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Review Article

On Recent Developments in Biosynthesis and Application of Au and Ag Nanoparticles from Biological Systems

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Gold nanoparticles (AuNPs) and silver nanoparticles (AgNPs) are extensively studied nanoparticles (NPs) and are known to have profound applications in medicine. The researcher made continuous efforts for the environmental-friendly and economical methods, such as biogenic methods known as green synthesis. There are many strategies for separating and applying gold (Au) and silver (Ag) nanoparticles, of which biological routes have emerged as efficient, low-cost, and environmentally friendly techniques. This review focuses on recent developments of green synthesized AuNPs and AgNPs using biogenic sources such as algae, animals, plants, microbes, bacteria, fungi, and so on. Hence, it discusses their numerous biomedical applications and separating Au and Ag nanoparticles from plants, bacteria, fungi, and algae.

1. Introduction

Nanotechnology explains the use of materials at the nanometer level, which starts with the synthesis and ends with its application. Nanoparticles, whose dimension is defined between 1 and 100 nm [1], have created a historical revolution in the industrial sectors due to their exceptional surface activity and electrical, magnetic, and optical properties. This is achieved by modifying materials to different conformations by changing the structure. Since Faraday reported on gold nano-sized form in 1856 [2], significant contributions in this field have been observed in the late twentieth century with the advancement in technology for the analysis in the nanometer range (1–100 nm). Scanning tunneling microscope (STM) was the beginning of the technology for a better understanding of materials. Many applications have been proposed in nanotechnology [3]. However, the opportunities of nanotechnologies are yet to be explored for potential applications [4–7]. Due to improved surface properties, there is a tremendous deviation in the properties of materials in the nanometer range compared to their bulk [8–13]. The quantum confinement in nanoparticles leads to quantized energy levels in valence and conduction bands; hence, enhanced electronic and optical properties are exhibited by nanomaterials [14–17].

Although chemically synthesized nanostructures have been used during various stages of civilization, nature has its own processes for synthesizing nanomaterials. The idea of biosynthesis of nanoparticles has evolved from the need for the synthesis of nanoparticle processes and the knowledge of metal bioremediation [18–20]. Total potential should be investigated to assess against either physical techniques or concoction strategies for various applications. In liquid suspensions, the strength of nanoparticles is significantly improved within sight of biomolecules [21, 22]. Notably, the biosynthesis of nanoparticles has attracted attention due to their reliable and eco-friendly nature [23, 24]. Biosynthesis of nanoparticles offers controlled size and morphology due to the slow rate of formation of nanoparticles and its stabilization due to dilution with medium and steric hindrance due to attached molecules [25–28].

The application of nanotechnology in biological fields is known as nanobiotechnology. It is a multidisciplinary field that currently recruits approaches, technology, and facility

available in conventional and advanced avenues of engineering, physics, chemistry, and biology [29]. Medicinal nanotechnology applications include molecular imaging, cancer detection, and therapeutic application, in vivo sensors, X-ray absorbers, and so on, which have been explored further [30–34]. Other important nanotechnology applications are for the cultivation, processing, and packaging of food due to its antimicrobial property [35–38]. The utilization of nanotechnology is noticeable in each circle of life [39–44]. Two metallic nanoparticles, namely silver and gold, have been reported widely in the literature for various applications.

Silver is one of the most studied nanometals [45–48]. It shows antimicrobial properties similar to silver ions and also exhibits antibacterial activity [49, 50]. Silver-based compounds as a source of silver ions have been used in antimicrobial applications. This phenomenon is called the oligodynamic effect [51, 52]. The growth of a wide range of microorganisms is hindered in the silver and silver compounds. Thus, the enormous importance of silver as new antibacterial material has been observed [53–55]. Gold nanoparticles also demonstrate antimicrobial, antibacterial, and anticancer properties similar to gold ions [48–50, 56–64]. The growth of a wide range of microorganisms is hindered in the gold and gold compounds-thus, the enormous importance of gold nanoparticles as new antibacterial material has been observed [48, 50, 61]. It has been reported that reductases might cause the reduction of silver (and gold) ions to elemental silver (and gold) in the plant, bacteria, algae, and fungi systems [65–67]. The high surface area to volume ratio of silver/gold nanoparticles leads to a high number of silver/gold atoms exposed to the environment. This causes effective interaction of nanoparticles on the surface of other particles and, in turn, in contact with microorganisms. The small nanoparticles (1–10 nm) may be transported through the cell membrane to reach within the cell and disrupt the cell [68, 69].

The silver and gold nanoparticles show antimicrobial properties against different species of fungus and bacterium [30, 43, 70–73]. The size and morphology of the nanoparticles affect antimicrobial activity [74, 75]. The silver nanoparticles enhance the antimicrobial property of the antibiotics [76]. A possible health hazard in humans is probably due to the accumulation of silver nanoparticles [41, 78–78]. The accumulation of nanoparticles in the tissue has been observed that can be hazardous [79, 80]. The influence of nanoparticles as a catalyst in reactions, especially in the anaerobic decomposition process, can be extended to industrial processes [81, 82]. The anticipated impact of silver nanoparticles on well-being recommends considering the use of silver nanoparticles for the constituent of the ink [39, 40, 42, 83, 84].

