1):33–40. doi:10.2217/nmn.09.77

222. Abdel-Aziz MS, Shaheem MS, El-Nakeety AA, Abdel-Wahhab MA. Antioxidant and antibacterial activity of silver nanoparticles biosynthesized using Chenopodium album leaf extract. *J Saudi Chem Soc.* 2014;18(4):356–363. doi:10.1016/j.jscs.2013.09.011

223. Dipankar C, Murugan S. The green synthesis, characterization and evaluation of the biological activities of silver nanoparticles synthesized from Iresine herbstii leaf aqueous extracts. *Colloids Surf B.* 2012;98:112–119. doi:10.1016/j.colsurfb.2012.04.006

224. Bindhu M, Umadevi M. Antibacterial and catalytic activities of green synthesized silver nanoparticles. *Spectrochim Acta A.* 2015;135:373–378. doi:10.1016/j.saa.2014.07.045

225. Ghosh S, Patil S, Ahire M, et al. Synthesis of silver nanoparticles using Dioscorea bulbifera tuber extract and evaluation of its synergistic potential in combination with antimicrobial agents. *Int J Nanomed.* 2012;7:483. doi:10.2147/IJNN.S30631

226. Manikandan R, Manikandan B, Raman T, et al. Biosynthesis of silver nanoparticles using ethanolic petals extract of Rosa indica and characterization of its antibacterial, anticancer and anti-inflammatory activities. *Spectrochim Acta A.* 2015;138:120–129. doi:10.1016/j.saa.2014.10.043

227. Patil RS, Kokate MR, Kolekar SS. Bioinspired synthesis of highly stabilized silver nanoparticles using Ocimum tenuiflorum leaf extract and their antibacterial activity. *Spectrochim Acta A.* 2012;91:234–238. doi:10.1016/j.saa.2012.02.009

228. Wongpreecha J, Polanich D, Suteewong T, Kaewsaneha C, Tongboriboonrat P. One-pot, large-scale green synthesis of silver nanoparticles-chitosan with enhanced antibacterial activity and low cytotoxicity. *Carbohydr Polym.* 2018;199:641–648. doi:10.1016/j.carbpol.2018.07.039

229. Lok C-N, Ho C-M, Chen R, et al. Silver nanoparticles: partial oxidation and antibacterial activities. *JBC.* 2007;12(4):527–534. doi:10.1007/s00757-007-0208-z

230. Martinez-Castanon G, Nino-Martinez N, Martinez-Gutierrez F, Martinez-Mendoza J, Ruiz F. Synthesis and antibacterial activity of silver nanoparticles with different sizes. *J Nanopart Res.* 2008;10(8):1343–1348. doi:10.1007/s11051-008-9428-6

231. Asghar MA, Zahir E, Shahid SM, et al. Iron, copper and silver nanoparticles: green synthesis using green and black tea leaves extracts and evaluation of antibacterial, antifungal and alatroxin B 1 adsorption activity. *LWT.* 2018;90:98–107. doi:10.1016/j.lwt.2017.12.009

232. Khatami M, Sharifi I, Nobre MA, Zaffarnia N, Aftaoomian MR. Waste-grass-mediated green synthesis of silver nanoparticles and evaluation of their anticancer, antifungal and antibacterial activity. *Green Chem Lett Res.* 2018;11(2):125–134. doi:10.1080/17518253.2018.1444979

233. Muthamil S, Devi VA, Balasubramaniam B, Balamurugan K, Pandian SK. Green synthesized silver nanoparticles demonstrating enhanced in vitro and in vivo antibiotic activity against Candida spp. *J Basic Microbiol.* 2018;58(4):343–357. doi:10.1002/jobm.201700529

234. Bonilla JJA, Guerrero DJP, Rgt S, et al. Green synthesis of silver nanoparticles using maltose and cysteine and their effect on cell wall envelope shapes and microbial growth of candida spp. *J Nanosci Nanotechnol.* 2017;17(3):1729–1739. doi:10.1166/jnn.2017.12822

235. Marulasiddeshwara M, Dakshayani S, Kumar MS, Chethana R, Kumar PR, Devaraja S. Facile-one pot-green synthesis, antibacterial, antifungal, antioxidant and antiplatelet activities of lignin capped silver nanoparticles: a promising therapeutic agent. *Mater Sci Eng C.* 2017;81:182–190. doi:10.1016/j.msec.2017.07.054

