Eco-Friendly Synthesis of Silver Nanoparticles: Principles and Their Antimicrobial Characteristics

Chapter · October 2024

DOI: 10.1201/9781003468950-10

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CHAPTER 10

Eco-Friendly Synthesis of Silver Nanoparticles: Principles and Their Antimicrobial Characteristics

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Sustainable Nanoremediation: Modern Technologies for a Clean Environment.
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ABSTRACT

The advancement of eco-friendly techniques for creating nanoparticles is a crucial step in the progress of nanotechnology as a dependable, environmentally sustainable method for producing a large variety of biocompatible materials and nanomaterials, including metal/metal oxide nanomaterials and nanocomposites.Therefore, green synthesis is viewed as a crucial technique to minimize the adverse effects related to the conventional methods of synthesis for nanoparticles that are frequently used in laboratories and industry. We used silver nanoparticles (AgNPs) as an example when describing the fundamentals of "ecofriendly" synthesis approaches in this chapter due to their excellent antibacterial properties and capacity to combat pathogens that cause infections, including gram-positive and Gram-negative bacteria as well as multidrug-resistant pathogens. We focused on the functionality of bio- elements as reducing agents. Additionally, covered are nanoparticle stability, photodegradation, toxicity, and related surface engineering methods for improving biocompatibility. We finished by discussing antibacterial properties for use in biomedical applications.

10.1 INTRODUCTION

The phrase "nanotechnology" refers to the fabrication of materials at the nanoscale (between 1 and 100 nm), their formulation, modification, and use, where these newly generated nanomaterials display novel features in comparison to the same materials at their bulk size (Bayda et al., 2020; Whitesides, 2005). In general, nanoparticles (NPs) can be divided into inorganic and organic NPs. Organic NPs include carbon nanoparticles like carbon nanotubes, fullerenes, and quantum dots, while inorganic NPs include gold (Au), silver (Ag), copper (Cu), and other magnetic nanoparticles (MNPs). Au and Ag NPs, for example, are becoming more attractive due to their outstanding properties and practical adaptability (Khan et al., 2017; Sanzari et al., 2019; Jabir et al., 2020; Albukhaty et al., 2020; Yazdi et al., 2020). Nanobiotechnology provides essential tools and knowledge of nanotechnology to detect and treatment of different diseases. These include the application of nanoscale materials, such as biocompatible nanoparticles in life sciences include, including medicines, biotechnology, gene, drug

delivery, and tissue engineering (Jihad et al., 2021; Albukhaty et al., 2018, 2021; Al-Kaabi et al., 2021).

Recent advances in nanobiotechnology have drawn a lot of attention because they address the sustainability concerns raised by traditional synthesis techniques (Castillo-Henríquez et al., 2020).

One of the most significant metallic nanoparticles is Ag NPs, which have elevated surface area-to-volume ratio as well as the ability to alter their biological, physical, and chemical characteristics (Pirtarighat et al., 2019; Akter et al., 2018; Marassi et al., 2018), so that these superior nanoparticles have been exploited for multiple scientific types of research and different applications such as medicine, food, industrial materials, and pharmacy (Akter et al., 2018, Marassi et al., 2018; Kumar et al., 2018; Fortunati et al., 2013; Tavaf et al., 2017).

There are different approaches for obtaining high quantity and good control of nanoparticles by different synthesis methods covering chemical, physical, and biological procedures that are relevant to their use (Wu et al., 2013; Khashan et al., 2021; Safat et al., 2021). Interestingly, biosynthesis of Ag NPs exhibits good results, solubility, and bio-stability (Prasher et al., 2020). Additionally, under the ideal circumstances for applied research, these methods ensure to be rapid, low-toxic, simple to prepare, reliable, and well-produced in terms of size and shape (Long et al., 2022; Tian et al., 2014). Therefore, it appears that biological methods for producing Ag NPs hold great promise. The purpose of this chapter is on recently developed approaches for the eco-friendly synthesis of Ag NPs using different natural elements such as herbal extracts, bacteria, and fungi and their antimicrobial and photocatalytic activities with a proposal of their mechanism.

10.2 SILVER NANOPARTICLES SYNTHESIS

Two general methods usually have been performed to fabricate nanomaterials and components on a nanoscale; these approaches include the bottom-up method, which is frequently a great option for creating uniformly sized nanoparticles covering a uniform framework in which catalysts (enzymes and reducing agent) synthesize and are controlled by the catalyst from molecular components of their own. In contrast, the top-down method uses bigger (macroscopic) starting structures that can have their geometry externally altered when developing nanostructures (Begum et al., 2022). (Fig. 10.1a).

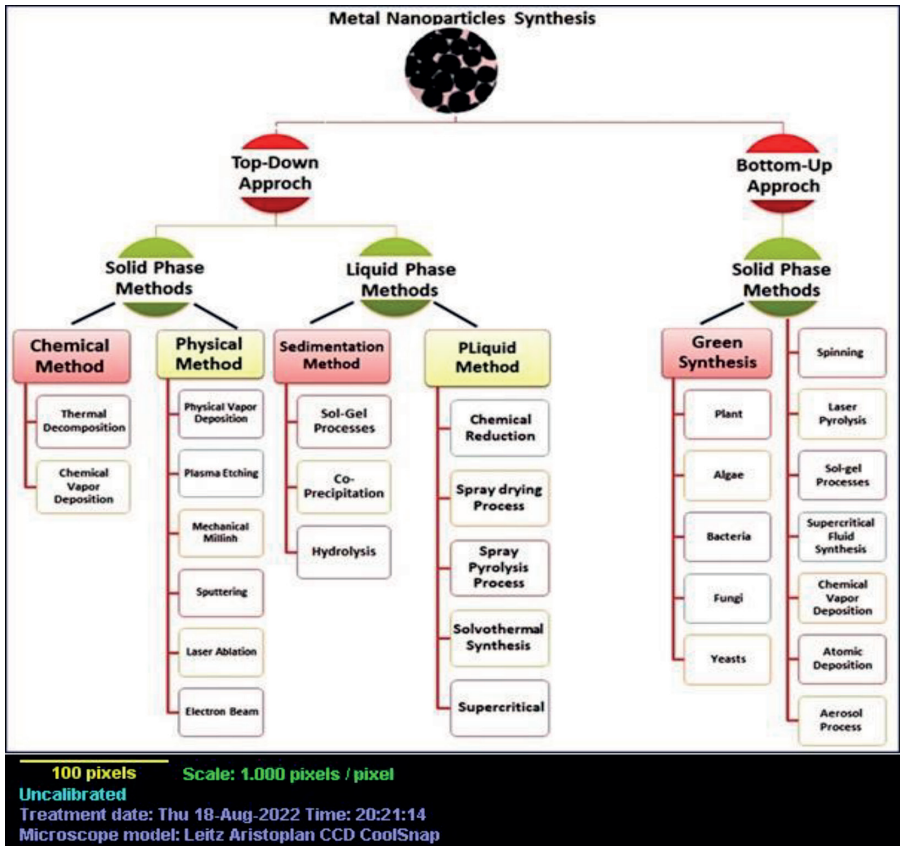

FIGURE 10.1A ~~is a schematic~~ diagram of the various methods for creating nanoparticles.

Various approaches are obtainable for fabricating Ag NPs including chemical (Modan and Plăiașu, 2020; Rashid et al., 2013; Slepička et al., 2020), physical (Sarkar et al., 2009; Mafune et al., 2000), and biosynthesis methodologies (Roy et al., 2019; Okafor et al., 2013). The chemical reduction, electrochemical, irradiation-assisted chemical, and pyrolysis processes are the main types of chemical processes for manufactured Ag NPs (Nakamura et al., 2019). These methods include arc-discharge (Tien et al., 2008), organic and inorganic reducing chemicals are used to reduce silver nanoparticles, which is the most used method of synthesis (Garcia-Barrasa et al., 2011). For the reduction of Ag^{+} ions, a number of reducing agents could be utilized, including hydrogen (sodium ascorbate, borohydride, and citrate), as well as Tollens reagent. As a result of the reduction, metallic Ag ions are produced, which then aggregate to form oligomeric clusters. Eventually, these clusters

cause the emergence of metallic colloidal silver particles (Garcia-Barrasa et al., 2011). To prevent AgNPs from agglomerating, stabilizing agents must be used during AgNP synthesis (Restrepo and Villa, 2021). It is important to remember that polymeric materials work well as protective agents to keep nanoparticles stable (Mahendia et al., 2013; Cunha et al., 2017). The physical methods commonly used for the production of Ag NPs are laser ablation, ultra-sonication, microwave (MW) irradiation, evaporation-condensation, gamma irradiation, and lithography. In these methods, NPS is integrated by evaporation condensation using a tube heater operating at barometric weight. The most important physical methods are laser removal and condensation evaporation. Without the use of chemical reagents, laser ablation is one of the most effective ways to create Ag NPs. By varying the number of laser pulses, it is possible to regulate the particle size of colloids (Pyatenko et al., 2004). However, this wide range of chemical, physical, or biological techniques used to synthesize silver nanoparticles can produce AgNPs of various sizes, homogeneity, and shape (Khodashenas and Ghorbani, 2015). Based on their morphology and shape, silver nanostructures can be divided into different groups (Loiseau et al., 2019). For example, cubes such as silver nanocubes with sharp (Zhou et al., 2016), spheres as chicory-silver nanospheres (Khatami et al., 2018), triangles as saponin-capped silver nanotriangles (Debnath and Das, 2019), prisms as citrate-capped silver nanoprisms (Haber and Sokolov, 2017), sheets as silver nanosheets using glucose and aluminum nitrate (Chen et al., 2006), disks as silver nanodisks (Kim and Lee, 2015), rods as tannic acid-silver nanorods (Patarroyo et al., 2016), bars as silver nano bars (Zhang et al., 2012), wires as silver nanowires from AgCl seeds (Puchana-Rosero et al., 2016), and flower-like (Lu et al., 2016), as shown in Figure 10.1b.

10.3 GREEN SYNTHESIS

There are numerous physical and chemical processes now being employed to produce nanoparticles. However, biogenic reduction of metal precursors to produce equivalent NPs is more cost-effective, chemical free, and environmentally benign for use in biological and medicinal applications. A scientific revolution has been initiated by the utilization of biological agents to produce silver nanoparticles because of their availability, usability, and environmentally friendly nature. Ag NPs can be biosynthesized using biological components including bacterial, fungal, yeast, algal, and plant

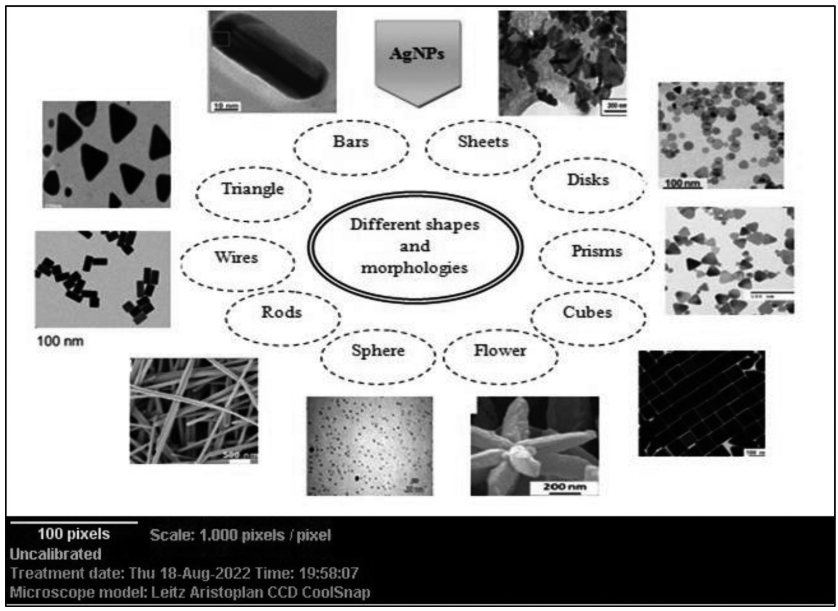

FIGURE 10.1B Images from transmission electron microscopy (TEM) of various silver nanoparticle morphologies and forms.

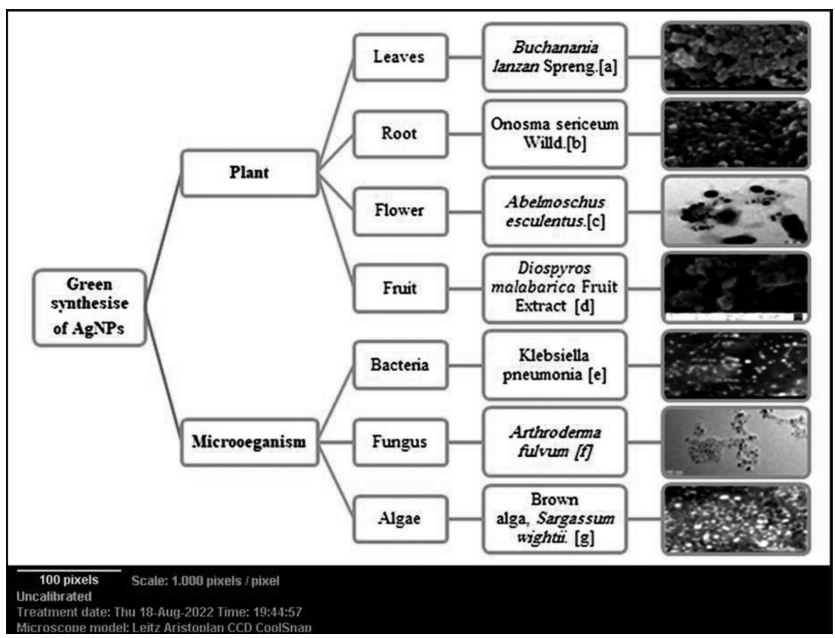

FIGURE 10.2 Detailed generally, biological components are utilized to biosynthesize Ag NPs.

extracts (Eid et al., 2020; Vahabi et al., 2011; Shu et al., 2020; Abdel-Raouf et al., 2019; Purohit et al., 2022; Çalhan and GÜndoĞan, 2020; Devanesan and AlSalhi, 2021; Xue et al., 2016), as shown in Figure 10.2.

Recent research has concentrated on the potential of biogenesis of Ag NPs using different strains of bacteria, including *Pseudomonas stutzeri* (Bachii and Abd-Al Sahib), Lactobacillus strains (Mohd Yusof et al., 2020), *Bacillus licheniformis* (Tan et al., 2021), *Escherichia coli* (Birla et al., 2009), *Brevibacterium casei* (Kalishwaralal et al., 2010), fungi including *Fusarium oxysporum* (Yin et al., 2016), Ganoderma neo-japonicum Imazeki (Gurunathan et al., 2013; Khane et al., 2022; Ali et al., 2016; Mirzaie et al., 2022), plant. Several biomolecules, including biopolymers (Leung et al., 2010), starch (Kumar et al., 2014), fibrinolytic enzyme (Deepak et al., 2011), and amino acids (Shankar and Rhim, 2015), were also used, as schematically illustrated in Figure 10.3, which depicts the methodology for producing silver nanoparticles using a variety of biological components. According to recent research, three general factors must be considered in green synthesis: the solvent medium, eco-friendly reducing reagents, and nanoparticle stabilizer (Peralta-Videa et al., 2016). Green synthesis may be superior to traditional synthesis because the ZnO NPs manufactured seem pure and devoid of nasty chemicals, be pure and devoid of nasty chemicals, thereby making them suitable for biological, therapeutic approaches, and pharmaceutical purposes (Gur et al., 2022; Abdelmigid et al., 2022). Several other researchers use plant extracts or bacterial proteins as reductants to manipulate nanoparticle size, shape, and monodispersity (Rajeshkumar and Bharath, 2017).

The generated nanoparticles are rapidly water-soluble, high density and stable, of which are extra benefits of green fabrication techniques (Karagoly et al., 2022).

AgNPs' biological activity is determined by their morphology and structure, which in turn is determined by the particles' sizes and shapes (Raza et al., 2016; Alshareef et al., 2017). AgNPs synthesized from algae, and bacterial sources have a size range of 100 nm or more, whereas AgNPs synthesized from algae, algal plants, pteridophytes, gymnosperms, and biopolymer sources have a size range of less than 50 nm. Instead of using plant extracts, the authors of this study used microorganisms and bio-polymers to synthesize AgNP, and they agitated the reaction mixture constantly to prevent agglomeration. In some cases, the production of nanoparticles can be sped up by mechanically agitating the reaction mixture. Aging, the synthesized AgNP solution morphed the nanospheres into flower-like frameworks (Table 10.1).