Very few studies have been conducted for silver-gold bimetallic nanoparticles. In a competitive process involving both silver and gold ions, the reduction of gold ions is accelerated and is an important feature. Silver particles are relatively small and do not form a uniform layer around the gold nanoparticles; otherwise, this would have led to considerable damping of the gold surface plasmon band [85]. Silver-gold bimetallic nanoparticles are effectively shown to be a catalyst for many reactions [86]. Large bimetallic Au-Ag particles of 50–500 nm were formed with some cubic structure, possibly due to interactions between the bioorganic capping molecules bound to the gold and silver nanoparticles, while pure Ag particles were smaller with 15–90 nm and predominantly spherical [87]. Core-shell bimetallic nanoparticle formation is also possible [85]. The biosynthesis of silver nanoparticles, like any inorganic nanoparticles, requires three important steps, namely, the reduction of silver ions, crystal nucleation, and crystal growth [88, 89]. The first step is the bioreduction of silver ions may be due to either enzymatic reactions or the effect of some reducing compounds or a combination of both. Controlled growth of the crystals to nanoparticles and stabilization of nanoparticles are the other two key steps in the synthesis. The biological environment, especially, proteins may be effective in the stabilization of nanoparticles [19, 25, 90–92].

The application of green synthesized NPs to control phytopathogens and formulation of nanopesticides and their smart delivery systems to enhance effectiveness have also been addressed. Moreover, the possible threats to human health and the environment caused by NPs are of increasing concern. This review paper discusses the synthesis and applications of gold NPs and silver NPs via green synthesis. The biosynthesis of Ag and Au NPs is described briefly. Then a variety of sources of green materials are discussed. Two separate tables showed the use of different biomaterials (such as fungi, bacteria, enzymes, and plants) for the production of Au and Ag NPs. Subsequently, the potential applications of Au and Ag NPs were discussed in the field of biomedical. Finally, the rest of the article has been divided into two parts. First, we focus on the synthesis of silver and gold nanoparticles from algae, bacteria, fungi, and plants, and next, we focus on their application. In the end, we summarize the findings reported in this work.

2. Synthesis of Ag and Au Nanoparticles

Several methods of biosynthesis have been reported in the literature [84]. However, the technical feasibility is not well understood yet. When microorganisms expose to a new environment in the presence of silver and gold ions, the response depends on the organism. Some organisms reduce the silver and gold ions as a part of detoxification, leading to the formation of silver and gold nanoparticles [93]. Hypothetical mechanisms for AuNPs cluster formation and silver ions reduction are shown in Figure 1. An attribute of biosynthesis may be the stability of silver and gold nanoparticles. Biomolecules synthesized during the process could be the possible reason for the stability of nanoparticles [84]. The characterization of nanoparticles includes UV-visible spectroscopy for primer examination and transmission electron microscopy for the size. Dynamic light scattering and X-ray diffraction techniques give a more extensive viewpoint of particle size, crystallinity, and so on [94–96]. The size distribution and morphology of nanoparticles can also be controlled due to the slow biological process.

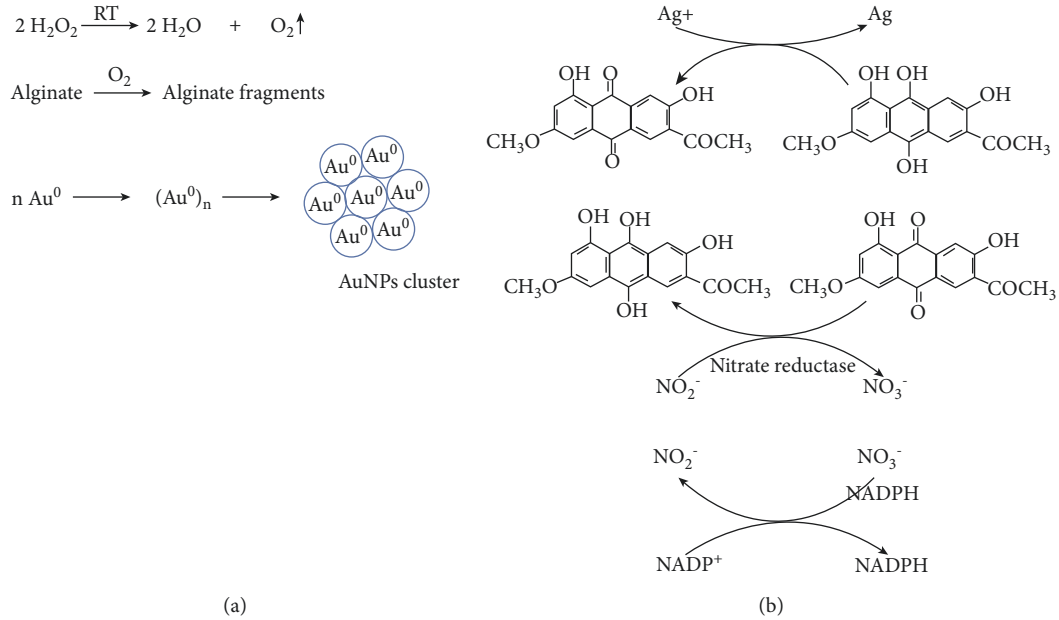

Figure 1: (a) Hypothetical mechanisms for AuNPs cluster formation (adapted from Ahmed et al. [172]) and (b) hypothetical mechanisms for silver ions reduction (adapted from Durán et al. [173]).