236. Sonker AS, Pathak J, Kannaujyya V, Sinha R, Pathak J, Kannaujyya V. Characterization and in vitro antitumor, antibacterial and antifungal activities of green synthesized silver nanoparticles using cell extract of Nostoc sp. strain HKAR-2. *Can J Biotechnol.* 2017;1(1):26–37. doi:10.24870/cjbt.2017-000103

237. Phull A-R, Abbas Q, Ali A, Raza H, Zia M, Haq I-U. Antioxidant, cytotoxic and antimicrobial activities of green synthesized silver nanoparticles from crude extract of Berberia ciliata. *Future J Pharm Sci.* 2016;2(1):31–36. doi:10.1016/j.fjs.2016.03.001

238. Khatabi M, Nejad MS, Salari S, Almani PGN. Plant-mediated green synthesis of silver nanoparticles using Trifolium resupinatum seed exudate and their antifungal efficacy on Neosfusicoccum parvum and Rhizoctonia solani. *IET Nanobiotechnol.* 2016;10(4):237–243. doi:10.1049/iet-nbt.2015.0078

239. Sánchez-Navarro M, Ruiz-Torres CA, Niño-Martinez N, et al. Cytotoxic and bactericidal effect of silver nanoparticles obtained by green synthesis method using annona muricata aqueous extract and functionalized with 5-fluorouracil. *Bioorgn Chem Appl.* 2018;2018:8. doi:10.1155/2018/6506381

240. Lakshmanan G, Sathiayaseelan A, Kalaielvanch P, Murugesan K. Plant-mediated synthesis of silver nanoparticles using fruit extract of Cleome viscosa L.: assessment of their antibacterial and anticancer activity. *Kurbala Int J Med Sci.* 2018;4(1):61–68.

241. Elella MHA, Mohamed RR, Abdel-Aziz MM, Sabaa MW. Green synthesis of antimicrobial and antitumor N, N-trimethylchitosan chloride/poly (acrylic acid)/silver nanocomposites. *Int J Biol Macromol.* 2018;111:706–716.

242. Palem RR, Ganesh SD, Kronkova Z, Slavikova M, Saha N, Sahá P. Green synthesis of silver nanoparticles and biopolymer nanocomposites: a comparative study on physico-chemical, antimicrobial and anticancer activity. *Bull Mate Sci.* 2018;41(2):55.

243. Dadashpour M, Firouzi-Amandi A, Pourhassan-Moghaddam M, et al. Biomimetic synthesis of silver nanoparticles using Matricaria chamomilla extract and their potential anticancer activity against human lung cancer cells. *Mater Sci Eng C.* 2018;92:902–912.

244. Oves M, Aslam M, Rauf MA, et al. Antimicrobial and anticancer activities of silver nanoparticles synthesized from the root hair extract of Phoenix dactylifera. *Mater Sci Eng.* 2018;89:429–443.
245. Sun RW-Y, Chen R, Chung NP-Y, Ho C-M, Lin C-LS, Che C-M. Silver nanoparticles fabricated in Hepes buffer exhibit cytoprotective activities toward HIV-1 infected cells. Cheml Commun. 2005;40:5059–5061.

246. Zodrow K, Brunet L, Mahendra S, et al. Polysulfone ultrafiltration membranes impregnated with silver nanoparticles show improved biofouling resistance and virus removal. Water Res. 2009;43(3):715–723.

247. Hebeish A, El-Rafie M, El-Sheikh M, Seleem AA, El-Naggar ME. Antimicrobial wound dressing and anti-inflammatory efficacy of silver nanoparticles. Int J Biol Macromol. 2014;65:509–515.

248. Maneerung T, Tokura S, Rujiravanit R. Impregnation of silver nanoparticles into bacterial cellulose for antimicrobial wound dressing. Carbohydr Polym. 2008;72(1):43–51.

249. Chen J-P, Chiang Y. Bioactive electrospun silver nanoparticles-containing polyurethane nanofibers as wound dressings. J Nanosci Nanotechnol. 2010;10(11):7560–7564.

250. Jacob JM, John MS, Jacob A, et al. Bactericidal coating of paper towels via sustainable biosynthesis of silver nanoparticles using Ocimum sanctum leaf extract. Mater Res Express. 2018;5(4):45401.