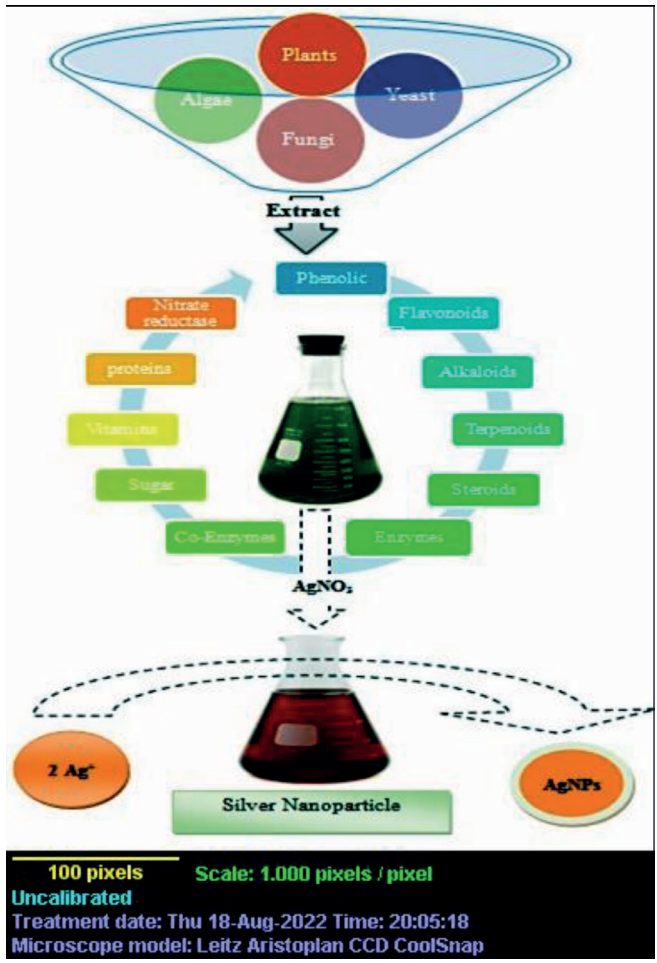

FIGURE 10.3 A schematic illustration of the method for producing silver nanoparticles in a sustainable manner using different biological entities.

When comparing different nanoparticles, those with smaller sizes and truncated-triangular shapes appear to be the most effective. Many studies have been able to synthesize AgNPs in a variety of shapes and sizes, but there are still some restrictions. For the synthesis of monodisperse and uniformly sized silver colloids, an abundance of a potent reducing agent like sodium borohydride ($NaBH_4$) was used to enhance the efficiency of production when it comes to morphology and structure (Hong and Lee, 2018). By optimizing the synthesis methods—including the number of byproducts, temp, pH, and

TABLE 10.1 Displayed Green Synthetic Ag NPs Produced Using Several Living Things, Including Plants, Bacteria, Fungi, Yeasts, and Algae.

Reducing factor	Size and shape	Characterization	Application	Ref no.
		Bacteria		
Culture Supernatant of *Shewanella sp.* ARY1	38 nm spherical	UV, FTIR, XRD, EDX, TEM, and SEM.	Antibacterial activity	(Mondal et al., 2020)
Thermophilic *Bacillus Sp.* AZ1	~7–31 nm spherical	UV, SEM, EDX and TEM	Antimicrobial activity	(Deljou and Goudarzi, 2016)
		Fungi and yeast		
Enteromorpha flexuosa	2–32 nm circular	UV, XRD, EDX, and TEM.	Antibacterial and antifungal activity against *E. coli, S. cerevisiae, C. Albicans, S. aureus, S. epidermidis, B. subtilis, B. pumulis, E. faecalis*	(Yousefzadi et al., 2014)
The culture supernatants of *Aspergillus sydowii*	1 and 24 nm spherical	UV, TEM and XRD.	Antifungal/antiproliferative activities	(Wang et al., 2021)
		Algal extracts		
Yeast strain MKY3	2–5 nm	UV, TEM, XRD, and XRP	Antifungal/antiproliferative activities	(Kowshik et al., 2003)
Aqueous filtrate of *Sargassum wightii*	18.45–41.59 nm spherical	UV, FTIR, XRD, FESEM, EDX, Z-P, and DLS.	Enzyme inhibitory, antibacterial, and antioxidant	(Deepak et al., 2018 Sep 18)
		Plant extracts		
leaf extract of *Prunus dulcis L.* (almond tree)	14.6 nm spherical	FTIR,XRD, UV, SEM, TEM, and Z-P.	Antioxidant and Antimicrobial Activity	(Aktepe and Baran, 2021)

TABLE 10.1 *(Continued)*

Reducing factor	Size and shape	Characterization	Application	Ref no.
Syzygium cumini fruit extract	~47 nm nearly spherical	UV, FTIR, XRD, and SEM.	Antibacterial, antioxidant, and anti-inflammatory	(Chakravarty et al., 2022)
Extract of *Jasminum officinal* L. Leaves	9.22 nm spherical	UV, FTIR, TEM, Z-P and XRD.	Cytotoxic Activity against Bladder and Breast Cancer (MCF-7) Cell Lines	(Elhawary et al., 2020)
Diospyros malabarica aqueous fruit extract	17.4 nm spherical	UV, XRD, FTIR, DLS, Z-P, FESEM, EDX, TEM and P-L.	Antibacterial, anticancer effect	(Bharadwaj et al., 2021)
Citrus limon Zest Extract	23 nm spherical	UV, Z-P, DLS, SEM, EDX, XRD, and TEM.	Antioxidant and antimicrobial properties	(Khane et al., 2022)
Root extract of *Duchesnea indica*	20.49 nm spherical	UV, TEM, SEM, XRD, EDX, FTIR, and Z-P.	Antimicrobial, anti-inflammatory, analgesic, and muscle relaxant	(HsanIlahi et al., 2021)
Root Extracts of *Rubus ellipticus* Sm.	13.85–34.30 nm spherical	UV, FTIR, XRD, FESEM, TEM and EDX.	Antioxidant and antibacterial activity	(Khanal et al., 2022)
Malva Sylvestris Flower Extract	20–30 nm spherical	UV, FTIR, SEM, TEM, and XRD	Antibacterial and catalytic activity	(Mehdizadeh et al., 2021)
Plumeria rubra Flower Extract	20–80 nm Spherical	UV, FTIR and TEM	Antimicrobial activities	(Mandal, 2018)

the quantity of limiting and stabilizing factors—biological processes make it easier to control the shape, size, and dispersion of the generated nanoparticles (Uzair et al., 2020; Tiburu et al., 2017).

10.4 CHARACTERIZATION

The behavior, bio-distribution, safety, and effectiveness of nanoparticles are largely dependent on their physicochemical qualities. In order to assess the functional characteristics of the produced nanoparticles, it is crucial to characterize AgNPs. According to Shin et al. (2015) size distribution, electrostatics, surface area, general form, and aggregation are a few physiochemical characteristics that may have a significant effect on the physiological interactions between nanomaterials and their intended biological targets.

The identification of AgNPs is thus considered a critical factor in assessing the performance properties of the related synthesized particles. The physiological interactions that take place between nanomaterials and their respected biological targets may be significantly impacted by specific physiochemical properties, such as particles size, electrostatics, surface area, particular shape, and aggregation, according to a study by Shin et al. (2015). Numerous analytical techniques, such as UV, FTIR, X-RD, XPS, DLS, SEM, TEM, and AFM analysis, have been used to characterize the materials (Gurunathan et al., 2015).

The ideas and use of several analytical techniques for the characterization of AgNPs have been discussed in a number of reputable books and reviews; however, the fundamentals of the key approaches are summarized below for clarity, optimization of the synthesis processes, taking into account the quantity of precursors, temperature, pH, and reducing and stabilizing agents used (Zhang et al., 2016).

10.4.1 UV-VISIBLE SPECTROSCOPY

An essential and effective technique for the comprehensive categorization of synthesized nanoparticles is UV-vis spectroscopy. It is also used to examine AgNPs' stability and manufacturing process (Ajitha et al., 2018; Fayaz et al., 2010). Due to the distinct optical characteristics of AgNPs, they strongly interact with specific light wavelengths (Ren et al., 2020). Also, UV-vis spectroscopy is said to be quick, easy, and simple to use. It is quick to measure different types of NPs and is both sensitive and selective for them.

Additionally, colloidal suspension particle characterization does not require calibration (Reddy et al., 2019).

According to the reports, since the valence band and conduction band are so close together in AgNPs, electrons can move freely between them. An SPR absorption band is formed when the electrons of silver nanoparticles collectively oscillate in resonance with the light wave, which is caused by the free electrons discussed here (Das et al., 2010).

The chemical environment, particle size, and dielectric medium all play a role in the absorption of AgNPs (Fayaz et al., 2010; Reddy et al., 2019). This peak, attributed to a surface plasmon, has been observed for a wide range of metal nanoparticles, from 2 nm to 100 nm (Salem et al., 2020). Furthermore, using UV-vis spectroscopy, an SPR peak at the same wavelength was identified, and the stability of AgNPs extracted via biological methods was established for more than a year.

10.4.2 X-RAY DIFFRACTION (XRD)

Depending on the constituent amount's intensity, there may be an increase or decrease. With information on unit cell size and shape derived from peak positions and information on electron density within the unit cell or atomic placement derived from peak intensities, this method has been used to represent the metallic nature of particles (Bunaciu et al., 2015; Thakar et al., 2022; Heera and Shanmugam, 2015).

10.4.3 DYNAMIC LIGHT SCATTERING (DLS)

The emotional light scattering technique (DLS) is used to measure the size of nanoparticles in suspensions and to determine the degree to which they have aggregated.

10.5 MECHANISM OF GREEN SYNTHESIS OF SILVER NANOPARTICLE AND SURFACE MODIFICATION

Lessening, stabilizing, and capping agents available through chemical methods are more limited in scope. Many plethoras of biological and eco-friendly AgNP synthesis techniques have been discovered through recent literature searches and experiments (Kaabipour and Hemmati, 2021). Researchers have used green, cost-effective, and environmentally friendly

methods for the establishment of sustainable silver nanoparticles (Kumar et al., 2016; Bhardwaj et al., 2020), including microbial-taken compounds from (bacteria, fungi, yeasts, and actinomycetes) (Kiran et al., 2014; Daphne et al., 2018; Srivastava et al., 2019; Bayram et al., 2018; Abdel-Raouf et al., 2019) and also using microbial-taken combinations from (bacteria, fungi, yeasts, and actinomycetes) (Rajeshkumar and Bharath, 2017; Ranoszek-Soliwoda et al., 2019). In light of this, it is clear that biological agents in this approach represent a wide range of reagents that restore chemical reagents and incorporate the use of bioactive compounds like alkaloids, phenolic compounds, terpinoids, enzymes, proteins, sugars, saccharides, and vitamins (Mukherjee et al., 2018; May and Oluwafemi, 2016; Nadagouda et al., 2008) that are thought to show promise in the reduction and stabilization of metal salts into nanoparticles that in turn act as reducing agents.

Furthermore, this biogenic technique is classified under bottom-up synthesis methods (Rafique et al., 2017) one-step procedure, and this method appears to be more atomically efficient since it does not need the protection/deprotection steps often employed in organic synthesis in order to construct particles (Albrecht and Evans, 2006). Follow the principles of green chemistry by using less energy for synthesis by operating at near-ambient temperature, pressure, and pH (Parveen et al., 2016). This method can improve nanoparticles in a number of ways, including crystallinity, stability, size, and shape. Biomolecules (large macromolecules like proteins, polysaccharides, lipids, and nucleic acids, and small natural molecules like primary and secondary metabolites) produced by living organisms can convert the positive oxidation state of silver ion Ag^{+} into the zero oxidation state of atoms Ag^{0} and form the nanosilver particles in the biosynthesis of colloidal dispersions of AgNPs (Mittal et al., 2013).

In one of the studies reported by Liu and Hurt (2010), it was demonstrated that when AgNPs were exposed to the aquatic environment, silver ions would be released, decreasing the stability of the AgNPs. Additionally, Lee et al. (2012) hypothesized that first-order kinetics controls the release of Ag ions. When assessing these synthesized NPs, it is important to take into account a number of variables that impact the release rates of Ag ions. These variables primarily include particle size, and environmental variables including pH, temperature, time, radiation, and dissolved oxygen (Zhang et al., 2011; Liu et al., 2010) and capping agents (Ortega-Arroyo et al., 2013).

However, in most cases, the bioreduction of silver ions to create silver nanocrust by bio compounds derived from a biological source of plant or organism is rarely achieved.

Generally, Flavonoids, membrane proteins, NAD $(P)^+$ reductases, dehydrogenases, citric acid, polyphenols, and secondary metabolites are examples of reducing agents (Karatoprak et al., 2017), whereas extracellular proteins, enzymes, peptides, and tannic acids are examples of capping agents (Akhtar et al., 2013). However, there have been no published results on the identification of proteins involved in plant-mediated AgNPs production. Earlier research by de Barros et al. (2018) on protein role in the synthesis of AgNPs by fungus was elucidated; it involves nitrogen and sulfur containing groups.

10.6 MICROBIAL-MEDIATED SYNTHESIS OF AGNPS

Microorganisms' ability to synthesize metal nanoparticles is being considered a potential biological source. There are two distinct steps involved in creating AgNPs by microbes: intracellular formulation and extracellular fabrication (Roy et al., 2019). Methods that use enzymes and other biomolecules already present in microbial cells to convert Ag ions to NPs are called "intracellular" (Rana et al., 2020), and the concentration of Ag inside the cell leads to the nucleation of the formed AgNPs. This process is carried out continuously as the microorganisms proliferate. The living cells are extracted once the cells have grown to their maximum potential. Additionally, unique handling techniques are used to release the manufactured NPs from the retrieved cells (Roy et al., 2019). However, not all species have been shown to have the capability to transform metals into their nano forms.

Both an intracellular and an extracellular method exist for the microbial production of silver nanoparticles (Das et al., 2014). Intracellular silver buildup initiates silver nanoparticle production and furthers microbial development. Upon completion of the optimal period for bacterial development, nanoparticles containing viable cells are extracted.

Therefore, the generated nanoparticles need to be released from the collected cells in a certain way. Bacterial populations' extracellular secretions are extracted and employed as raw materials in the extracellular manufacturing process. In general, microorganisms are resistant to silver ions and efficient producers of AgNPs. It is hypothesized that the extracts' biomolecular mixtures (including enzymes/proteins, amino acids, polysaccharides, vitamins, etc.) are responsible for the reduction of Ag^+ ions. However, the precise process is not yet known. The bacterial strain *Streptomyces sp*. LK3 was used by Karthik et al. (2014) to show that AgNPs may be synthesized outside of cells. During the synthesis process the reduction of nitrate to nitrite

can be performed by nitrate reductase. Generally, the presence of the enzyme nitrate reductase is the cornerstone of the widely accepted process to explain the mechanism of biogenic mediated silver nanoparticle (Ahmed and Ikram, 2016; Roy et al., 2013; Kalimuthu et al., 2008), as illustrated in Fig. 10.4.

Nitrate (NO_3?) is changed into nitrite (NO_2?) by the enzyme. After the nitrate ion (NO_3) is reduced to nitrate (NO_2), the silver ion (Ag^+) receives the electron and is then reduced to metallic silver (Ag^0). Producing silver nanoparticles using pure nitrate reductase from the fungus *F. oxysporum* (Kumar et al., 2007) provided a clear proof of this. The reduction of Ag^+ to Ag^0 can also occur in the absence of nitrate reductase due to functional groups on the bacterial cell wall (Kalimuthu et al., 2008).

When compared to bacteria, the high concentration of enzymes, proteins, and reducing components on the cell surface of fungus makes them a superior choice for the creation of nanoparticles. Fungal systems contain enzymes (such as naphthoquinones and anthraquinones) that can reduce Ag^+ that has been trapped on cell surfaces by the fungi (Kumar et al., 2007; Slawson et al., 1992; Mukherjee et al., 2001). The synthesis of AgNPs using yeast was unsuccessful. Nonetheless, there are very few reports to be found. It is believed that the combinational impact of bio-molecules in the extract is responsible for the formation of silver nanoparticles. Algae are no exception to this rule. In the presence of enzymes, actinomycetes are able to manufacture silver nanoparticles. It is believed that intracellular interactions lead to metal ion reduction (Mukherjee et al., 2001; Narayanan and Sakthivel, 2011).

10.7 PLANT-MEDIATED SYNTHESIS OF AGNPS

Plant extracts are favored over microbial creation of nanoparticles because of their low synthesis rate, rapidity, high efficiency, and viability. Synthesis of AgNPs from plant extract is likely to occur by an enzymatic process, the same to that used by microbes. Due to the presence of a complex of diverse antioxidant metabolites in plant cells that prevent oxidation and damage to biological components (Jain et al., 2021; Al-Musawi et al., 2022), the chemicals used for the stabilization and final capping of the nanoparticles must be distinct from those used for microbes. This means that biomolecules including enzymes, glycosides, and saponins can help stabilize the nanoparticle (Shang et al., 2019; Tripathi et al., 2013). Literature suggests that when metal salts are added to a herb extract, silver ions bind to water-soluble chemicals through --OH and --COOH groups.