Biosynthesized silver nanoparticles exhibit antimicrobial and antibacterial properties. Other properties such as optical, thermal, and electrical need further studies. Properties of silver and gold nanoparticles have been explored in aqueous suspensions due to the difficult isolation of silver and gold nanoparticles.

2.1. Synthesis from Algae. Vinosha et al. [97] synthesized gold nanoparticles using *Halymenia dilatata*. Minhas et al. [98] studied silver nanoparticles formation using algae. Silver nitrate solution, whose colour changed to brownish when 10 mL of algal extract was mixed in 90 mL solution of 1 mM ($AgNO_3$), noticeably indicated silver nanoparticles formation. The SEM analysis showed that the silver nanoparticles were irregular, face-centered cubic structures with particle sizes between 200 nm and 300 nm. Wide-angle X-ray scattering was used to determine the crystal size, crystal structure, and morphology of silver nanoparticles. X-ray diffraction (XRD) studies showed a broad peak, which is probably an indication of the high polydispersity of the particles. The radius of the silver nanoparticles had an inverse relation with the width of the peak. The chemical composition of the sample has been estimated by Fourier transform infrared spectroscopy (FTIR). It showed the stretching band at 3,296 cm^{-1} that indicated the presence of the –OH group of algal polysaccharides or –NH group of amide. Ramakrishna et al. [99] studied gold nanoparticle formation using algae. When 5 mL of the algae extract were added to 1 mM aqueous $AuCl_4^{-1}$ solution (45 ml) in a 250 ml Erlenmeyer flask. The flasks were kept on a magnetic stirrer at room temperature, and the solutions changed to ruby red, indicating the formation of gold nanoparticles. HRTEM analysis showed that the gold nanoparticles are polydispersed, having shape disparity, face-centered cubic structures with particle sizes between 12 nm and 57 nm with an average size of around 27.5 nm. The catalytic activity of biosynthesized gold nanoparticles was reported using the reduction of nitroarenes to their corresponding amino arenes.

2.2. Synthesis from Bacteria. A few bacteria, exposed to high metal ion concentrations, reduce the metal ions or form complexes with metal ions for their survival [100]. In some microorganisms, the metabolic pathway is associated with metal ions, which, in turn, are required for the growth of the microorganisms, leading to the metal ion reduction to corresponding elemental metals and then crystallization of nanoparticles. Reference [101] studied the crystalline silver nanoparticles synthesis using *Pseudomonas stutzeri*. Silver is deposited in the periplasmic membrane with particles crystallized in distinct shapes such as equilateral triangles and hexagons. Large particles with distinct shapes as well as small colloidal particles could be found all over the cell wall. Even though, the energy-dispersive spectrum gives the concept of the elemental analysis of nanoparticles, the precision in suggesting the chemical formula as Ag_2S is necessary [102]. The authors had used a high concentration of silver ions, namely, 50 mM for the silver nanoparticles formation, but a mechanism to tolerate higher silver ion concentrations by *P. stutzeri* for growth is poorly understood [101, 102].

Mukherjee et al. [67] studied silver nanoparticle synthesis using Enterogermina. Enterogermina 5 ml oral suspension bottle was purchased from a local medical shop to provide the spores of multiantibiotic resistant *Bacillus clausii*. The bacterial strain was cultured in nutrient broth, and it was kept in a shaker incubator at 37°C for 24 hours. It was then centrifuged at 10,000 rpm for 10 minutes to remove all unwanted biomass. Precipitated cells were washed with phosphate buffer. The pellet was dissolved in distilled water

and ultrasonicated for 5 min to get the intracellular enzyme used to produce silver nanoparticles. Then ultrasonicated cells were centrifuged at 10,000 rpm and 4°C for 10 minutes. A UV-visible spectrophotometer confirmed the formation of silver nanoparticles.

Zhang et al. [24] studied silver nanoparticles preparation by *Corynebacterium* strain SH09, found in the close vicinity of silver mines. It is found that both diamine silver complex and silver nitrate solutions are the sources of silver ions, and specific uptake of silver by the organism follows Monod's kinetics. They analyzed the silver nanoparticles using an absorption spectrum having a peak at 430 nm. From the TEM images, the size range of the silver nanoparticles was between 10 and 15 nm. From the XRD pattern, the average size of the silver nanoparticles was 9.9 nm. Silver reduction by some ketone or aldehyde groups on the cell wall could not explain the complete mechanism of the formation of silver nanoparticles. In a silver-rich environment, *Aeromonas* species SH10 predominantly synthesized silver nanoparticles, having a maximum absorption peak related to surface plasmon resonance at 425 nm [26]. This microorganism showed the same response as that of the *Corynebacterium* strain. However, more details were needed to understand the mechanism of the bioreduction of silver ions.

Lengke et al. [103] studied the silver nanoparticles biosynthesis using *Plectonema boryanum* because cyanobacteria form one of the largest and most important groups of photoautotrophic bacteria on Earth. They have a high-affinity transport system for nitrate. Interestingly, the location of the formation of silver nanoparticles varied with temperature. At 25°C, silver nanoparticles were formed within the cells (size < 10 nm) as well as outside the cells (size 1–200 nm). At 60°C, spherical silver nanoparticles (size between 1 and 40 nm) were deposited at the cell surfaces instead of intracellular formation. At 100°C, the cyanobacterial cells were coated with nanoparticles, and some filaments were separated into their constituent cells. Spherical silver nanoparticles later resulted in the precipitation of octahedral crystal platelets of silver within the cells and outside the cells. Octahedral silver was formed only at 100°C. Particle size decreased with temperature between 25°C and 100°C. Cyanobacteria utilize nitrate as the key nitrogen source for their growth. Thus, nitrate becomes vital for the generation of metabolic energy and redox balance. Cyanobacterial cells cannot survive at elevated temperatures. Therefore, in the death phase of cells, silver nanoparticles were formed inside the cells and released into the medium through the cell membrane. Dead cyanobacteria also released organics that caused silver formation outside the cells from the solution [103]. Antimicrobial and photocatalytic activity of nanoparticles produced using green process using cyanobacteria [104].

Singh et al. [105] synthesized silver and gold nanoparticles using *Sporosarcina koreensis* DC4 strain. The synthesized nanoparticles were characterized by UV-visible spectrophotometry, which displayed maximum absorbance at 424 nm and 531 nm for silver and gold nanoparticles, respectively. The crystalline nature of synthesized nanoparticles was obtained by X-ray diffraction spectroscopy. It was shown that a 3 g concentration of silver nanoparticles sufficiently enhances the antimicrobial efficacy of commercial antibiotics against pathogenic microorganisms—the size of silver and gold nanoparticles was found to be 102 nm and 92.4 nm, respectively.

Shahverdi et al. [106] observed rapid silver nanoparticle formation using several enterobacterial strains. Several organisms, namely, *Pseudomonas aeruginosa*, *Bacillus cereus*, *Escherichia coli*, *Lactobacillus acidophilus*, *Enterobacter cloacae*, *Bacillus subtilis*, *Klebsiella pneumonia*, *Staphylococcus aereus*, and *Aspergillus niger*, were used in this study. Culture filtrates of these organisms were reacted with $AgNO_3$ solution. The solution turned into yellowish-brown colour for three strains, namely, *E. coli*, *E. cloacae*, and *K. pneumonia*. The overall reaction process was completed within 5 minutes. UV-visible spectrophotometric analysis showed peaks at 419 nm, 430 nm, and 420 nm for *E. coli*, *K. pneumonia*, and *E. cloacae*. Their peak intensities increased steadily with time. The most significant absorption peak was observed for *Klebsiella* samples. The particle size histogram showed that silver nanoparticles had sizes between 28.2 and 122 nm (average particle size of 52.5 nm). The existence of elemental silver was confirmed using the dispersive energy spectrum. It showed a peak at 3 keV, which is the typical absorption energy of silver nanoparticles due to surface plasmon resonance [106]. The main benefit of this process was a drastic reduction in time from some days to hardly any minutes in obtaining nanoparticles, which is a significant finding towards the objective of developing a method for the fast silver nanoparticles formation. However, the silver nanoparticles formed were not stable after 5 minutes. The work did not report any enhanced stability of silver nanoparticles on prolonged storage.

Kalishwaralal et al. [107] used nonpathogenic *Bacillus licheniformis* for the extracellular silver nanoparticles formation from the standpoint of ease of mass production and safety in handling the organism. SEM analysis showed that the size of the nanoparticles was close to 50 nm. EDS confirmed the presence of elemental silver in which a band of the peak was observed at 3 keV. XRD studies confirmed the crystalline nature of silver nanoparticles, and its spectrum showed intense peaks at 20 values. The silver nanoparticles formed were highly stable. This study used nonpathogenic bacteria. *Morganella* species, a silver resistant microorganism, synthesized silver nanoparticles having a size range between 15 nm and 25 nm. The particles were stable at 37°C for over six months [108]. The optimum Ag^+ ions concentration was established to be 5 mM, for which maximum silver nanoparticles were formed. Silver nanoparticles were formed even at 10 mM, indicating the species' resistance to silver ions at high concentration, which is higher than that of *E. coli*, for which a detectable amount of nanoparticles appeared only at a silver ion concentration of 1 mM. They explained that several silver-specific proteins were secreted outside the cells during the growth of the organism, which interacted specifically with silver ions and reduced it to atomic silver. These proteins in this system were the reason for the stability of the silver nanoparticles [108].