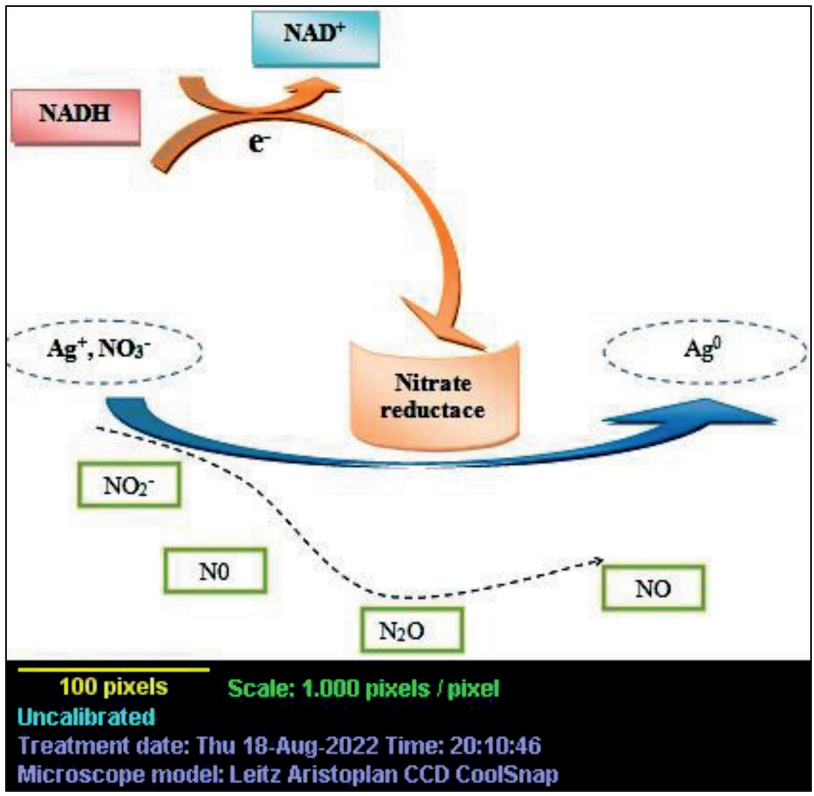

FIGURE 10.4 Biosynthesis of AgNPs using nitrate reductase.

This causes structural reforms in the protein complex that make it easier for the metal ion to change into a silver nanoparticle (Huang et al., 2015; Mikhailova, 2020). Proteins contribute to the reduction of silver and the production of AgNPs through their amino groups and cysteine residues (Kasithevar et al., 2017). Silver nanoparticles can be formed with the help of "capping" agents such as alkanes, amines, phenols, polyphenols, alkaloids, lignans, terpenoids, and flavonoids (Mandal et al., 2005; Elavazhagan and Arunachalam, 2011). Because of their potent antioxidant action, flavonoids are of special importance here. Nanoparticles are colloid-stable in water due to the hydrophilic functional groups of surrounding molecules (Ebrahiminezhad et al., 2017). Garlic extract's sucrose and fructose are very fascinating since they function as reducing and stabilizing chemicals (Von White et al., 2012). Additionally, polyols are in charge of the mechanism that converts Ag^+ into silver nanoparticles (Ghosh et al., 2012). Terpenoids, which are

surface-active substances, are anticipated to adsorb on the surface of AgNPs to stabilize the nanoparticles and stop AgNPs from clumping together (Parlinska-Wojtan et al., 2016). One way that terpenoids might help turn Ag^{+} ions into Ag0 nanoparticles is by changing the C--O group of the terpenes into the --C--O group (Shankar et al., 2004).

It is thought that terpenoids help reduce metal ions by turning aldehydic groups in their molecules into carboxylic acids (Mahendia et al., 2013).

Li et al. (2007) have said that *Capsicum annuum* extract can be used to make AgNPs. Research has shown that to understand how AgNPs grow, you need to know how recognition-reduction-limited nucleation is related to growth. The first step in the recognition process was for proteins in the *C. annuum* extract and Ag ions to interact electrostatically. Extract proteins then reduce the number of Ag ions. This makes silver nuclei, which change the structure of proteins in a second step. Also, these nuclei grew because silver ions were taken away and then more atoms were added. By Ostwald ripening, the polycrystalline phase changed into the single crystalline phase as the AgNPs aged for longer (Jain et al., 2021). This made the AgNPs bigger. Bar et al. (2009) report that the Jatropha curcas seed extract can be used to make green silver NPs. As a result, it was found that curcain, which is an enzyme, curcacycline A, which is a cyclic octapeptide, and curcacycline B, which is a cyclic nonapeptide, could be used as reducing and capping agents. Characterized by XRD, UV-Vis, and TEM spectroscopy, AgNPs were found to have two different distributions: some spherical particles with a diameter of 20–40 nm and other irregular particles that were bigger. Further research showed that the enzyme curcain stabilized the larger NPs, while the cavities in the cyclic peptides stabilized the smaller ones (curcacycline A and curcacycline B). There is evidence that supports that carbonyl groups in amino acid residues or protein peptides are the ones responsible for presenting high affinity for metals (Lin et al., 2005).

Therefore, the protein can act as an encapsulating agent and preserve the NPs by inhibiting their aggregation. The cyclic protein curcacycline A or curcacycline B was thought to have first trapped the Ag ions in their core structure. Under the right processing circumstances, the amide groups of the host peptide reduced and stabilized AgNPs in situ. It was thought that the cyclic peptide cavity supported the smaller AgNPs since the radius of the majority of the generated AgNPs was equivalent to its cavity, but the enzyme curcain's massive, folded protein structure was thought to stabilize the irregularly sized AgNPs. The AgNPs produced by curcain latex was also shown to be stable even after one month, according to studies (Jain et al., 2021; Jain et al., 2021). According to the proposed mechanism of biosynthesized AgNPs

using the *Phyllanthus amarus* leaf extract by Ajitha et al. (2018), the leaf extract itself served as a capping and reducing agent, significantly affecting the nanoparticles' size and form as illustrated in Fig. 10.5.

This mechanism suggests that the antioxidant phytochemicals of the leaf extract reduced the positively charged metal ions (Ag^{+} ions) to a neutral state (Ag^{0} atoms) and to small Ag^{0} particles by electron donation to the ions with the help of the bioreducing agents in the first stage. The Ag0 atoms then expanded into petal shapes, which, with the help of bio-capping agents, coalesced into nanostructures resembling flowers. It is usual for reduced metals to undergo nucleation and cluster formation, with the resulting clusters assembling into particles that are stabilized by complexing with or making electrostatic interactions with oxygen-containing groups like --COO and --OH (Wu et al., 2014), The phytochemicals that caused the AgNPs to form also stopped them from further aggregating, in accordance with our suggested mechanism, by coating them and providing capping agents rich in electron-rich hydroxyl groups onto the particles.

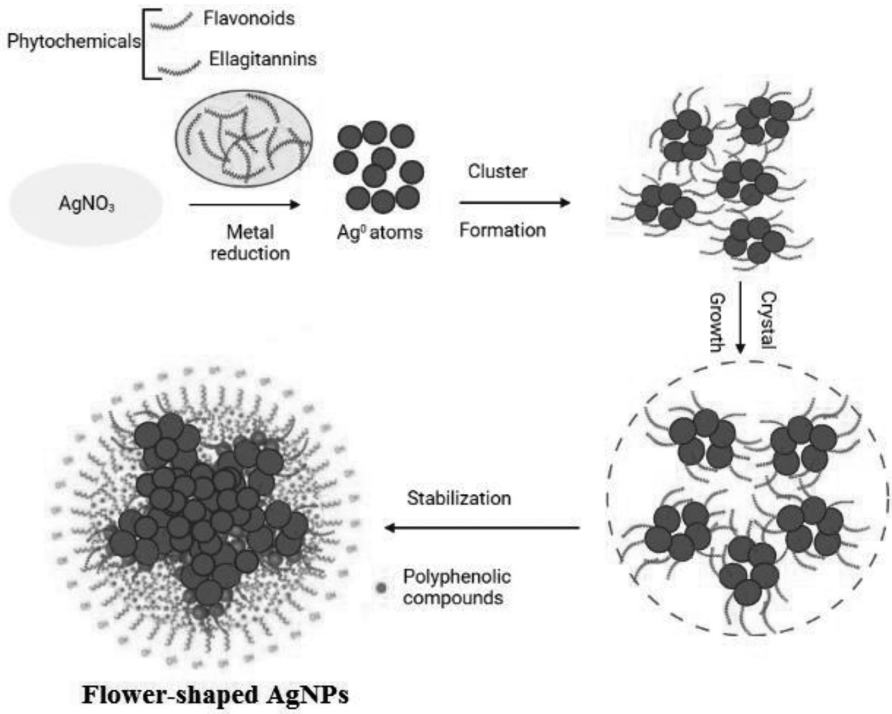

FIGURE. 10.5 Mechanism of flower-shaped AgNPs production using *Phyllanthus amarus* leaf extract.

To produce efficient engineered nanoparticles a deeper comprehension of nanoparticle structure is required. There are three main parts to a nanoparticle's structure: the core, the shell, and the surface (Christian et al., 2008). Different techniques, reaction conditions, and precursors can be used to synthesize the nanoparticle's core, while a shell can be added if required. However, when a single salt is used to create a nanoparticle, the shell and core often both consist of the same substance. The last and maybe most important consideration is the surface, which can be considered functional in several ways depending on the setting. The goal should be either to keep nanoparticles from clumping together or to endow them with a distinct role. The functionalization of the nanoparticle surface is the result of temporary van der Waals interactions between the chemicals and the nanoparticle surface (Roy et al., 2019).

Biological molecules operate as an in situ reducing and capping agent during green nanoparticle formation, reducing metal salts and covering the formed nanoparticles. This capping has advantages over others because (i) it stops the nanoparticles from aggregating together, (ii) it lessens the toxicity, and (iii) it boosts the antimicrobial effect (Roy et al., 2019).

The dose of biochemical reagents found in the extract has a considerable impact on the size and size distribution of the metallic nanoparticles as summarized in Table 10.2. Fast reaction rates and favorable conditions for the creation of smaller nanoparticles are made possible due to the presence of a powerful reductant in the concentrate. If the biomolecules quickly remove the salt, resulting in the constant generation of new nuclei or secondary nuclei, then the size distribution will be quite narrow. As a backup strategy, biomolecules can build a monolayer on the nanoparticle surface to inhibit aggregation (Restrepo and Villa, 2021). In contrast, recent studies about antibiotic-mediated production of nanoparticles highlight the importance of surface functionalization with antibiotics increases their biocidal action (Rai et al., 2010). Since extract-mediated nanoparticles have biomolecules attached to their surfaces, their antibacterial activity is greatly increased.

It has been suggested that "capping" agents can alter the relative surface area of a nanocrystal by attaching selectively to distinct types of facets with differing surface free energy (Xia et al., 2015). Thus, nanoparticle "capping" can serve several purposes, including preventing nanoparticle agglomeration, lessening toxicity, and boosting antibacterial characteristics. Furthermore, these compounds can increase the affiliation probability and activity of AgNPs on the bacterial cells (Roy et al., 2019; El-Rafie et al., 2011). Interestingly, the "capping" compounds found in plants often have their own antibacterial action, which can boost the efficacy of AgNPs (Mikhailova, 2020).

TABLE 10.2 Size, morphology, and antimicrobial activity of green synthesized AgNPs using various plant, microbial, and algal biomolecule

Biological materials	Size and morphology	Antibacterial activity against	Ref.
		Plants	
leaf extract of *elephantopus scaber*	37.86 nm spherical	*B. subtilis*, *L. lactis*, *P. fluorescens*, *P. aeruginosa*, *A. flavus*, and *A. penicillioides*	(Francis et al., 2017)
Acacia rigidula extract	8–66 nm spherical	*E. coli, P.s aeruginosa*, *B. subtilis*	(Escárcega-González et al., 2018)
Phyllanthus amarus Seeds	8–66 nm spherical	*E. coli, B. subtilis, Klebsiella pneumoniae,* and *Staphylococcus aureus*	(Joseph et al., 2021)
Phyllanthus niruri leaf extracts	8–66 nm spherical	*Streptococcus* spp., *E. coli*, *E. faecalis*, *E. clocae*, *Citrobacter freundii*, *Burkholderia cepacia* complex, *S. typhi*, carbapenem-resistant Enterobacteriaceae, MRSA, and VRE	(Kumar et al., 2020)
Phyllanthus amarus leaf extract	30–42 nm flower-shaped	*E. coli*, *Pseudomonas* spp., *Bacillus* spp., *Staphylococcus* spp., *A. niger*, *A. flavus*, and *Penicillium* spp.	(Singh et al., 2014)
Nelumbo nucifera leaf extract	30–40 nm spherical	*B. subtilis*, *E. coli*, *S. typhi*, and *V.cholerae*	(Premanand et al., 2016)
		Algae	
aqueous extract of seaweed *Enteromorpha compressa*	4 and 24 nm Spherical shaped	Bacterial : *E. coli*, *S. aureus*, *K. pneumonia*e, *Pseudomonas* sp., and *S. paratyphi* Fungal : *A. flavus*, *A. niger, A. ochraceus*, *A. terreus,* and *F. moniliforme*	(Ramkumar et al., 2017)
Ulva compressa Cladophora glomerata	66.3 nm /81.8 nm; cubic	*K. pneumoniae*, *P. aeruginosa*, *E. coli*, *E. faecium*, and *S. aureus*	(Minhas et al., 2018)
Spirogyra varians	~35 nm uniform and quasi-spherical	*S.aureus, B. cereus, S. typhimurium, E. coli*, and *Listeria monocytogenes*	(Salari et al., 2016)
Spatoglossum asperum	20–46 nm spherical	*K. pneumoniae*	(Ravichandran et al., 2018)
Spyridia fusiformis	5–50 nm spherical	*S. aureus*, *K. pneumoniae*	(Murugesan et al., 2017)
Nostoc sp.	51–100 nm; spherical	*R. solanacearum*, *X. campestris*, *A. niger*, and *T. harzianum*	(Sonker et al., 2017)

TABLE 10.2 *(Continued)*

Biological materials	Size and morphology	Antibacterial activity against	Ref.
		Fungi and yeasts	
Mushroom *Pleurotus ostreatus*	10–40 nm spherical	*B. subtilis*, *B. cereus*, *S. aureus*, *E. coli*, and *P. aeruginosa*	(Al-Bahrani et al., 2017)
Arthroderma fulvum	15.5 nm spherical	*Candida* spp., *Aspergillus* spp., and *Fusarium* spp.	(Xue et al., 2016)
Penicillium polonicum	10–15 nm spherical	*A. baumanii*	(Neethu et al., 2018)
Endophytic fungus *Curvularialunata*	10–50 nm spherical	*E. coli*, *P. aeruginosa*, *S.paratyphi*, *B. subtillis*, *S. aureus*, and *B.cereus*	(Ramalingmam et al., 2015)
		Bacteria	
Pseudomonas deceptionensis DC5	10–30 nm spherical	*V. parahaemolyticus*, *C. albicans*, *S. aureus*, *S. enterica*, and *B. anthracis*	(Jo et al., 2015)
Halotolerant *Bacillus endophyticus* SCU-	~5.1 nm spherical	*C. albicans*, *E. coli*, *S. typhi*, and *S. aureus*	(Gan et al., 2018)
Bacillus thuringiensis	10–30 nm spherical	*E. coli*	(Nayak et al., 2016)
Phenerochaete chrysosporium (MTCC-787)	34–90 nm spherical and oval	*P. aeruginosa*, *K. pneumoniae*, *S. aureus*, and *S. epidermidis*	(Suresh et al., 2014)
		Actinomycetes	
Streptacidiphilus durhamensis	~8–48 nm. spherical	*S. aureus*, *B. subtilis*, *E. coli*, *P. aeruginosa*, *K. pneumoniae*, and *P. mirabilis*	(Buszewski et al., 2018)
Nocardiopsis sp. MBRC-1	30–90 nm spherical	*B. subtilis*, *P. aeruginosa*, and *Candida albicans*	(Manivasagan et al., 2013)
Streptomyces sp.	20–45 nm; various	*C. albicans*, *C. Tropicalis,* and *C. krusei*	(Sanjenbam et al., 2014)
Streptomyces rochei	22–85 nm spherical	*B. subtilis*, *S. aureus*, *P. aeruginosa*, *B. cereus*, *S. typhimurium*, *E. coli*, *V. fluvialis*, and *V. damsela*	(Abdelnaby et al., 2016)

10.8 ANTIBACTERIAL ACTIVITY OF AGNPS

Silver nanostructures have proven remarkable potential in several industrial, environmental (Kaabipour and Hemmati, 2021), and medicinal applications (Wei et al., 2015). Silver's antibacterial properties, found via experimentation in the ancient world, perhaps contributed to its widespread usage in eating and drinking utensils made of silver (Srikar et al., 2016). It was generally accepted that the silver was employed in aqueous solutions, coins, and plates for aseptic and antibacterial purposes, and to preserve food and dairy articles until the 19th century because it kept them fresh longer than other containers (Kremer et al., 1996). The synthesis or modification of antimicrobial compounds, as well as alternative therapeutics, is required due to the dramatic growth in microbial infections and the quick development in drug resistance to existing antibiotics (Shankar and Rhim, 2017). In vitro studies indicate that silver nanoparticles (AgNPs) are effective antibacterial agents that can circumvent bacterial resistance to conventional antibiotics. As a result, the creation of AgNPs as antibacterial agents is considered necessary. The high surface-to-volume ratio and crystalline surface structure of AgNPs suggest they may be effective antibacterial agents, making them one of the many promising nanomaterials. The buildup of AgNPs in the cell wall and the creation of "pits" in the bacterial cell walls, ultimately leading to cell death, were observed in the seminal study reported by Sondi and Salopek-Sondi (2004), proving the antibacterial action of AgNPs against *E. coli*. Antibacterial activity against the same *E. coli* strainpathoginic bacteria was enhanced when the particles were smaller and had a higher surface-to-volume ratio (Baker et al., 2005).

Furthermore, antimicrobial activity of AgNPs is also influenced by the size and shape of the particle (Bistarelli et al., 2018). Bactericidal action against Gram-positive and Gram-negative bacteria, including extremely multi-resistant strains like methicillin-resistant *S. aureus*, was demonstrated by AgNPs manufactured by four distinct kinds of saccharides with an average size of 25 nm. As mentioned previously, the size is not the sole factor in determining efficacy but AgNPs also interact with the Gram-negative bacterium *E. coli* in a way that is shape-dependent (Raza et al., 2016). Additional research was conducted to examine the effectiveness of AgNPs as an antibacterial agent against yeast, *E. coli*, and *S. aureus*. Complete growth suppression was seen in yeast and *E. coli* at low doses of AgNPs, but *S. aureus* was very slightly affected (Chouhan and Guleria, 2020).