Sowani et al. [109] synthesized silver and gold nanoparticles using actinomycete *Gordonia amicalis* HS-11. The cell-free supernatant of this bacterium was incubated with 1 mM $HAuCl_4$ or $AgNO_3$ at pH 9.0 in a boiling water bath, and spherical gold and silver nanoparticles were synthesized in an extracellular manner. Reference [15] developed a process for the rapid silver nanoparticles formation using culture supernatant of *B. subtilis*. This process was assisted with microwave irradiation in water. The silver nanoparticles produced by *B. subtilis* were stable for up to six months without much aggregation. The most significant advantage of this method was that they could have highly stable, monodispersed, and crystalline nanoparticles rapidly by a simple process when they combined the bioprocess with microwave irradiation. The microwave radiation provided faster heating with uniform temperature distribution around the nanoparticles. The culture supernatant of *Bacillus* flexus was employed as a reducing agent in synthesizing silver nanoparticles extracellularly [110]. The extracellular culture supernatant with the silver nanoparticles showed antibacterial properties against *B. subtilis*, *E. coli*, *P. aeruginosa*, and *Streptococcus pyogenes* [110].

The reduction of ions to elemental form in the presence of cell-free supernatant of *P. aeruginosa* resulted in silver nanoparticles. This led to the formation of silver nanoparticles [111]. The formation of spherical AgNP was the outcome with the cell-free supernatant of *Streptomyces viridochromogenes* by reduction of silver ions [112]. These biosynthesized nanoparticles exhibited antibacterial properties against different bacterial strains. Antifungal activity against *Candida albicans* was displayed by these nanoparticles [112]. The silver nanoparticles were biosynthesized using extracts of *Actinomycetes* sp. [50, 113]. Also, spherical silver nanoparticles were biosynthesized using cell-free supernatant of *Streptomyces* sp. to study the antimicrobial property [114]. Synthesizing silver nanoparticles from silver ions were observed using cell-free supernatant of *Streptomyces* sp. to study the cytotoxicity against adenocarcinoma lung cancer cell line [115]. Antimicrobial property against *Vibrio parahaemolyticus*, *Bacillus anthracis*, *Salmonella enterica*, *B. cereus*, *E. coli*, and *C. albicans* has been observed for the formation of the silver nanoparticles [116]. Nanoparticles were synthesized using *B. licheniformis* and utilized for their antimicrobial activity [117]. Different media were screen for the formation of the silver nanoparticles using bacteria [118].

2.3. Synthesis from Fungus. Intracellular biosynthesis of silver nanoparticles by *Verticillium* species was observed without change in colour [27]. Silver nanoparticles of 25 nm ± 12 nm sizes with different morphology were identified from the TEM images. The EDS spectrum showed that the silver nanoparticles were thick as thick layers on the surface of the mycelia. Probably different mechanisms for the reduction of Ag^+ are negatively charged carboxyl groups in the different proteins present on the cell wall of the mycelia, enzymes in the cytoplasmic membrane, and enzymes contained by the cytoplasm.

Ahmad et al. [65] studied silver nanoparticles formation using the extracellular phase of *Fusarium oxysporum*. Silver ions reduction to elemental silver leading to nanoparticle formation was believed to be due to NADH-dependent reductase. This reductase is specific to *F. oxysporum* since the reaction of the NADH-dependent reductase with *Fusarium moniliforme* did not show any intracellular or extracellular silver nanoparticles formation. The nanoparticles formed were found to be stable even a long time after the reaction. The capping of nanoparticles with the secreted proteins of the fungi might induce stability. Fluorescence spectra showed that the probable mechanism for the metal ions reduction occurred by a shuttle quinone and a nitrate-reductase enzyme in the extracellular process. The production of "naphthoquinones" and "anthraquinones" by the *Shewanella putrefaciens* is reported [119]. These compounds are produced extracellularly and are found in the cell-free supernatant, which can reduce the metal ions extracellular compounds.

Using nitrate reductase, in vitro silver nanoparticles formation has been reported by Anil Kumar et al. [120]. The cell-free culture filtrate of *F. oxysporum* was used as the source of nitrate reductase. The silver nanoparticles formed in vitro are stable even after one month of the reaction. They were crystalline. The advantage of this method is the development of a new synthetic process for nanomaterials using purified enzymes with a better understanding of the mechanism, that is, materials for reduction and simplicity in downstream processing.

Seetharaman et al. [59] used *Salacia chinensis* plant leaves for the growth of endophytic fungi. Silver nanoparticles were developed by reacting with silver nitrate and an extracellular filtrate of *P. liquidambaris* as a reducing and stabilizing agent. Endophytic fungi are the intriguing group of the fungal community that occupies in healthy tissues of plants. Endophytic fungi are vital resources for silver nanoparticles synthesis. Fungi are a good source for any kind of metal nanoparticles synthesis in comparison to other sources such as plants and other microbes. Fungal strains such as *A. niger*, *Aspergillus flavus*, *Alternaria alternate*, *Cladosporium cladosporioides*, *Fusarium solani*, *F. oxysporum*, *Penicillium brevicompactum*, *Trichoderma asperellum*, and *Verticillium* sp. have shown the efficacy for the production of metal nanoparticles. Salacia Chinensis leave was sterilized under aseptic condition. Sterilized leaf segments were inoculated in potato dextrose agar (PDA) medium supplemented with antibiotics and incubated at 28°C for 15 day. Four isolates were recovered in which only one fungal endophyte (SA1) is able to synthesize silver nanoparticles.

Phanerochaete chrysosporium has been employed in the silver ions bioreduction for silver nanoparticles formation [120]. The absorbance spectrum of AgNP has a peak at 470 nm. This deviation in maximum is due to a larger size and a larger size distribution (i.e., between 50 nm and 200 nm), which has been confirmed by SEM images. Bioreduction of silver by the functional groups present in the mycelia could be responsible for the silver nanoparticles formation. The reduction is incomplete and required further

study. The same group has also used *Aspergillus flavus* to form silver nanoparticles, which have maximum absorption at 420 nm [121]. The reaction stabilized after 72 hours. The size of the silver nanoparticles was 8.92 ± 1.61 nm, which was confirmed by TEM analysis. The proteins secreted may be the probable reason for the silver nanoparticles stability.

Bhainsa and D'souza [122] studied extracellular silver nanoparticles formation using *Aspergillus fumigatus*. After 24 h of incubation with $AgNO_3$ in cell-free supernatant, the colour of the medium was intense brown. The authors claimed that this is a rapid method for the nanoparticles formation. They have also claimed that the nanoparticles formed were quite stable even up to 4 months. The fungus Aspergillus sydowii was utilized in the biosynthesis of gold nanoparticles [123].

Nanda et al. [124] studied silver nanoparticles forming using phylloplane fungus. Silver nanoparticles were synthesized from Ag^+ ions by treating different extracts of the phylloplane fungus, *Aspergillus tamarii*, with $AgNO_3$. Phylloplane fungi were isolated and enumerated from the leaves of *Centella asiatica* (medicinal plant). Silver nanoparticles showed good antibacterial properties. The bioactive compounds and silver nanoparticles produced by phylloplane fungus *A. tamarii* revealed considerable antibacterial and antifungal activities. The nanoparticles exposed to sunlight were found more efficient than in dark, medium synthesis for the antimicrobial activity against the test pathogens.

Extracellular silver nanoparticles formation has been reported using *Fusarium semitectum* [100]. Particles were almost 30% in the 25 nm ranges, another 20% in the 35 nm ranges, and the rest of them in the 42 nm ranges as per the TEM image analysis. Spectroscopic studies indicated that proteins by acting as a coating on silver nanoparticles might have played a significant role in the stability. *P. chrysosporium* also reduced silver ions to yield silver nanoparticles [121]. A peak was obtained at around 420 nm in the UV-visible spectrum. The FTIR spectrum revealed the presence of many functional groups, which may contribute to the silver nanoparticle's stability. The average size of the nanoparticles was 16 nm. Broader size distribution was observed for the nanoparticles.

Further extracellular functionalized silver nanoparticles formation was illustrated using *C. cladosporioide* strains [125]. The extracellular production of the silver nanoparticles was obtained within 24 hours. Since it is a commonly available fungus in marshland regions, it could be a cost-effective process. In the UV-visible spectrum, the peak is at 415 nm. The XRD pattern showed that the silver nanoparticles formed were crystalline. TEM images revealed a broad size distribution (between 10 nm and 100 nm). The mechanism of bioreduction has not been explained in detail in this work. The TEM analysis showed that the particles were polydispersed and spherical in nature, with almost 32% in the range of 20 nm, 22% in the range of 10 nm, and 23% in the range of 30 nm [125].

Nayak et al. [126] have studied the biosynthesis of silver nanoparticles using *Penicillium* species. The silver nanoparticles were synthesized by adding silver nitrate to the culture extract of *Penicillium italicum*. The UV-visible spectrophotometer showed the absorption peak at 419–421 nm, and the scanning electron microscopy showed the particle size of 33 nm. The synthesized silver nanoparticles were found to have diverse antimicrobial activities against the pathogens at different pH.

Sadowski et al. [127] have studied the extracellular biosynthesis of silver nanoparticles using *Penicillium* species. The SEM analysis indicated that the nanoparticles were partially aggregated, which may be due to drying operations. Laser diffraction studies showed that the nanoparticles were polydisperse in nature. The study on the effect of the pH on the zeta potential of the silver nanoparticles indicated that the silver nanoparticles had a negative zeta potential. The isoelectric point of the nanoparticle suspension was below pH 2, where coagulation occurred. At pH above 5, the high negative values of the zeta potential (above 25) indicated stability due to electrostatic repulsion. In acidic solutions (a pH of less than 3), the silver nanoparticles form aggregates. This is supported by low negative values of the zeta potential. This is an indication of the instability of nanoparticles. The key benefit of this technique is the widespread availability of *Penicillium* species in the waste biomass of antibiotic-producing industries.

Ballottin et al. [128] studied the synthesis of silver nanoparticles using a *F. oxysporum* fungal filtrate solution. The morphology of the biogenic silver nanoparticles was observed by transmission electron microscopy. The average hydrodynamic diameter of nanoparticles was determined by dynamic light scattering, and the surface charge was measured in a Zetasizer Nano series equipment. They have presented more pronounced antimicrobial effects due to the lower concentration of stabilizing agents (proteins).