The effectiveness of different antibiotics, including penicillin G, amoxicillin, erythromycin, clindamycin, and vancomycin against *S. aureus* and

E. coli, was found to be enhanced in the presence of biologically produced AgNPs from the culture supernatants of *K. pneumoniae* (Jijie et al., 2017).

Silver nanoparticles (AgNPs) are effective against *E. coli*, but hydrogel-AgNP nanocomposites are more effective. Chitosan-Ag-nanoparticle composite was confirmed to have more potent antibacterial activity than its components at their respective concentrations (Sanpui et al., 2008).

This is likely due to the fact that one-pot synthesis encourages the creation of tiny AgNPs connected to the polymer, which can be dispersed in fluids of pH 6.3. When AgNPs were biologically produced using *S. aureus* culture supernatants, they showed significant antimicrobial activity against methicillin-resistant *S. aureus*, methicillin-resistant *S. epidermidis*, and *Streptococcus pyogenes* (Thomas et al., 2014), but only moderate antimicrobial activity against *S. typhi* and *K. pneumoniae*. In *E. coli*, the leakage of reducing sugars and proteins revealed the mechanisms of AgNP-induced cell death. Furthermore, AgNPs can damage bacterial cell membrane structure by destroying its permeability by forming numerous pits and holes in its surface (Vazquez-Muñoz et al., 2019). The silver nanocrystalline chlorhexidine (AgCHX) complex was highly effective against Gram-positive/negative bacteria and methicillin-resistant *S. aureus* (MRSA). It was found that the MICs of nanocrystalline Ag (III) CHX were significantly lower than those of the ligand (CHX), silver nitrate ($AgNO_3$), and gold (Au (III)). Several applications of silver nanoparticles (AgNPs) are depicted in Figure 10.6.

Nanoparticles immobilized on an amine-functionalized silica surface are more effective than colloidal AgNPs and have a higher concentration of silver ions in solution, as reported by Agnihotri et al. (2013). Silver/polyrhodanine-decorated silica nanoparticles form a nanocomposite that shows promising and improved antibacterial activity against *E. coli* and *S. aureus* (Song et al., 2013). In addition, the physical and surface properties of silver were tested against *S. aureus*, *B. megaterium*, *P. vulgaris*, and *S. sonnei* (Khurana et al., 2014). Particles with a hydrodynamic size of 59 nm were found to be more effective against bacteria than particles with a size of 83 nm. Gurunathan et al. (2013) also showed that antibiotics' antibacterial and anti-biofilm action was effective against significant pathogens like *P. aeruginosa*, *Shigella flexneri*, *S. aureus*, and *S. pneumoniae*.

These results suggest that at the lowest concentrations of antibiotics and AgNPs, the combination has significant antibacterial and anti-biofilm effects. Nanocomposite spheres composed of AgNPs coated on polymer colloids demonstrated impressive antibacterial activity (Chen et al., 2014; Jain et al., 2021).

Much attention has recently been paid to graphene and silver nanoparticle (AgNPs) nanocomposites killing bacteria. Compared to AgNPs, the graphene oxide (GO)-Ag nanocomposite was much more effective at killing *E. coli* bacteria than AgNPs. Based on the results of a study, scientists thought that silver nanoparticles might kill bacteria. AgNPs can release Ag^{+} ions that can stick to the walls and membranes of bacterial cells and even get into the cytoplasm. Antimicrobial activity is caused by the reactive oxygen species (ROS) made inside the cell by Ag+ ions.

This causes a chain of events: (1) DNA synthesis is stopped, (2) mRNA synthesis is stopped, (3) the cell is destroyed, and the cell contents leak out, (4) protein synthesis is stopped, (5) cell-wall synthesis is stopped, (6) mitochondria are damaged, and (7) the electron transport chain is stopped. When all of these things happen, cells die. It has been shown that AgNPs are antimicrobial on their own, in addition to releasing silver ions.

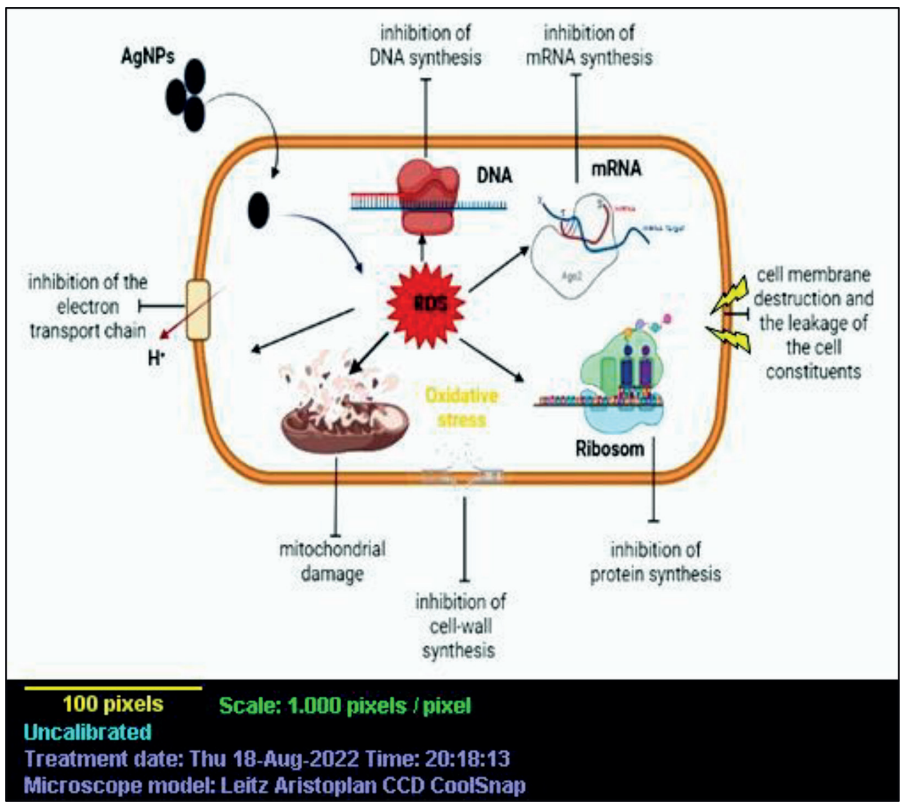

FIGURE 10.6 The suggested mechanism of antibacterial activity of silver nanoparticles' on bacterial cells.

Numerous studies, including those using a wide variety of plant extracts, suggest that AgNPs may physically interact with the cell surfaces of various bacteria. The biological effects of AgNP occur through several different pathways. Intracellular adhesion, penetration, and disruption of organelles and biomolecules (Dakal et al., 2016), as well as oxidative stress, are essential regulators of many bacterial functions. AgNPs were found attached to and deposited on the cell surface of bacteria, especially Gram-negative bacteria. AgNPs can enter Gram-negative bacteria cells through a water-filled channel called a porin in the outer membrane. The primary role of porins is the passive transport across the membrane of hydrophilic molecules of varying sizes and charges. Because silver ions are less likely to penetrate the thicker cell wall of Gram-positive bacteria, their action from AgNPs is more pronounced in Gram-negative bacteria (Chauhan et al., 2016). Since the negative charge of lipopolysaccharides encourages AgNP adherence, it is likely that they also strengthen the cell walls of Gram-negative bacteria, making them more vulnerable to silver nanoparticles (Pal et al., 2007). Some studies have suggested that the ability of silver nanoparticles to adhere to the bacterial cell wall is due to an electrostatic interaction between the positively charged silver ions and the negatively charged surface of the cell membrane caused by the carboxyl, phosphate, and amino groups in the cell wall. Because of their electrostatic attraction to one another, silver nanoparticles can cross the cell membrane and alter its molecular composition and permeability. This causes the proton motive force (PMF) to dissipate and the membrane to degrade (Netala et al., 2015; Rashid et al., 2017).

AgNPs could also be used as a way to get more Ag+ into bacterial cells. The proton motive force would lower the pH of the environment, which would cause more Ag^{+} to be released (Ovais et al., 2016; McQuillan et al., 2012). Also, it is thought that when silver nanoparticles come in contact with bacteria, they make free radicals that damage the cell membrane and make it porous (Mikhailova, 2020). Some researchers say that AgNPs can damage DNA while inside a bacterial cell because they stick to the surface of bacteria and change the way their membranes work (Rajeshkumar and Bharath, 2017; Rajeshkumar and Bharath, 2017). For example, the review by MaQuillan et al. (2012) shows that the main way silver nanoparticles work is by breaking down cell membranes. Also, as the silver nanoparticles break down, silver ions that kill bacteria are released. These silver ions can interact with proteins in the cell wall that contain thiols and change how they work. When nanoparticles of silver attach to proteins and come in contact with the outer membrane, they can form complexes with electronic donors

like oxygen, phosphorus, nitrogen, or sulfur. The most detailed explanation of how thiol groups work is found in the literature. Silver nanoparticles stop enzymes and proteins that are bound to a membrane from working because they break disulfide bonds and block active sites (Cakić et al., 2016).

Reports say that AgNPs may change the ratio of trans to cis unsaturated fatty acids in membranes. This could change how fluid the membrane is and how the lipid bilayer is made. It could cause changes to the structure of the membrane that stop it from working, making the membrane more permeable and weakening its integrity (Mikhailova, 2020).

AgNP accumulation on the cellular membranes results in problems with bilayer integrity and fissures, and AgNP penetration into the cell and interactions with vital proteins induce cell death. Ag ions have the potential to interact with thiol groups and the disulfide bonds of cellular metabolism enzymes, inactivating them and resulting in oxidative stress in microorganisms (Rashid et al., 2017; McQuillan et al., 2012). Thus, the antibacterial impact of nanoparticles interacting with *P. aeruginosa*'s cell membrane and generating ROS was evaluated (Yan et al., 2018). ROS oxidizes fatty acid double bonds in the membrane, generating free radicals that damage the cell membrane (Gamboa et al., 2019).

According to the discussion by Mikhailova (2020), the AgNPs were shown to have a catalytic activity to generate disulfide connections between oxygen molecules in cells and hydrogen atoms in thiol groups. Disulfide bonds, which silver catalyzes the creation of, alter the shape and structure of enzymes in cells and hence their function. Cells exposed to a 900 ppb Ag^{+} solution showed changes in the expression of several proteins and enzymes, including 30S ribosomal subunit, succinyl coenzyme A synthetase, maltose transporter (MalK), and fructose bisphosphate aldolase. By forming a complex with the 30S ribosomal subunit, silver ions inactivate the ribosome complex and halt protein synthesis. The influence of Ag NPs on on ribosomal, transcriptional, and translation processes leads to the production of unfinished, membrane-forming precursor proteins, which ultimately leads to cell death. Disruption of cellular metabolism is caused by AgNPs because of their effect on succinyl coenzyme-a-synthetase, an enzyme critical to the tricarboxylic acid cycle (Rai et al., 2012).

Interruptions of bacterial RNA transcription as well as purines, pyrimidines, and fatty acids were related to the bactericidal effects of AgNPs. Silver nanoparticles induce oxidative stress by suppressing a wide range of cellular metabolic processes; this includes impeding nutrient uptake, altering gene expression, disrupting ATP production, and preventing cytochrome oxidase

and NADH-succinate dehydrogenase from doing their jobs in the microbial respiratory chain. When AgNPs come into contact with DNA in a cell, it can cause replication errors (Bao et al., 2015). Ag^+ ion was discovered to form complexes with nucleic acids, which were then shown to disrupt the H-bonds between antiparallel base pairs.

AgNPs can also cause a change in the state of DNA molecules, from relaxed to compact, which reduces their capacity to replicate. Intercalation of AgNPs into the DNA helix has been shown to inhibit the transcription process in microorganisms (Morones et al., 2005). The phosphorylation cycle and the dephosphorylation cascade represent the relaying signal pathway needed for microbial activity and cellular function in microbial cells.

10.9 CONCLUSION

Over the past ten years, there has been a lot of interest in the biosynthesis of nanoparticles using reducing agents sourced from biological sources such plants, plant extracts, and microorganisms. The employment of no harmful or destructive components makes the green synthesis of NPs extremely cost-effective and a potential solution to the issue of antibiotic-resistant bacteria. When trying to create better treatments for bacterial infections, knowing how an antibacterial system works is a crucial first step. In general, nanoparticles have proven to be an effective replacement for antibiotic therapy and combinational therapy due to their astounding potential to address the issue of antibiotic-resistant microorganisms. In conclusion, AgNPs are a product with potential medical and hygiene applications, and their environmentally friendly synthesis can pave the way for these uses.

KEYWORDS

- **silver nanoparticles**
- **green-synthesis**
- **antibacterial activity**
- **photocatalytic properties**

REFERENCES

Abdelmigid, H. M.; Morsi, M. M.; Hussien, N. A.; Alyamani, A. A.; Alhuthal, N. A.; Albukhaty, S. Green Synthesis of Phosphorous-Containing Hydroxyapatite Nanoparticles (Nhap) as a Novel Nano-Fertilizer: Preliminary Assessment on Pomegranate (*Punica Granatum* L.). *Nanomaterials* **2022,** *12,* 1527. https://doi.org/10.3390/nano12091527

Abdelnaby, H.; Abo-Elala, G. M.; Abdel-Raouf, U. M.; Hamed, M. Antibacterial and Anticancer Activity of Extracellular Synthesized Silver Nanoparticles from Marine *Streptomyces Rochei* MHM13. *Egypt. J. Aquat. Res.* **2016,** *42,* 301–312.

Abdel-Raouf, N.; Al-Enazi, N. M.; Ibraheem, I. B.; Alharbi, R. M.; Alkhulaifi, M. M. Biosynthesis of Silver Nanoparticles by Using of the Marine Brown Alga Padina Pavonia and their Characterization. *Saudi J. Biol. Sci.* **2019,** *26* (6), 1207–1215.

Abdel-Raouf, N.; Al-Enazi, N. M.; Ibraheem, I. B.; Alharbi, R. M.; Alkhulaifi, M. M. Biosynthesis of Silver Nanoparticles by Using of the Marine Brown Alga Padina Pavonia and Their Characterization. *Saudi J. Biol. Sci.* **2019,** *26* (6), 1207–1215.

Agnihotri, S.; Mukherji, S.; Mukherji, S. Immobilized Silver Nanoparticles Enhance Contact Killing and Show Highest Efficacy: Elucidation of the Mechanism of Bactericidal Action of Silver. *Nanoscale.* **2013,** *5* (16), 7328–7340.

Ahmed, S.; Ikram, S. Biosynthesis of Gold Nanoparticles: A Green Approach. *J. Photochem. Photobiol. B: Biol.* **2016,** *161,* 141–153.

Ajitha, B.; Reddy, Y. A.; Jeon, H. J.; Ahn, C. W. Synthesis of Silver Nanoparticles in an Eco-Friendly Way Using Phyllanthus Amarus Leaf Extract: Antimicrobial and Catalytic Activity. *Adv. Powder Technol.* **2018,** *29* (1), 86–93.

Akhtar, M. S.; Panwar, J.; Yun, Y. S. Biogenic Synthesis of Metallic Nanoparticles by Plant Extracts. *ACS Sustai. Chem. Eng.* **2013,** *1* (6), 591–602.

Aktepe, N.; Baran, A. Fast and Low Cost Biosynthesis of Agnps with Almond Leaves: Medical Applications with Biocompatible Structures: Fast and Low Cost Biosynthesis of Agnps. *Progr. Nutr.* [Online] **2021,** *23* (3), E2021271. https://mattioli1885journals.com/index.php/progressinnutrition/article/view/11996 (accessed Jul 22, 2022).

Akter, M.; Sikder, M. T.; Rahman, M. M.; Ullah, A. K. M. A.; Hossain, K. F. B.; Banik, S.; Hosokawa, T.; Saito, T.; Kurasaki, M. A Systematic Review on Silver Nanoparticles-Induced Cytotoxicity: Physicochemical Properties and Perspectives. *J. Adv. Res.* **2018,** *9,* 1–16.

Al-Bahrani, R.; Raman, J.; Lakshmanan, H.; Hassan, A. A.; Sabaratnam, V. Green Synthesis of Silver Nanoparticles Using Tree Oyster Mushroom *Pleurotus Ostreatus* and Its Inhibitory Activity Against Pathogenic Bacteria. *Mater. Lett.* **2017,** *186,* 21–25.

Albrecht, M. A.; Evans, C. W.; Raston, C. L. Green Chemistry and the Health Implications of Nanoparticles. *Green Chem.* **2006,** *8* (5), 417–432.

Albukhaty, S.; Al-Bayati, L.; Al-Karagoly, H.; Al-Musawi, S. Preparation and Characterization of Titanium Dioxide Nanoparticles and In Vitro Investigation of their Cytotoxicity and Antibacterial Activity Against *Staphylococcus Aureus* and *Escherichia coli*. *Anim. Biotechnol.* **2020,** 1–7.

Albukhaty, S.; Al-Karagoly, H.; Allafchian, A. R.; Jalali, S. A. H.; Al-Kelabi, T.; Muhannad, M. Production and Characterization of Biocompatible Nanofibrous Scaffolds Made of B-Sitosterol Loaded Polyvinyl Alcohol/Tragacanth Gum Composites. *Nanotechnology* **2021,** *33,* 085102.