Gudikandula et al. [129] studied the synthesis of silver nanoparticles using culture filtrate extracts made from two white-rot fungi. Characterization of silver nanoparticles was carried out using UV-visible spectroscopy, TEM, and FTIR. The average size of 15 nm size of silver nanoparticles was confirmed by TEM analysis. Electron microscopy techniques indicated a size range of 15–25 nm. The antibacterial activity was also reported using four Gram-negative and four Gram-positive bacteria.

Kumari et al. [130] studied the synthesis of silver nanoparticles using *Trichoderma viride*. Different sizes and shapes of silver nanoparticles were obtained by varying pH, reaction time, and temperature of the reaction mixture. The smallest spherical (2–5 nm) nanoparticles were obtained at 30°C, pH 7.0 after 24 h of incubation. Silver nanoparticles characterized by UV-visible spectroscopy, dynamic light scattering (DLS), transmission electron microscope (TEM), and fourier transform infrared spectroscopy (FTIR). Antimicrobial activity reported against human pathogens.

2.4. Synthesis from Plant and Their Extracts. Plants or their extracts, especially flavonoids, have also been known for the bioremediation of metals for a long time [131]. Plant-mediated silver and gold nanoparticle synthesis has been studied extensively [50]. Recently, Gulbagca et al. used *Rosa*

canina plant extract to biosynthesized silver nanoparticles [132]. Algebaly et al. [133] biosynthesized silver nanoparticles using *Calligonum comosum* roots and *Azadirachta indica* leaf extracts. They showed the capability of tested plant extract for conversion of Ag ions to AgNPs with a mean size ranging between 90.8 and 183.2 nm in diameter. Currently, plant extracts are exploited for silver nanoparticles formation. The plant quercetin, a flavonoid, was used to biosynthesize silver and copper nanoparticles in micelle solution, which are stable to a great extent [134]. The silver nanoparticles formed with the alfalfa plant were between 2 and 20 nm in diameter with a small polydispersity, which shows efficient in vivo synthesis of silver nanoparticles. The silver nanoparticles further join to form larger arrangements, signifying potential control synthesis [135]. Karimzadeh et al. [136] biosynthesized silver nanoparticles using *Oxalis corniculata*. Iyer and Panda [137] studied the formation of gold and silver nanoparticles by seed plants. The shape of the nanoparticles was found spherical with a size range of 3 nm to 30 nm. It was observed that the particles size was reduced by increasing temperature. Small silver nanoparticles were produced in 25 min in sunlight, while larger nanoparticles of sizes between 3 nm and 30 nm were formed in 48 h in the dark conditions. The rate of production was found to be increased in the presence of sunlight. Antibacterial activity against *E. coli* DH5 α was reported. Saratale et al. [138] used punica granatum leaves to biosynthesized Ag NPs. They also investigated the antidiabetic activity of Ag NPs. Ag NPs size ranged from 35 to 60 nm, and the average size was 48 nm. Balasubramanian et al. [139] biosynthesized gold nanoparticles using *Jasminum auriculatum* leaf extract and studied their catalytic, antimicrobial, and anticancer activities. Khan et al. [140] reported synthesis of biogenic silver nanoparticles (PG-AgNPs) using the peel extract of *Punica granatum*. Recently, Zahid et al. [141] reported biogenic synthesis of gold nanoparticles from date palm seeds (*Phoenix dactylifera* L.).

Terpenoids such as citronellol, geraniol, and linalool, usually found in geranium leaf extracts, may be reason for the silver ions reduction [142]. Using neem (*Azadirachta indica*) leaf broth, the silver ions reduction to yield silver nanoparticles was observed [85, 143–145]. Neem leaf broth facilitated the gold nanoparticles formation and gold-silver bimetallic nanoparticles formation. In this case, the silver, gold, and gold-silver bimetallic nanoparticles formation were possibly made by reducing sugars and/or terpenoids [85]. The aloe vera leaf extract also showed a route for the silver nanoparticles formation and gold nanoparticles formation [142, 146]. Even though this process did not give consistent morphology in gold nanoparticles, spherical silver nanoparticles of 15.2 ± 4.2 nm has been formed by Aloe Vera leaf extract [142]. The reason for the difference in the morphology of the gold and silver nanoparticles synthesized is not well understood [142]. *Terminalia bellirica* fruit extract have been used to synthesized silver nanoparticles at ambient temperature [147]. Formation of silver nanoparticles identified using UV-visual spectroscopy. Aqueous *T. bellirica* extract contains a high amount of gallic acid. Silver nanoparticles have gained a lot of impact because of their applications in interdisciplinary fields such as medicine, biosensors, and electronics. Fruits extract were used with silver nitrate and stirred, which shows a brown colour, and that indicated the formation of silver nanoparticles. Silver nanoparticles have exhibited antibacterial activity against bacteria by interacting with the bacterial cell wall. The antioxidant activity of silver nanoparticles has been examined. Lower concentration synthesized silver nanoparticles shown better activity than the extract. *Capsicum annuum* leaf extract has also been studied for the formation of silver nanoparticles [148]. This method gave spherical particles with 10 ± 2 nm sizes after 5 hours of contact between leaf extract and silver ion solution, and a further increase in size of the nanoparticles with time implies a potential and rapid method for the nanoparticles formation [148]. Phoenix dactylifera root fibers have been also used to synthesized silver nanoparticles [149]. The reaction was carried out in the dark at room temperature to avoid photoactivation of $AgNO_3$. Maximum yield of 79% was optimized at 1% plant root extract with 0.1 M $AgNO_3$ solution mixture after 48 h incubation at 50°C. Size of the silver nanoparticles were predicted 15 to 40 nm with spherical shape. The powdered, sun-dried biomass of *Cinnamomum camphora* leaf is another cost-effective choice [150]. The biomass showed both silver and gold nanoparticles formation. Because of the presence of anisotropic nanoparticles, the shapes of the particles were not uniform. The probable mechanism could be polyol component-dependent bioreduction and water-soluble heterocyclic component stabilization [150].