Albukhaty, S.; Naderi-Manesh, H.; Tiraihi, T.; Sakhi Jabir, M. Poly-L-Lysine-Coated Superparamagnetic Nanoparticles: A Novel Method for the Transfection of Pro-BDNF into Neural Stem Cells. *Artif. Cells Nanomed. Biotechnol.* **2018,** *46,* S125–S132.

Ali, M.; Kim, B.; Belfield, K. D.; Norman, D.; Brennan, M.; Ali, G. S. Green Synthesis and Characterization of Silver Nanoparticles Using Artemisia Absinthium Aqueous Extract—A Comprehensive Study. *Mater. Sci. Eng. C.* **2016 ,** *58,* 359–365.

Al-Kaabi, W. J.; Albukhaty, S.; Al-Fartosy, A. J. M.; Al-Karagoly, H. K.; Al-Musawi, S.; Sulaiman, G. M.; Dewir, Y. H.; Alwahibi, M. S.; Soliman, D. A. Development of *Inula Graveolens* (L.) Plant Extract Electrospun/Polycaprolactone Nanofibers: A Novel Material for Biomedical Application. *Appl. Sci.* **2021,** *11,* 828.

Al-Musawi, M. H.; Ibrahim, K. M.; Albukhaty S. *In Vitro* Study of Antioxidant, Antibacterial, and Cytotoxicity Properties of *Cordia Myxa* Fruit Extract. *Iran J. Microbiol.* **2022,** *14* (1), 97–103. doi: 10.18502/ijm.v14i1.8810.

Alshareef, A.; Laird, K.; Cross, R. B. Shape-Dependent Antibacterial Activity of Silver Nanoparticles on *Escherichia coli* and Enterococcus Faecium Bacterium. *Appl. Surf. Sci.* **2017,** *424,* 310–315.

Anil Kumar, S.; Abyaneh, M. K.; Gosavi, S. W.; Kulkarni, S. K.; Pasricha, R.; Ahmad, A.; Khan, M. I. Nitrate Reductase-Mediated Synthesis of Silver Nanoparticles From AgNo3. *Biotechnol. Lett.* **2007,** *29* (3), 439–445.

Chakravarty, A.; Ahmad, I.; Singh, P.; Sheikh, M. U. D.; Aalam, G.; Sagadevan, S.; Ikram, S. Green Synthesis of Silver Nanoparticles Using Fruits Extracts of *Syzygium Cumini* and their Bioactivity. *Chem. Phys. Lett.* **795,** *2022,* 139493. doi:10.1016/j.cplett.2022.139493.

Bachii, S. A.; Abd-Al Sahib, W. H. Preparation and Characterization of Silver Nanoparticles Biosynthesis by Pseudomonas Stutzeri Environmental Bacteria Isolated from Oil Fields and Their Antimicrobial Activity.

Baker, C.; Pradhan, A.; Pakstis, L.; Pochan, D. J.; Shah, S. I. Synthesis and Antibacterial Properties of Silver Nanoparticles. *J. Nanosci. Nanotechnol.* **2005,** 5 (2), 244–249.

Bao, H.; Yu, X.; Xu, C.; Li, X.; Li, Z.; Wei, D.; Liu Y. New Toxicity Mechanism of Silver Nanoparticles: Promoting Apoptosis and Inhibiting Proliferation. *PLoS ONE* **2015,** *10* (3), E0122535.

Bar, H.; Bhui, D. K.; Sahoo, G. P.; Sarkar, P.; De, S. P.; Misra A. Green Synthesis of Silver Nanoparticles Using Latex of Jatropha Curcas. *Colloids Surf. A: Physicochem. Eng. Asp.* **2009,** *339* (1–3), 134–139.

Bayda, S.; Adeel, M.; Tuccinardi, T.; Cordani, M.; Rizzolio, F. The History of Nanoscience and Nanotechnology: From Chemical–Physical Applications to Nanomedicine. *Molecules* **2020,** *25,* 112. https://doi.org/10.3390/molecules25010112

Bayram, S.; Zahr, O.; Re, J. D.; Blum, A. S. TMV Disk Scaffolds for Making Sub-30 Nm Silver Nanorings. In *Inprotein Scaffolds*; Humana Press: New York, NY, 2018; pp 109–118.

Begum, S. J. P.; Pratibha, S.; Rawat, J. M.; Venugopal, D.; Sahu, P.; Gowda, A.; Qureshi, K. A.; Jaremko, M. Recent Advances in Green Synthesis, Characterization, and Applications of Bioactive Metallic Nanoparticles. *Pharmaceuticals* **2022,** 1*5,* 455. https://doi.org/10.3390/ph15040455

Bharadwaj, K. K.; Rabha, B.; Pati, S.; Choudhury, B. K.; Sarkar, T.; Gogoi, S. K.; Kakati, N.; Baishya, D.; Kari, Z. A.; Edinur, H. A. Green Synthesis of Silver Nanoparticles Using *Diospyros Malabarica* Fruit Extract and Assessments of their Antimicrobial, Anticancer and Catalytic Reduction of 4-Nitrophenol (4-NP). *Nanomaterials (Basel).* **2021,** *11* (8), 1999. doi: 10.3390/nano11081999. PMID: 34443829; PMCID: PMC8401075.

Bhardwaj, B.; Singh, P.; Kumar, A.; Kumar, S.; Budhwar V. Eco-Friendly Greener Synthesis of Nanoparticles. *Adv. Pharmaceut. Bull.* **2020,** *10* (4), 566.

Birla, S. S.; Tiwari, V. V.; Gade, A. K.; Ingle, A. P.; Yadav, A. P.; Rai, M. K. Fabrication of Silver Nanoparticles by Phoma Glomerata and Its Combined Effect Against *Escherichia coli*, Pseudomonas Aeruginosa and Staphylococcus Aureus. *Lett. Appl. Microbiol.* **2009,** *48* (2), 173–179.

Bistarelli, S.; Rossi, F.; Santini, F. Not Only Size, but also Shape Counts: Abstract Argumentation Solvers are Benchmark-Sensitive. *J. Logic Comput.* **2018,** *28* (1), 85–117.

Bunaciu, A. A.; Udriştioiu, E. G.; Aboul-Enein, H. Y. X-Ray Diffraction: Instrumentation and Applications. *Crit. Rev. Anal. Chem.* **2015,** *45* (4), 289–299.

Buszewski, B.; Railean-Plugaru, V.; Pomastowski, P.; Rafińska, K.; Szultka-Młyńska, M.; Golinska, P.; Wypij, M.; Laskowski, D.; Dahm, H. Antimicrobial Activity of Biosilver Nanoparticles Produced by a Novel *Streptacidiphilus Durhamensis* Strain. *J. Microbiol. Immunol. Infect.* **2018,** *51,* 45–54.

Cakić, M.; Glišić, S.; Nikolić, G.; Nikolić, G. M.; Cakić, K.; Cvetinov, M. Synthesis, Characterization and Antimicrobial Activity of Dextran Sulphate Stabilized Silver Nanoparticles. *J. Mol. Struc.* **2016,** *1110,* 156–161.

Çalhan, S. D.; Gündoğan, M. Biosynthesis of Silver Nanoparticles Using Onosma Sericeum Willd. and Evaluation Oftheir Catalytic Properties and Antibacterial and Cytotoxic Activity. *Turk. J. Chem.* **2020,** *44* (6), 1587–600.

Castillo-Henríquez, L.; Alfaro-Aguilar, K.; Ugalde-Álvarez, J.; Vega-Fernández, L.; Montes De Oca-Vásquez, G.; Vega-Baudrit, J. R. Green Synthesis of Gold and Silver Nanoparticles from Plant Extracts and their Possible Applications as Antimicrobial Agents in the Agricultural Area. *Nanomaterials* **2020,** *10,* 1763. https://doi.org/10.3390/nano10091763

Chauhan, N.; Tyagi, A. K.; Kumar, P.; Malik, A. Antibacterial Potential of Jatropha Curcas Synthesized Silver Nanoparticles Against Food Borne Pathogens. *Front. Microbiol.* **2016,** *7,* 1748.

Chen, C. Y.; Hu, Y.; Lin, H. L. A Novel Low Temperature Sintering Process for Pmnn-PZT Ceramics. *Mater. Chem. Phys.* **2006,** *99* (1), 26–29.

Chen, G.; Lu, J.; Lam, C.; Yu, Y. A Novel Green Synthesis Approach for Polymer Nanocomposites Decorated with Silver Nanoparticles and their Antibacterial Activity. *Analyst* **2014,** *139* (22), 5793–5799.

Chouhan, S.; Guleria, S. Green Synthesis of Agnps Using Cannabis Sativa Leaf Extract: Characterization, Antibacterial, Anti-Yeast and A-Amylase Inhibitory Activity. *Mater. Sci. Energy Technol.* **2020 ,** *3,* 536–544.

Christian, P.; Von Der Kammer, F.; Baalousha, M.; Hofmann, T. Nanoparticles: Structure, Properties, Preparation and Behaviour in Environmental Media. *Ecotoxicology* **2008,** *17* (5), 326–343.

Cunha, M. N.; Felgueiras, H. P.; Gouveia, I.; Zille, A. Synergistically Enhanced Stability of Laccase Immobilized on Synthesized Silver Nanoparticles with Water-Soluble Polymers. *Colloids Surf. B: Biointerfaces.* **2017,** *154,* 210–220.

Dakal, T. C.; Kumar, A.; Majumdar, R. S.; Yadav, V. Mechanistic Basis of Antimicrobial Actions of Silver Nanoparticles. *Front. Microbiol.* **2016,** *7,* 1831.

Daphne, J.; Francis, A.; Mohanty, R.; Ojha, N.; Das, N. Green Synthesis of Antibacterial Silver Nanoparticles Using Yeast Isolates and Its Characterization. *Res. J. Pharm. Technol.* **2018,** *11* (1), 83–92.

Das, R.; Nath, S. S.; Chakdar, D.; Gope, G.; Bhattacharjee R. Synthesis of Silver Nanoparticles and their Optical Properties. *J. Exp. Nanosci.* **2010 ,** *5* (4), 357–362.

Das, V. L.; Thomas, R.; Varghese, R. T.; Soniya, E. V.; Mathew, J.; Radhakrishnan, E. K. Extracellular Synthesis of Silver Nanoparticles by the Bacillus Strain CS 11 Isolated from Industrialized Area. *3 Biotech* **2014,** *4* (2), 121–126.

De Barros, C. H.; Cruz, G. C.; Mayrink, W.; Tasic, L. Bio-Based Synthesis of Silver Nanoparticles from Orange Waste: Effects of Distinct Biomolecule Coatings on Size, Morphology, and Antimicrobial Activity. *Nanotechnol. Sci. Appl.* **2018,** *11,* 1.

Debnath, B.; Das, R. Controlled Synthesis of Saponin-Capped Silver Nanotriangles and their Optical Properties. *Plasmonics* **2019,** *14* (6), 1365–1375.

Deepak, P.; Amutha, V.; Birundha, R.; Sowmiya, R.; Kamaraj, C.; Balasubramanian, V.; Balasubramani, G.; Aiswarya, D.; Arul, D.; Perumal, P. Facile Green Synthesis of Nanoparticles from Brown Seaweed Sargassum Wightii and Its Biological Application Potential. *Adv. Nat. Sci.: Nanosci. Nanotechnol.* **2018,** *9* (3), 035019.

Deepak, V.; Umamaheshwaran, P. S.; Guhan, K.; Nanthini, R. A.; Krithiga, B.; Jaithoon, N. M.; Gurunathan, S. Synthesis of Gold and Silver Nanoparticles Using Purified URAK. *Colloid Surf. B* **2011,** *86,* 353–358.

Deljou, A.; Goudarzi S. Green Extracellular Synthesis of the Silver Nanoparticles Using Thermophilic *Bacillus Sp*. AZ1 and Its Antimicrobial Activity Against Several Human Pathogenetic Bacteria. *Iran. J. Biotechnol.* **2016,** *14* (2), 25.

Devanesan, S.; Alsalhi, M. S. Green Synthesis of Silver Nanoparticles Using the Flower Extract of Abelmoschus Esculentus for Cytotoxicity and Antimicrobial Studies. *Int. J. Nanomed.* **2021,** *16,* 3343.

Ebrahiminezhad, A.; Taghizadeh, S.; Ghasemi, Y. Green Synthesis of Silver Nanoparticles Using Mediterranean Cypress (Cupressus Sempervirens) Leaf Extract. *Am. J. Biochem. Biotechnol.* 2017.

Eid, A. M.; Fouda, A.; Niedbała, G.; Hassan, S. E.-D.; Salem, S. S.; Abdo, A. M.; Hetta, H. F.; Shaheen, T. I. Endophytic *Streptomyces Laurentii* Mediated Green Synthesis of Ag-NPs with Antibacterial and Anticancer Properties For Developing Functional Textile Fabric Properties. *Antibiotics* **2020,** *9,* 641. https://doi.org/10.3390/antibiotics9100641

Elavazhagan, T.; Arunachalam, K. D. Memecylon Edule Leaf Extract Mediated Green Synthesis of Silver and Gold Nanoparticles. *Int. J. Nanomed.* **2011,** *6,* 1265.

Elhawary, S.; El-Hefnawy, H.; Alzahraa, F. A.; Sobeh, M.; Mostafa, E.; Osman, S.; El-Raey, M. Green Synthesis of Silver Nanoparticles Using Extract of Jasminum Officinal L. Leaves and Evaluation of Cytotoxic Activity Towards Bladder (5637) and Breast Cancer (MCF-7) Cell Lines. *Int. J. Nanomed*. **2020,** *15,* 9771–9781 https://doi.org/10.2147/ijn.s269880

El-Rafie, M. H.; El-Naggar, M. E.; Ramadan, M. A.; Fouda, M. M.; Al-Deyab, S. S.; Hebeish, A. Environmental Synthesis of Silver Nanoparticles Using Hydroxypropyl Starch and their Characterization. *Carbohydr. Polym.* 2011**,** *86* (2), 630–635.

Escárcega-González, C. E.; Garza-Cervantes, J. A.; Vazquez-Rodríguez, A.; Montelongo-Peralta, L. Z.; Treviño-Gonzalez, M. T.; Díaz Barriga-Castro, E., Saucedo-Salazar, E. M.; Chávez Morales, R. M.; Regalado-Soto, D. I.; Treviño-González, F. M.; Carrazco Rosales, J. L.; Villalobos Cruz, R.; Morones-Ramirez, J. R. In Vivo Antimicrobial Activity of Silver Nanoparticles Produced Via a Green Chemistry Synthesis Using Acacia Rigidula as a Reducing and Capping Agent. *Int. J. Nanomed.* **2018,** *13,* 2349–2363, https://doi.org/10.2147/ijn.s160605

Fayaz, A. M.; Balaji, K.; Girilal, M.; Yadav, R.; Kalaichelvan, P. T.; Venketesan, R. Biogenic Synthesis of Silver Nanoparticles and their Synergistic Effect with Antibiotics: A Study Against Gram-Positive and Gram-Negative Bacteria. *Nanomedicine* **2010,** *6* (1), 103–109.

Fortunati, E.; Peltzer, M.; Armentano, I.; Jiménez, A.; Kenny, J. M. Combined Effects of Cellulose Nanocrystals and Silver Nanoparticles on the Barrier and Migration Properties of PLA Nano-Biocomposites. *J. Food Eng.* **2013,** *118,* 117–124.

Francis, S., Joseph, S., Koshy, E. P.; Mathew, B. Microwave Assisted Green Synthesis of Silver Nanoparticles Using Leaf Extract of Elephantopus Scaber and Its Environmental and Biological Applications. *Artif. Cells Nanomed. Biotechnol.* **2017,** *46* (4), 795–804. doi:10.1080/21691401.2017.1345921

Gamboa, S. M.; Rojas, E. R.; Martínez, V. V.; Vega-Baudrit, J. Synthesis and Characterization of Silver Nanoparticles and their Application as an Antibacterial Agent. *Int. J. Biosen. Bioelectron.* **2019,** *5,* 166–173.

Gan, L.; Zhang, S.; Zhang, Y.; He, S.; Tian, Y. Biosynthesis, Characterization and Antimicrobial Activity of Silver Nanoparticles by A Halotolerant *Bacillus Endophyticus* SCU-L. *Prep. Biochem. Biotechnol.* **2018,** *48,* 582–588.

Garcia-Barrasa, J.; Lopez-De-Luzuriaga, J. M.; Monge, M. Silver Nanoparticles: Synthesis Through Chemical Methods in Solution and Biomedical Applications. *Cent. Eur. J. Chem.* **2011,** *9,* 7–19.

Garcia-Barrasa, J.; Lopez-De-Luzuriaga, J. M.; Monge, M. Silver Nanoparticles: Synthesis Through Chemical Methods in Solution and Biomedical Applications. *Cent. Eur. J. Chem.* **2011,** *9,* 7–19.

Ghosh, S.; Patil, S.; Ahire, M.; Kitture, R.; Kale, S.; Pardesi, K.; Cameotra, S. S.; Bellare, J.; Dhavale, D. D.; Jabgunde, A.; Chopade, B. A. 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.

Gur, T.; Meydan, I.; Seckin, H.; Bekmezci, M.; Sen, F. Green Synthesis, Characterization and Bioactivity of Biogenic Zinc Oxide Nanoparticles. *Environ. Res.* **2022,** 2*04,* 111897.

Gurunathan, S.; Han, J. W.; Kim, E. S.; Park, J. H.; Kim, J. H. Reduction of Graphene Oxide by Resveratrol: A Novel and Simple Biological Method for the Synthesis of an Effective Anticancer Nanotherapeutic Molecule. *Int. J. Nanomed.* **2015,** *10,* 2951.

Gurunathan, S.; Raman, J.; Abd Malek, S. N.; John, P. A.; Vikineswary, S. Green Synthesis of Silver Nanoparticles Using Ganoderma Neo-Japonicum Imazeki: A Potential Cytotoxic Agent Against Breast Cancer Cells. *Int. J. Nanomed.* **2013,** *8,* 4399.

Gurunathan, S.; Han, J. W.; Eppakayala, V.; Jeyaraj, M.; Kim, J. H. Cytotoxicity of Biologically Synthesized Silver Nanoparticles in MDA-MB-231 Human Breast Cancer Cells. *Biomed. Res. Int.* **2013,** *2013,* 535796.

Haber, J.; Sokolov, K. Synthesis of Stable Citrate-Capped Silver Nanoprisms. *Langmuir* **2017,** *33,* 10525–10530.

Heera, P.; Shanmugam, S. Nanoparticle Characterization and Application: An Overview. *Appl. Sci.Int. J. Curr. Microbiol. Appl. Sci.* **2015,** *4* (8), 379–386.

Holt, K. B.; Bard, A. J. Interaction of Silver (I) Ions with the Respiratory Chain of Escherichia coli: An Electrochemical and Scanning Electrochemical Microscopy Study of the Antimicrobial Mechanism of Micromolar Ag+. *Biochemistry* **2005,** *44* (39), 13214–13223.

Hong, S. H.; Lee, W. G. Preparation and Characterization of Expanded Graphite/Ag Nanoparticle Composites for the Improvement of Thermal Diffusion. *Korean Chem. Eng. Res.* **2018,** *56* (3), 410–415. https://doi.org/10.9713/kcer.2018.56.3.410

Ilahi, I.; Khuda, F.; Sahibzada, M. U. K.; Alghamdi, S.; Ullah, R.; Zakiullah; Dablool, Anas S.; Alam, M.; Khan, A.; Khalil, A. A. K. Synthesis of Silver Nanoparticles Using Root Extract of Duchesnea Indica and Assessment of Its Biological Activities. *Arab. J. Chem.* **2021,** *14* (5), 103110, doi:10.1016/j.arabjc.2021.103110

Huang, J.; Lin, L.; Sun, D.; Chen, H.; Yang, D.; Li, Q. Bio-Inspired Synthesis of Metal Nanomaterials and Applications. *Chem. Soc. Rev.* **2015,** *44* (17), 6330–6374.

Jabir, M.; Sahib, U. I.; Taqi, Z.; Taha, A.; Sulaiman, G.; Albukhaty, S.; Al-Shammari, A.; Alwahibi, M.; Soliman, D.; Dewir, Y. H. Linalool-loaded Glutathione-Modified Gold Nanoparticles Conjugated with CALNN Peptide as Apoptosis Inducer and NF-κB Translocation Inhibitor in SKOV-3 Cell Line. *Int. J. Nanomed.* **2020,** *15,* 9025.

Jain, A. S.; Pawar, P. S.; Sarkar, A.; Junnuthula, V.; Dyawanapelly, S. Bionanofactories for Green Synthesis of Silver Nanoparticles: Toward Antimicrobial Applications. *Int. J. Mol. Sci.* **2021,** *22* (21), 11993.

Jain, A. S.; Pawar, P. S.; Sarkar, A.; Junnuthula, V.; Dyawanapelly, S. Bionanofactories for Green Synthesis of Silver Nanoparticles: Toward Antimicrobial Applications. *Int. J. Mol. Sci.* **2021,** *22,* 11993. https://doi.org/10.3390/ijms222111993

Jain, A. S.; Pawar, P. S.; Sarkar, A.; Junnuthula, V.; Dyawanapelly, S. Bionanofactories for Green Synthesis of Silver Nanoparticles: Toward Antimicrobial Applications. *Int. J. Mol. Sci.* **2021,** *22,* 11993. https://doi.org/10.3390/ijms222111993

Jain, A. S.; Pawar, P. S.; Sarkar, A.; Junnuthula, V.; Dyawanapelly, S. Bionanofactories for Green Synthesis of Silver Nanoparticles: Toward Antimicrobial Applications. *Int. J. Mol. Sci.* **2021,** *22,* 11993. https://doi.org/10.3390/ijms222111993

Jihad, M. A.; Noori, F. T. M.; Jabir, M. S.; Albukhaty, S.; Almalki, F. A.; Alyamani, A. A. Polyethylene Glycol Functionalized Graphene Oxide Nanoparticles Loaded with *Nigella Sativa* Extract: A Smart Antibacterial Therapeutic Drug Delivery System. *Molecules* **2021,** *26,* 3067.

Jijie, R.; Barras, A.; Teodorescu, F.; Boukherroub, R.; Szunerits, S. Advancements on the Molecular Design of Nanoantibiotics: Current Level of Development and Future Challenges. *Mol. Syst. Des. Eng.* **2017,** *2* (4), 349–369.

Jo, J. H.; Singh, P.; Kim, Y.J.; Wang, C.; Mathiyalagan, R.; Jin, C.-G.; Yang, D. C. *Pseudomonas Deceptionensis* DC5-Mediated Synthesis of Extracellular Silver Nanoparticles. *Artif. Cells Nanomed. Biotechnol.* **2015,** *44,* 1576–1581.

Joseph, J.; Deborah, K.; Raghavi, R.; Mary Shamya, A.; Aruni, W. Green Synthesis of Silver Nanoparticles Using *Phyllanthus Amarus* Seeds and their Antibacterial Activity Assessment. *Biomed. Biotechnol. Res. J.* **2021,** *5,* 35–38.

Kaabipour, S.; Hemmati, S. A Review on the Green and Sustainable Synthesis of Silver Nanoparticles and One-Dimensional Silver Nanostructures. *Beilstein J. Nanotechnol.* **2021,** *12,* 102–136. doi: 10.3762/bjnano.12.9. PMID: 33564607, PMCID: PMC7849236

Kaabipour, S.; Hemmati, S. A Review on the Green and Sustainable Synthesis of Silver Nanoparticles and One-Dimensional Silver Nanostructures. *Beilstein J. Nanotechnol.* **2021,** *12* (1), 102–136.

Kalimuthu, K.; Suresh Babu, R.; Venkataraman, D.; Bilal, M.; Gurunathan, S. Biosynthesis of Silver Nanocrystals by *Bacillus Licheniformis*. *Colloids Surf. B Biointerfaces* **2008,** *65* (1), 150–153. doi: 10.1016/j.colsurfb.2008.02.018

Kalishwaralal, K.; Deepak, V.; Pandian, S. R.; Kottaisamy, M.; Barathmanikanth, S.; Kartikeyan, B.; Gurunathan, S. Biosynthesis of Silver and Gold Nanoparticles Using Brevibacterium Casei. *Colloids Surf. B: Biointerfaces* **2010,** *77* (2), 257–262.

Karagoly, H.; Rhyaf, A.; Naji, H.; Albukhaty, S.; Almalki, F. A.; Alyamani, A. A.; Albaqami, J.; Aloufi, S. Green Synthesis, Characterization, Cytotoxicity, and Antimicrobial Activity of Iron Oxide Nanoparticles Using *Nigella Sativa* Seed Extract. *Green Process. Synth.* **2022,** *11,* 254–265.

Karatoprak, G. Ş.; Aydin, G.; Altinsoy, B.; Altinkaynak, C.; Koşar, M.; Ocsoy, I. The Effect of Pelargonium Endlicherianum Fenzl. Root Extracts on Formation of Nanoparticles and their Antimicrobial Activities. *Enzyme Microb. Technol.* **2017,** *97,* 21–26.

Karthik, L.; Kumar, G.; Kirthi, A. V.; Rahuman, A. A.; Bhaskara Rao, K. V. Streptomyces Sp. LK3 Mediated Synthesis of Silver Nanoparticles and Its Biomedical Application. *Bioprocess Biosyst. Eng.* **2014,** *37* (2), 261–267.

Kasithevar, M.; Saravanan, M.; Prakash, P.; Kumar, H.; Ovais, M.; Barabadi, H.; Shinwari, Z. K. Green Synthesis of Silver Nanoparticles Using Alysicarpus Monilifer Leaf Extract and Its Antibacterial Activity Against MRSA and Cons Isolates in HIV Patients. *J. Interdiscip. Nanomed.* **2017,***2* (2), 131–141.

Khan, I.; Saeed, K.; Khan, I. Nanoparticles: Properties, Applications and Toxicities. *Arab. J. Chem.* **2017,** *12,* 908–931.

Khane, Y.; Benouis, K.; Albukhaty, S.; Sulaiman, G. M.; Abomughaid, M. M.; Al Ali, A.; Aouf, D.; Fenniche, F.; Khane, S.; Chaibi, W.; Henni, A.; Bouras, H. D.; Dizge, N. Green Synthesis of Silver Nanoparticles Using Aqueous *Citrus Limon* Zest Extract: Characterization and Evaluation of their Antioxidant and Antimicrobial Properties. *Nanomaterials* **2022,** *12,* 2013. https://doi.org/10.3390/nano12122013

Khashan, K. S.; Sulaiman, G. M.; Abdulameer, F. A.; Albukhaty, S.; Ibrahem, M. A.; Al-Muhimeed, T.; Alobaid, A. A. Antibacterial Activity of TiO2 Nanoparticles Prepared by One-Step Laser Ablation in Liquid. *Appl. Sci.* **2021,** *11,* 4623.

Khatami, M.; Zafarnia, N.; Heydarpoor Bami, M.; Sharifi, I.; Singh, H. Antifungal and Antibacterial Activity of Densely Dispersed Silver Nanospheres with Homogeneity Size which Synthesized Using Chicory: An In Vitro Study. *J. Mycol. Med.* **2018,** *28,* 637–644.

Khodashenas, B.; Ghorbani, H. R. Synthesis of Silver Nanoparticles With Different Shapes. *Arab. J. Chem.* 2015*,* 1–16.

Khurana, C.; Vala, A. K.; Andhariya, N.; Pandey, O. P.; Chudasama, B. Antibacterial Activity of Silver: The Role of Hydrodynamic Particle Size at Nanoscale. *J. Biomed. Mater. Res. A* **2014,** *102,* 3361–3368.

Kim, B. H.; Lee, J. S. One-Pot Photochemical Synthesis of Silver Nanodisks Using A Conventional Metal-Halide Lamp. *Mater. Chem. Phys.* **2015,** *149,* 678–685.

Kiran, G. S.; Dhasayan, A.; Lipton, A. N.; Selvin, J.; Arasu, M. V.; Al-Dhabi, N. A. Melanin-Templated Rapid Synthesis of Silver Nanostructures. *J. Nanobiotechnol.* **2014,** *12* (1), 1–3.

Kowshik, M.; Ashtaputre, S.; Kulkani, S. K.; Parknikar, K. M. M. Extracellular Synthesis of Silver Nanoparticles by a Silver-Tolerant Yeast Strain MKY3. *Nanotechnology* **2003,** *14,* 95–100. doi: 10.1088/0957-4484/14/1/321

Kremer, J. R.; Mastronarde, D. N.; Mcintosh, J. R. Computer Visualization of Three-Dimensional Image Data Using IMOD. *J. Struc. Biol.* **1996,** *116* (1), 71–76.

Kumar, P.; Singh, P. K.; Hussain, M.; Kumar Das, A. Synthesis of Silver Metal Nanoparticles Through Electric Arc Discharge Method: A Review. *Adv. Sci. Lett.* **2016,** *22* (1), 3–7.

Kumar, B.; Smita, K.; Cumbal, L.; Debut, A.; Pathak, R. N. Sonochemical Synthesis of Silver Nanoparticles Using Starch: A Comparison. *Bioinorg. Chem. Appl.* **2014,** *2014,* 784268.

Kumar, S.; Shahid, M.; Khan, M. A.; Kumar, N.; Khan, H. M. Biosynthesis of Silver Nanoparticles From Phyllanthus Niruri Leaf Extracts and Its Antibacterial Activity

Against Antibiotics-Resistant Clinical Isolates. *Pathology* **2020,** *52,* S127. doi:10.1016/j.pathol.2020.01.432

Kumar, S. S. D.; Rajendran, N. K.; Houreld, N. N.; Abrahamse, H. Recent Advances on Silver Nanoparticle and Biopolymer-Based Biomaterials for Wound Healing Applications. *Int. J. Biol. Macromol.* **2018,** *115,* 165–175.

Lee, Y. J.; Kim, J.; Oh, J.; Bae, S.; Lee, S.; Hong, I. S.; Kim, S. H. Ion-Release Kinetics and Ecotoxicity Effects of Silver Nanoparticles. *Environ. Toxicol. Chem.* **2012,** *31* (1), 155–159.

Khanal, L. N.; Sharma, K. R.; Paudyal, H.; Parajuli, K.; Dahal, B.; Ganga, G. C.; Pokharel, Y. R.; Kalauni, S. K.; Green Synthesis of Silver Nanoparticles from Root Extracts of Rubus Ellipticus Sm. and Comparison of Antioxidant and Antibacterial Activity. *J. Nanomater.* **2022** 1832587. https://doi.org/10.1155/2022/183258

Leung, T. C.; Wong, C. K.; Xie, Y. Green Synthesis of Silver Nanoparticles Using Biopolymers, Carboxymethylated-Curdlan and Fucoidan. *Mater. Chem. Phys.* **2010,** *121,* 402–405.

Li, S.; Shen, Y.; Xie, A.; Yu, X.; Qiu, L.; Zhang, L.; Zhang, Q. Green Synthesis of Silver Nanoparticles Using Capsicum Annuum L. Extract. *Green Chem.* **2007,** *9* (8), 852–858.

Lin, Z.; Wu, J.; Xue, R.; Yang Y. Spectroscopic Characterization of Au3+ Biosorption by Waste Biomass of Saccharomyces Cerevisiae. *Spectrochim. Acta A Mol. Biomol. Spectrosc.* **2005,** *61* (4), 761–765.

Liu, J.; Hurt, R. H. Ion Release Kinetics and Particle Persistence in Aqueous Nano-Silver Colloids. *Environ. Sci. Technol.* **2010,** *44* (6), 2169–2175.

Liu, J.; Sonshine, D. A.; Shervani, S.; Hurt, R. H. Controlled Release of Biologically Active Silver from Nanosilver Surfaces. *ACS Nano* **2010,** *4* (11), 6903–6913.

Loiseau, A.; Asila, V.; Boitel-Aullen, G.; Lam, M.; Salmain, M.; Boujday, S. Silver-Based Plasmonic Nanoparticles for and their Use in Biosensing. *Biosensors* **2019,** *9,* 78. https://doi.org/10.3390/bios9020078

Long, Y.; Hu, S.; Lei, P.; Li, Y. Preparation of Green Silver Nanoparticles with High Antibacterial Ability Using N-Maleoyl Chitosan and Montmorillonite. *Mater. Lett.* **2022,** 3*16,* 132044.

Lu, Y.; Zhang, C. Y.; Zhang, D. J.; Hao, R.; Hao, Y. W.; Liu, Y. Q. Fabrication of Flower-Like Silver Nanoparticles for Surface-Enhanced Raman Scattering. *Chin. Chem. Lett.* **2016,** *27* (5), 689–692.

Mafune, F.; Kohno, J.-Y.; Takeda, Y.; Kondow, T.; Sawabe, H. Formation and Size Control of Silver Nanoparticles by Laser Ablation in Aqueous Solution. *J. Phys. Chem. B* **2000,** *104,* 9111–9117.

Mahendia, S.; Kumar Tomar, A.; Goyal, P. K.; Kumar, S. Tuning of Refractive Index of Poly (Vinyl Alcohol: Effect of Embedding Cu and Ag Nanoparticles. *J. Appl. Phys.* 2013**,** *113* (7), 073103.

Mahendia, S.; Kumar Tomar, A.; Goyal, P. K.; Kumar, S. Tuning of Refractive Index of Poly (Vinyl Alcohol: Effect of Embedding Cu and Ag Nanoparticles. *J. Appl. Phys.* **2013,** *113* (7), 073103.

Mandal, P.; Babu, S. S.; Mandal, N. C. Antimicrobial Activity of Saponins from Acacia Auriculiformis. *Fitoterapia* **2005,** *76* (5), 462–465.

Manivasagan, P.; Venkatesan, J.; Senthilkumar, K.; Sivakumar, K.; Kim, S. K. Biosynthesis, Antimicrobial and Cytotoxic Effect of Silver Nanoparticles Using A Novel *Nocardiopsis* sp. MBRC-1. *Biomed Res. Int.* **2013,** *2013,* 287638.

Marassi, V.; Di Cristo, L.; Smith, S. G. J.; Ortelli, S.; Blosi, M.; Costa, A. L.; Reschiglian, P.; Volkov, Y.; Prina-Mello, A. Silver Nanoparticles As a Medical Device In Healthcare

Settings: A Five-Step Approach for Candidate Screening of Coating Agents. *R. Soc. Open Sci.* **2018,** *5,* 171113.

May, B. M.; Oluwafemi, O. S. Sugar-Reduced Gelatin-Capped Silver Nanoparticles with High Selectivity for Colorimetric Sensing of Hg 2 and Fe 2 Ions in the Midst of Other Metal Ions in Aqueous Solutions. *Int. J. Electrochem. Sci.* **2016,** *11,* 8096–8108.

Mcquillan, J. S.; Groenaga Infante, H.; Stokes, E.; Shaw, A. M. Silver Nanoparticle Enhanced Silver Ion Stress Response in Escherichia coli K12. *Nanotoxicology* **2012,** *6* (8), 857–866.

Mikhailova, E. O. Silver Nanoparticles: Mechanism of Action and Probable Bio-Application. *J. Funct. Biomater.* **2020,** *11,* 84. https://doi.org/10.3390/jfb11040084

Mikhailova, E. O. Silver Nanoparticles: Mechanism of Action and Probable Bio-Application. *J. Funct. Biomater.* **2020,** *11,* 84. https://doi.org/10.3390/jfb11040084

Minhas, F. T.; Arslan, G.; Gubbuk, I. H.; Akkoz, C.; Ozturk, B. Y.; Asıkkutlu, B.; Arslan, U.; Ersoz, M. Evaluation of Antibacterial Properties on Polysulfone Composite Membranes Using Synthesized Biogenic Silver Nanoparticles with *Ulva Compressa* (L.) Kütz. and *Cladophora Glomerata* (L.) Kütz. Extracts. *Int. J. Biol. Macromol.* **2018,** *107,* 157–165.

Mirzaie, A.; Badmasti, F.; Dibah, H.; Hajrasouliha, S.; Yousefi, F.; Andalibi, R.; Kashtali, A. B.; Rezaei, A. H.; Bakhtiatri, R. Phyto-Fabrication of Silver Nanoparticles Using Typha Azerbaijanensis Aerial Part and Root Extracts. *Appl. Sci.Iran. J. Public Health.* **2022,** *51* (5), 1097.

Mittal, A. K.; Chisti, Y.; Banerjee, U. C. Synthesis of Metallic Nanoparticles Using Plant Extracts. *Biotechnol. Adv.* **2013,** *31* (2), 346–356. doi: 10.1016/j.biotechadv.2013.01.003

Modan, E. M.; Plăiaşu, A. G. Advantages and Disadvantages of Chemical Methods in the Elaboration of Nanomaterials. *Ann. "Dunarea Jos" Univ. Galati. Fascicle IX Metall. Mater. Sci.* **2020,** *43,* 53–60.

Mohd Yusof, H.; Abdul Rahman, N. A.; Mohamad, R.; Zaidan, U. H. Microbial Mediated Synthesis of Silver Nanoparticles by Lactobacillus Plantarum TA4 and Its Antibacterial and Antioxidant Activity. *Appl. Sci.* **2020,** *10* (19), 6973.

Mondal, A. H.; Yadav, D.; Mitra, S.; Mukhopadhyay, K. Biosynthesis of Silver Nanoparticles Using Culture Supernatant of Shewanella sp. ARY1 and Their Antibacterial Activity. *Int. J. Nanomed.* **2020,** *15,* 8295.

Morones, J. R.; Elechiguerra, J. L.; Camacho, A.; Holt, K.; Kouri, J. B.; Ramírez, J. T.; Yacaman, M. J. The Bactericidal Effect of Silver Nanoparticles. *Nanotechnology* 2005**,** *16* (10), 2346.

Mukherjee, K.; Gupta, R.; Kumar, G.; Kumari, S.; Biswas, S.; Padmanabhan, P. Synthesis of Silver Nanoparticles by Bacillus Clausii and Computational Profiling of Nitrate Reductase Enzyme Involved in Production. *J. Genet. Eng. Biotechnol.* **2018,** *16* (2), 527–536.

Mukherjee, P.; Ahmad, A.; Mandal, D.; Senapati, S.; Sainkar, S. R.; Khan, M. I.; Parishcha, R.; Ajaykumar, P. V.; Alam, M.; Kumar, R.; Sastry, M. Fungus-Mediated Synthesis of Silver Nanoparticles and their Immobilization in the Mycelial Matrix: A Novel Biological Approach to Nanoparticle Synthesis. *Nano Lett.* 2001**,** *1* (10), 515–519.

Mukherjee, P.; Ahmad, A.; Mandal, D.; Senapati, S.; Sainkar, S. R.; Khan, M. I.; Parishcha, R.; Ajaykumar, P. V.; Alam, M.; Kumar, R.; Sastry, M. Fungus-Mediated Synthesis of Silver Nanoparticles and their Immobilization in the Mycelial Matrix: A Novel Biological Approach to Nanoparticle Synthesis. *Nano Lett.* 2001**,** *1* (10), 515–519.

Murugesan, S.; Bhuvaneswari, S.; Sivamurugan, V. Green Synthesis, Characterization of Silver Nanoparticles of A Marine Red Alga *Spyridia Fusiformis* and their Antibacterial Activity. *Int. J. Pharm. Pharm. Sci.* **2017,** *9,* 192–197.

Nadagouda, M. N.; Varma, R. S. Green Synthesis of Ag and Pd Nanospheres, Nanowires, and Nanorods Using Vitamin: Catalytic Polymerisation of Aniline and Pyrrole. *J. Nanomater.* **2008,** *2008*.

Nakamura, S.; Sato, M.; Sato, Y.; Ando, N.; Takayama, T.; Fujita, M.; Ishihara, M. Synthesis and Application of Silver Nanoparticles (Ag NPs) for the Prevention of Infection in Healthcare Workers. *Int. J. Mol. Sci.* **2019,** *20,* 3620. https://doi.org/10.3390/ijms20153620

Narayanan, K. B.; Sakthivel, N. Synthesis and Characterization of Nano-Gold Composite Using Cylindrocladium Floridanum and Its Heterogeneous Catalysis in the Degradation of 4-Nitrophenol. *J. Hazard. Mater.* **2011,** *189* (1–2), 519–525.

Nayak, P. S.; Arakha, M.; Kumar, A.; Asthana, S.; Mallick, B. C.; Jha, S. An Approach Towards Continuous Production of Silver Nanoparticles Using *Bacillus Thuringiensis*. *RSC Adv.* **2016,** *6,* 8232–8242.

Neethu, S.; Midhun, S. J.; Radhakrishnan, E.; Jyothis, M. Green Synthesized Silver Nanoparticles by Marine Endophytic Fungus *Penicillium Polonicum* and Its Antibacterial Efficacy Against Biofilm Forming, Multidrug-Resistant *Acinetobacter Baumanii*. *Microb. Pathog.* **2018,** *116,* 263–272.

Netala, V. R.; Kotakadi, V. S.; Nagam, V.; Bobbu, P.; Ghosh, S. B.; Tartte, V. First Report of Biomimetic Synthesis of Silver Nanoparticles Using Aqueous Callus Extract of Centella Asiatica and Their Antimicrobial Activity. *Appl. Nanosci.* **2015,** *5* (7), 801–807.

Okafor, F.; Janen, A.; Kukhtareva, T.; Edwards, V.; Curley, M. Green Synthesis of Silver Nanoparticles, Their Characterization, Application and Antibacterial Activity. *Int. J. Environ. Res. Public Health* **2013,** *10,* 5221–5238. https://doi.org/10.3390/ijerph10105221

Ortega-Arroyo, L.; Martin-Martinez, E. S.; Aguilar-Mendez, M. A.; Cruz-Orea, A.; Hernandez-Pérez, I.; Glorieux, C. Green Synthesis Method of Silver Nanoparticles Using Starch as Capping Agent Applied the Methodology of Surface Response. *Starch-Stärke.* **2013,** *65* (9–10), 814–821.

Ovais, M.; Khalil, A. T.; Raza, A.; Khan, M. A.; Ahmad, I.; Islam, N. U.; Saravanan, M.; Ubaid, M. F.; Ali, M.; Shinwari, Z. K. Green Synthesis of Silver Nanoparticles via Plant Extracts: Beginning A New Era in Cancer Theranostics. *Nanomedicine* **2016,** *12* (23), 3157–3177.

Pal, S.; Tak, Y. K. Y Song, J. M. Does the Antibacterial Activvity of Silver Nanoparticles Depend on the Shape of the Nanoparicle? A Study of the Gram-Negative Bacterium Escherichia coli. *Appl. Environ. Microbiol.* **2007,** *73* (6), 1712–1720.

Parlinska-Wojtan, M.; Kus-Liskiewicz, M.; Depciuch, J.; Sadik, O. Green Synthesis and Antibacterial Effects of Aqueous Colloidal Solutions of Silver Nanoparticles Using Camomile Terpenoids as a Combined Reducing and Capping Agent. *Bioprocess Biosyst. Eng.* **2016,** *39* (8), 1213–1223. doi: 10.1007/s00449-016-1599-4

Ramalingmam, P.; Muthukrishnan, S.; Thangaraj, P.; Biosynthesis of Silver Nanoparticles Using an Endophytic Fungus, Curvularialunata and its Antimicrobial Potential. *J. Nanosci. Nanoeng.* **2015,** *1* (4), 241–247.

Parveen, K.; Banse, V.; Ledwani, L. In *Green Synthesis of Nanoparticles: Their Advantages and Disadvantages*, AIP Conference Proceedings; 2016 Apr 13, AIP Publishing LLC, Vol. 1724 (1); p 020048.

Patarroyo, J.; Genç, A.; Arbiol, J.; Bastús, N. G.; Puntes, V. One-Pot Polyol Synthesis of Highly Monodisperse Short Green Silver Nanorods. *Chem. Commun.* **2016,** *52* (73), 10960–10963.

Peralta-Videa, J. R.; Huang, Y.; Parsons, J. G.; Zhao, L.; Lopez-Moreno, L.; Hernandez-Viezcas, J. A.; Gardea-Torresdey, J. L. Plant-Based Green Synthesis of Metallic Nanoparticles: Scientific Curiosity or a Realistic Alternative to Chemical Synthesis? *Nanotechnol. Environ. Eng.* **2016,** *1,* 4.

Mandal, P.; Biosynthesis of Silver Nanoparticles by Plumeria Rubra Flower Extract: Characterization and Their Antimicrobial Activities. *Int. J. Eng. Sci. Invent.* **2018,** *7* (1), 01–06.

Pirtarighat, S.; Ghannadnia, M.; Baghshahi, S. Green Synthesis of Silver Nanoparticles Using the Plant Extract of *Salvia Spinosa* Grown In Vitro and Their Antibacterial Activity Assessment. *J. Nanostructure Chem.* **2019,** *9,* 1–9.

Prasher, P.; Sharma, M.; Mudila, H.; Gupta, G.; Sharma, A. K.; Kumar, D.; Bakshi, H. A.; Negi, P.; Kapoor, D. N.; Chellappan, D. K.; et al. Emerging Trends in Clinical Implications of Bio-Conjugated Silver Nanoparticles in Drug Delivery. *Colloid Interface Sci. Commun.* **2020,** *35,* 100244.

Premanand, G., Shanmugam, N., Kannadasan, N. et al. Nelumbo Nucifera Leaf Extract Mediated Synthesis of Silver Nanoparticles and their Antimicrobial Properties Against Some Human Pathogens. *Appl. Nanosci.* **2016,** *6,* 409–415. https://doi.org/10.1007/s13204-015-0442-6

Puchana-Rosero, M. J.; Adebayo, M. A.; Lima, E. C.; Machado, F. M.; Thue, P. S.; Vaghetti, J. C.; Umpierres, C. S.; Gutterres, M. Microwave-Assisted Activated Carbon Obtained from the Sludge of Tannery-Treatment Effluent Plant for Removal of Leather Dyes. *Colloids Surf. A: Physicochem. Eng. Asp.* **2016,** 5*04,* 105–115.

Purohit, A.; Sharma, R.; Shiv Ramakrishnan, R.; Sharma, S.; Kumar, A.; Jain, D.; Kushwaha, H. S.; Maharjan, E. Biogenic Synthesis of Silver Nanoparticles (AgNPs) Using Aqueous Leaf Extract of Buchanania Lanzan Spreng and Evaluation of Their Antifungal Activity Against Phytopathogenic Fungi. *Bioinorg. Chem. Appl.* **2022,** 2022.

Pyatenko, A.; Shimokawa, K.; Yamaguchi, M.; Nishimura, O.; Suzuki, M. Synthesis of Silver Nanoparticles by Laser Ablation in Pure Water. *Appl. Phys. A* **2004,** *79* (4), 803–806.

Rafique, M.; Sadaf, I.; Rafique, M. S.; Tahir, M. B. A Review on Green Synthesis of Silver Nanoparticles and Their Applications. *Artif. Cells Nanomed. Biotechnol.* **2017,** *45* (7), 1272–1291.

Rai, A.; Prabhune, A.; Perry, C. C. Antibiotic Mediated Synthesis of Gold Nanoparticles with Potent Antimicrobial Activity and their Application in Antimicrobial Coatings. *J. Mater. Chem.* **2010,** *20* (32), 6789–6798.

Rai, M. K.; Deshmukh, S. D.; Ingle, A. P.; Gade, A. K. Silver Nanoparticles: The Powerful Nanoweapon Against Multidrug-Resistant Bacteria. *J. Appl. Microbiol.* **2012,** *112* (5), 841–852.

Rajeshkumar, S.; Bharath, L. V. Mechanism of Plant-Mediated Synthesis of Silver Nanoparticles—A Review on Biomolecules Involved, Characterisation and Antibacterial Activity. *Chem.-Biol. Interact.* **2017,** 2*73,* 219–227.

Rajeshkumar, S.; Bharath, L. V. Mechanism of Plant-Mediated Synthesis of Silver Nanoparticles—A Review on Biomolecules Involved, Characterisation and Antibacterial Activity. *Chem. Biol. Interact.* **2017,** 2*73,* 219–227. doi: 10.1016/j.cbi.2017.06.019

Ramkumar, V. S.; Pugazhendhi, A.; Gopalakrishnan, K.; Sivagurunathan, P.; Saratale, G. D.; Dung, T. N. B.; Kannapiran, E. Biofabrication and Characterization of Silver Nanoparticles Using Aqueous Extract of Seaweed Enteromorpha Compressa and Its Biomedical Properties. *Biotechnol. Rep.* **2017,** *14,* 1–7. doi:10.1016/j.btre.2017.02.001

Rana, A.; Yadav, K.; Jagadevan, S. A Comprehensive Review on Green Synthesis of Nature-Inspired Metal Nanoparticles: Mechanism, Application and Toxicity. *J. Clean. Prod.* **2020,** *272,* 122880.

Ranoszek-Soliwoda, K.; Tomaszewska, E.; Małek, K.; Celichowski, G.; Orlowski, P.; Krzyzowska, M.; Grobelny, J. The Synthesis of Monodisperse Silver Nanoparticles with Plant Extracts. *Colloids Surf. B: Biointerfaces* **2019,** *177,* 19–24.

Rashid, M.; Or, M.; Akhter, K. N.; Chowdhury, J. A.; Hossen, F.; Hussain, M.; Hossain, M. Characterization of Phytoconstituents and Evaluation of Antimicrobial Activity of Silver-Extract Nanoparticles Synthesized From Momordica Charantia Fruit Extract. *BMC Complement. Altern. Med.* **2017,** *17* (1), 1–7.

Rashid, M. U.; Bhuiyan, K. H.; Quayum, M. E. Synthesis of Silver Nano Particles(Ag-NPs) and Their Uses for Quantitative Analysis of Vitamin C Tablets. *Dhaka Univ. J. Pharm. Sci.* **2013,** *12,* 2933.

Ravichandran, A.; Subramanian, P.; Manoharan, V.; Muthu, T.; Periyannan, R.; Thangapandi, M.; Ponnuchamy, K.; Pandi, B.; Marimuthu, P. N. Phyto-Mediated Synthesis of Silver Nanoparticles Using Fucoidan Isolated From *Spatoglossum Asperum* and Assessment of Antibacterial Activities. *J. Photochem. Photobiol. B Biol.* **2018,** *185,* 117–125.

Raza, M. A.; Kanwal, Z.; Rauf, A.; Sabri, A. N.; Riaz, S.; Naseem, S. Size- and Shape-Dependent Antibacterial Studies of Silver Nanoparticles Synthesized by Wet Chemical Routes. *Nanomaterials* **2016,** *6,* 74. https://doi.org/10.3390/nano6040074

Raza, M. A.; Kanwal, Z.; Rauf, A.; Sabri, A. N.; Riaz, S.; Naseem, S. Size- and Shape-Dependent Antibacterial Studies of Silver Nanoparticles Synthesized by Wet Chemical Routes. *Nanomaterials* **2016,** *6,* 74. https://doi.org/10.3390/nano6040074

Reddy, J. M.; Anitha, R.; Rajeshkumar, S.; Lakshmi, T. Characterisation of Cumin Oil Mediated Silver Nanoparticles Using UV-Visible Spectrophotometer and TEM. *Res. J. Pharm. Technol.* **2019,** *12* (10), 4931–4933.

Ren, W.; Lin, G.; Clarke, C.; Zhou, J.; Jin, D. Optical Nanomaterials and Enabling Technologies for High-Security-Level Anticounterfeiting. *Adv. Mater.* **2020,** *32* (18), 1901430.

Restrepo, C. V.; Villa, C. C. Synthesis of Silver Nanoparticles, Influence of Capping Agents, and Dependence on Size and Shape: A Review. *Environ. Nanotechnol. Monit. Manag.* **2021,** *15,* 100428.

Restrepo, C. V.; Villa, C. C. Synthesis of Silver Nanoparticles, Influence of Capping Agents, and Dependence on Size and Shape: A Review. *Environ. Nanotechnol. Monit. Manag.* **2021,** *15,* 100428.

Roy, A.; Bulut, O.; Some, S.; Mandal, A. K.; Yilmaz, M. D. Green Synthesis of Silver Nanoparticles: Biomolecule-Nanoparticle Organizations Targeting Antimicrobial Activity. *RSC Adv.* **2019,** *9* (5), 2673–2702.

Roy, A.; Bulut, O.; Some, S.; Mandal, A. K.; Yilmaz, M. D. Green Synthesis of Silver Nanoparticles: Biomolecule-Nanoparticle Organizations Targeting Antimicrobial Activity. *RSC Adv.* **2019,** *9* (5), 2673–2702.

Roy, A.; Bulut, O.; Some, S.; Mandal, A. K.; Yilmaz, M. D. Green Synthesis of Silver Nanoparticles: Biomolecule-Nanoparticle Organizations Targeting Antimicrobial Activity. *RSC Adv.* **2019,** *9* (5), 2673–2702.

Roy, A.; Bulut, O.; Some, S.; Mandal, A. K.; Yilmaz, M. D. Green Synthesis of Silver Nanoparticles: Biomolecule-Nanoparticle Organizations Targeting Antimicrobial Activity. *RSC Adv.* **2019,** *9* (5), 2673–2702.

Roy, N.; Gaur, A.; Jain, A.; Bhattacharya, S.; Rani, V. Green Synthesis of Silver Nanoparticles: An Approach to Overcome Toxicity. *Environ. Toxicol. Pharmacol.* **2013,** *36* (3), 807–812

Safat, S.; Buazar, F.; Albukhaty, S.; Matroodi, S. Enhanced Sunlight Photocatalytic Activity and Biosafety of Marine-Driven Synthesized Cerium Oxide Nanoparticles. *Sci. Rep.* **2021,** *11,* 14734.

Salari, Z.; Danafar, F.; Dabaghi, S.; Ataei, S. A. Sustainable Synthesis of Silver Nanoparticles Using Macroalgae *Spirogyra Varians* and Analysis of Their Antibacterial Activity. *J. Saudi Chem. Soc.* **2016,** *20,* 459–464.

Salem, S. S.; EL-Belely, E. F.; Niedbała, G.; Alnoman, M. M.; Hassan, S. E.-D.; Eid, A. M.; Shaheen, T. I.; Elkelish, A.; Fouda, A. Bactericidal and In-Vitro Cytotoxic Efficacy of Silver Nanoparticles (Ag-NPs) Fabricated by Endophytic Actinomycetes and Their Use as Coating for the Textile Fabrics. *Nanomaterials* **2020,** *10,* 2082. https://doi.org/10.3390/nano10102082

Sanjenbam, P.; Gopal, J.; Kannabiran, K. Anticandidal Activity of Silver Nanoparticles Synthesized Using *Streptomyces* sp. VITPK1. *J. Mycol. Médicale* **2014,** *24,* 211–219.

Sanpui, P.; Murugadoss, A.; Prasad, P. D.; Ghosh, S. S.; Chattopadhyay, A. The Antibacterial Properties of A Novel Chitosan–Ag-Nanoparticle Composite. *Int. J. Food Microbiol.* **2008,** *124* (2), 142–146.

Sanzari, I.; Leone, A.; Ambrosone, A. Nanotechnology in Plant Science: To Make a Long Story Short. *Front. Bioeng. Biotechnol.* **2019,** *7,* 120.

Sarkar, P.; Bhui, D. K.; Bar, H.; Sahoo, G. P.; De, S. P.; Misra, A. Synthesis and Photophysical Study of Silver Nanoparticles Stabilized by Unsaturated Dicarboxylates. *J. Lumin.* **2009,** *129,* 704–709.

Shang, Y.; Hasan, M. K.; Ahammed, G. J.; Li, M.; Yin, H.; Zhou, J. Applications of Nanotechnology in Plant Growth and Crop Protection: A Review. *Molecules* **2019,** *24,* 2558. https://doi.org/10.3390/molecules24142558

Shankar, S.; Rhim, J. W. Preparation and Characterization of Agar/Lignin/Silver Nanoparticles Composite Films with Ultraviolet Light Barrier and Antibacterial Properties. *Food Hydrocoll.* **2017,** *71,* 76–84.

Shankar, S. S.; Rai, A.; Ahmad, A.; Sastry, M. Rapid Synthesis of Au, Ag, and Bimetallic Au Core–Ag Shell Nanoparticles Using Neem (Azadirachta Indica) Leaf Broth. *J. Colloid Interface Sci.* **2004,** *275* (2), 496–502.

Shankar, S.; Rhim, J. W. Amino Acid Mediated Synthesis of Silver Nanoparticles and Preparation of Antimicrobial Agar/Silver Nanoparticles Composite Films. *Carbohydr. Polym.* **2015,** *130,* 353–363.

Shin, S. W.; Song, I. H.; Um, S. H. Role of Physicochemical Properties in Nanoparticle Toxicity. *Nanomaterials* **2015,** *5,* 1351–1365. https://doi.org/10.3390/nano5031351

Shu, M.; He, F.; Li, Z.; Zhu, X.; Ma, Y.; Zhou, Z.; Yang, Z.; Gao, F.; Zeng, M. Biosynthesis and Antibacterial Activity of Silver Nanoparticles Using Yeast Extract as Reducing and Capping Agents. *Nanosc. Res. Lett.* **2020,** *15* (1), 1–9.

Mehdizadeh, S.; Ghasemi, N.; Ramezani, M.; Mahanpoor, K. Biosynthesis of Silver Nanoparticles Using Malva Sylvestris Flower Extract and Its Antibacterial and Catalytic Activity. *Chem. Methodol.* **2021,** *5* (4) 356–366. doi:10.22034/chemm.2021.132490

Singh, K.; Panghal, M.; Kadyan, S.; Chaudhary, U.; Yadav, J. P. Green Silver Nanoparticles of Phyllanthus Amarus: As an Antibacterial Agent Against Multi Drug Resistant Clinical Isolates of Pseudomonas Aeruginosa. *J. Nanobiotechnol.* **2014,** *12* (1). doi:10.1186/s12951-014-0040-x

Slawson, R. M.; Van Dyke, M. I.; Lee, H.; Trevors, J. T. Germanium and Silver Resistance, Accumulation, and Toxicity in Microorganisms. *Plasmid* **1992,** *27* (1), 72–79.

Slepička, P.; Slepičková Kasálková, N.; Siegel, J.; Kolská, Z.; Švorčík, V. Methods of Gold and Silver Nanoparticles Preparation. *Materials* **2020,** *13,* 1. https://doi.org/10.3390/ma13010001

Sondi; Salopek-Sondi, B. Silver Nanoparticles as Antimicrobial Agent: A Case Study On E. coli as a Model for Gram-Negative Bacteria. *J. Colloid Interf. Sci.* **2004,** *275* (1), 177–182.

Song, J.; Kim, H.; Jang, Y.; Jang, J. Enhanced Antibacterial Activity of Silver/Polyrhodanine-Composite-Decorated Silica Nanoparticles. *ACS Appl. Mater. Interf.* **2013,** *5,* 11563–11568.

Sonker, A. S.; Pathak, J.; Kannaujiya, V. K.; Sinha, R. P. 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,* 26–37.

Srikar, S. K.; Giri, D. D.; Pal, D. B.; Mishra, P. K.; Upadhyay, S. N. Green Synthesis of Silver Nanoparticles: A Review. *Green Sustain. Chem.* **2016,** *6,* 34–56. doi: 10.4236/gsc.2016.61004.

Srivastava, S.; Bhargava, A.; Pathak, N.; Srivastava, P. Production, Characterization and Antibacterial Activity of Silver Nanoparticles Produced by Fusarium Oxysporum and Monitoring of Protein-Ligand Interaction Through In-Silico Approaches. *Microb. Pathogen.* **2019,** 1*29,* 136–145.

Suresh, G.; Gunasekar, P. H.; Kokila, D.; Prabhu, D.; Dinesh, D.; Ravichandran, N.; Ramesh, B.; Koodalingam, A.; Siva, G. V. Green Synthesis of Silver Nanoparticles Using *Delphinium Denudatum* Root Extract Exhibits Antibacterial and Mosquito Larvicidal Activities. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* **2014,** *127,* 61–66.

Tan, L. V.; Tran, T.; Thi, V. D. Biosynthesis of Silver Nanoparticles From *Bacillus Licheniformis* TT01 Isolated from Quail Manure Collected In Vietnam. *Processes* **2021,** *9,* 584. https://doi.org/10.3390/pr9040584

Tavaf, Z.; Tabatabaei, M.; Khalafi-Nezhad, A.; Panahi, F. Evaluation of Antibacterial, Antibofilm and Antioxidant Activities of Synthesized Silver Nanoparticles (Agnps) and Casein Peptide Fragments Against Streptococcus Mutans. *Eur. J. Integr. Med.* **2017,** *12,* 163–171.

Thakar, M. A.; Jha, S. S.; Phasinam, K.; Manne, R.; Qureshi, Y.; Babu, V. H. X Ray Diffraction (XRD) Analysis and Evaluation of Antioxidant Activity of Copper Oxide Nanoparticles Synthesized From Leaf Extract of Cissus Vitiginea. *Mater. Today: Proc.* **2022,** *51,* 319–324.

Thomas, R.; Janardhanan, A.; Varghese, R. T.; Soniya, E. V.; Mathew, J.; Radhakrishnan, E. K. Antibacterial Properties of Silver Nanoparticles Synthesized by Marine Ochrobactrum sp. *Braz. J. Microbiol.* **2014,** *45,* 1221–1227.

Tian, Y.; Wang, F. L.; Liu, Y. X.; Pang, F.; Zhang, X. Green Synthesis of Silver Nanoparticles on Nitrogen-Doped Graphene for Hydrogen Peroxide Detection. *Electrochim. Acta* **2014,** *146,* 646–651.

Tiburu, E. K.; Salifu, A.; Aidoo, E. O.; Fleischer, H. N.; Manu, G.; Yaya, A.; Zhou, H.; Efavi, J. K. Formation of Chitosan Nanoparticles Using Deacetylated Chitin Isolated from Freshwater Algae and Locally Synthesized Zeolite A and Their Influence on Cancer Cell Growth. *Proc. J. Nano Res.* **2017,** *48,* 156–170.

Tien, D. C.; Tseng, K. H.; Liao, C. Y.; Huang, J. C.; Tsung, T. T. Discovery of Ionic Silver in Silver Nanoparticle Suspension Fabricated by Arc Discharge Method. *J. Alloys. Compd.* **2008,** *463,* 408–411.

Tripathi, R. M.; Ranac, D.; Shrivastav, A.; Singh, R. P.; Shrivastav, B. R. Biogenic Synthesis of Silver Nanoparticles Using Saraca Indica Leaf Extract and Evaluation of Their Antibacterial Activity. *Nano Biomed. Eng.* **2013,** *5* (1).

Uzair, B.; Liaqat, A.; Iqbal, H.; Menaa, B.; Razzaq, A.; Thiripuranathar, G.; Fatima Rana, N.; Menaa, F. Green and Cost-Effective Synthesis of Metallic Nanoparticles by Algae: Safe Methods For Translational Medicine. *Bioengineering* **2020,** *7,* 129. https://doi.org/10.3390/bioengineering7040129

Vahabi, K.; Mansoori, G. A.; Karimi, S. Biosynthesis of Silver Nanoparticles by Fungus Trichoderma Reesei (A Route for Large-Scale Production of Agnps). *Insciences J.* **2011,** *1* (1), 65–79.

Vazquez-Muñoz, R.; Meza-Villezcas, A.; Fournier, P. G.; Soria-Castro, E.; Juarez-Moreno, K.; Gallego-Hernández, A. L.; Bogdanchikova, N.; Vazquez-Duhalt, R.; Huerta-Saquero, A. Enhancement of Antibiotics Antimicrobial Activity due to the Silver Nanoparticles Impact on the Cell Membrane. *PLoS ONE.* **2019,** *14* (11), E0224904.

Von White, G.; Kerscher, P.; Brown, R. M.; Morella, J. D.; Mcallister, W.; Dean, D.; Kitchens, C. L. Green Synthesis of Robust, Biocompatible Silver Nanoparticles Using Garlic Extract. *J. Nanomater.* **2012,** *2012*.

Wang, D., Xue, B., Wang, L. et al. Fungus-Mediated Green Synthesis of Nano-Silver Using *Aspergillus Sydowii* and Its Antifungal/Antiproliferative Activities. *Sci. Rep.* **2021, 11,** *10356*. https://doi.org/10.1038/s41598-021-89854-5

Wei, L.; Lu, J.; Xu, H.; Patel, A.; Chen, Z. S.; Chen, G. Silver Nanoparticles: Synthesis, Properties, and Therapeutic Applications. *Drug Disc. Today* **2015,** *20* (5), 595–601.

Whitesides, G. M. Nanoscience, Nanotechnology, and Chemistry. *Small* **2005,** *1,* 172–179.

Wu, X.; Lu, C.; Zhou, Z.; Yuan, G.; Xiong, R.; Zhang, X. Green Synthesis and Formation Mechanism of Cellulose Nanocrystal-Supported Gold Nanoparticles with Enhanced Catalytic Performance. *Environ. Sci.: Nano* **2014,** *1* (1), 71–79.

Wu, S.-H.; Mou, C.-Y.; Lin, H.-P. Synthesis of Mesoporous Silica Nanoparticles. *Chem. Soc. Rev.* **2013,** *42,* 3862–3875.

Xia, Y.; Xia, X.; Peng, H. C. Shape-Controlled Synthesis of Colloidal Metal Nanocrystals: Thermodynamic Versus Kinetic Products. *J. Am. Chem. Soc.* **2015,** *137* (25), 7947–7966.

Xue, B.; He, D.; Gao, S.; Wang, D.; Yokoyama, K.; Wang, L. Biosynthesis of Silver Nanoparticles by the Fungus Arthroderma Fulvum and Its Antifungal Activity Against Genera of Candida, Aspergillus and Fusarium. *Int. J. Nanomed.* **2016,** *11,* 1899.

Xue, B.; He, D.; Gao, S.; Wang, D.; Yokoyama, K.; Wang, L. Biosynthesis of Silver Nanoparticles by the Fungus *Arthroderma Fulvum* and Its Antifungal Activity Against Genera of *Candida*, *Aspergillus* and *Fusarium*. *Int. J. Nanomed.* **2016,** *11,* 1899–1906.

Yan, X.; He, B.; Liu, L.; Qu, G.; Shi, J.; Hu, L.; Jiang, G. Antibacterial Mechanism of Silver Nanoparticles in Pseudomonas Aeruginosa: Proteomics Approach. *Metallomics* **2018,** *10* (4), 557–564.

Yazdi, M. E. T.; Darroudi, M.; Amiri, M. S.; Hosseini, H. A.; Nourbakhsh, F.; Mashreghi, M.; Farjadi, M.; Kouhi, S. M. M.; Mousavi, S. H. Anticancer, Antimicrobial, and Dye Degradation Activity of Biosynthesised Silver Nanoparticle Using Artemisia Kopetdaghensis. *Micro Nano Lett.* **2020,** *15,* 1046–1050.

Yin, Y.; Yang, X.; Hu, L.; Tan, Z.; Zhao, L.; Zhang, Z.; Liu, J.; Jiang, G. Superoxide-Mediated Extracellular Biosynthesis of Silver Nanoparticles by the Fungus Fusarium Oxysporum. *Environ. Sci. Technol. Lett.* **2016,** *3* (4), 160–165.

Yousefzadi, M.; Rahimi, Z.; Ghafori, V. The Green Synthesis, Characterization and Antimicrobial Activities of Silver Nanoparticles Synthesized from Green Alga *Enteromorpha Flexuosa* (Wulfen) *J. Agardh. Mater Let.* **2014,** 1*37,* 1–4. doi: 10.1016/j.matlet.2014.08.110

Zhang, Q.; Moran, C. H.; Xia, X.; Rycenga, M.; Li, N.; Xia, Y. Synthesis of Ag Nanobars in the Presence of Single-Crystal Seeds and a Bromide Compound, and their Surface-Enhanced Raman Scattering (SERS) Properties. *Langmuir* **2012,** *28* (24), 9047–9054.

Zhang, W.; Yao, Y.; Sullivan, N.; Chen, Y. Modeling the Primary Size Effects of Citrate-Coated Silver Nanoparticles on their Ion Release Kinetics. *Environ. Sci. Technol.* **2011,** *45* (10), 4422–4428.

Zhang, X.-F.; Liu, Z.-G.; Shen, W.; Gurunathan, S. Silver Nanoparticles: Synthesis, Characterization, Properties, Applications, and Therapeutic Approaches. *Int. J. Mol. Sci.* **2016,** *17,* 1534. https://doi.org/10.3390/ijms17091534

Zhou, S.; Li, J.; Gilroy, K. D.; Tao, J.; Zhu, C.; Yang, X.; Sun, X.; Xia, Y. Facile Synthesis of Silver Nanocubes with Sharp Corners and Edges in an Aqueous Solution. *Acs Nano.* **2016,** *10* (11), 9861–9870. doi:10.1021/acsnano.6b05776