Annu et al. [151] studied the formation of silver nanoparticles using fresh lemons, oranges, and mosambi waste extract. Ten milliliter of silver nitrate solution was mixed to different concentrations of fruits waste extract in separate beakers, which were placed in a dark chamber in order to minimize the photoreduction of silver nitrate solution at room temperature. Transmission electron microscope revealed 9–46 nm size range of silver nanoparticles. The antimicrobial, antioxidant, and cytotoxic activity was also reported. Successful syntheses of silver nanoparticles in a tubular reactor were reported with the lixivium of sun-dried *Cinnamomum camphora* leaves [152]. The continuous-flow reactor for silver nanoparticles formation is reported for first time using the lixivium [152]. Though the mechanism is not clear, this study can be extended to any biosynthesis process. Various temperatures have been reported for the process. Narrow size distribution for silver nanoparticles was obtained [152].

The reduction of $AgNO_3$ has been done by an aqueous extract from pericarp obtained from palm date fruit [153]. The particle's size ranged 3 nm to 30 nm and was spherical in shape. The silver nanoparticles have also been synthesized by *Limonia acidissima* L. leaf extract [154]. The microscopic analysis using HRTEM results showed that the silver nanoparticles were spherical, with sizes ranging from 21 to 42 nm. Unripe Kokum green fruits were also used to synthesized silver nanoparticles with a size range of 5 to 30 nm [155]. Rasheed and Bilal [156] studied the biosynthesis of silver nanoparticles using the *Convolvulus arvensis* extract.

Various factors such as the concentration of the plant extract, reaction time, and different pH levels were investigated by UV-visible spectroscopy.

Yao et al. [157] studied the synthesis of silver nanoparticles using grape seed extract. The study was focused on their use for the catalytic degradation of a hazardous dye. The formation of silver nanoparticles was observed on adjustment of pH value of solution using NaOH. Furthermore, the higher temperature made silver particles grow bigger and so weaker catalytic activity. The size increase was probably due to the faster nucleation of seed particles and their subsequent growth to bigger silver nanoparticles. An average diameter of 54.8 nm silver nanoparticles were synthesized at room temperature (20°C). Antimicrobial nanoparticles were obtained from aqueous plant extracts [158]. The antimicrobial activity assays were carried on against bacterial and fungal strains. The paint formulated with a silver concentration of 0.015 wt% has shown more effective to inhibit the development of fungal and bacterial biofilm. An average diameter of 5–10 nm silver nanoparticles were biosynthesised from tulsi leaf extract [159]. The catalytic potential of the AgNPs was studied for the reduction of 4-nitrophenol to 4-aminophenol (100% conversion) in alkaline medium. Hitesh and Lata [160] studied the formation of silver nanoparticles using an aqueous floral extract of *Nelumbo nucifera*. *N. nucifera* flower has been investigated to be used as an effective reducing agent and stabilizing agent for the synthesis of silver nanoparticles contributing to the syntheses through floral extracts. Sowmyya and Lakshmi [161] studied the formation of silver nanoparticles using aqueous stem bark extract of *Soymida febrifuga*. The extract of *Soymida febrifuga* was mixed with silver nitrate. The reaction mixture was agitated and heated for 15 minutes. The solution was observed for a colour change to a brown colour, which confirmed the formation of AgNPs. The AgNPs were obtained with an average size of 10–30 nm and were mostly spherical in shape. The water-soluble phytochemicals in the extract helped in the reduction and stabilization of the AgNPs. Silver nanoparticles were synthesized using *S. asper* leaf extract [162]. Its infliction on photocatalytic efficiency, antibacterial activity, and interaction with human serum albumin (HSA) was described. The AgNPs were obtained with an average size of 13 nm. Beg et al. [163] studied the synthesis of silver nanoparticles using aqueous *Spathodea campanulata* leaf extracts. 20 mL of leaf extract was mixed with 10 mL 0.001 M of aqueous silver nitrate solution under constant stirring at 450 rpm. After 7 min of continuous stirring, the colour of the solution was changed completely from pale brown to deep brown and indicated the AgNPs formation. AgNPs with a size of 18.4 nm were obtained. The resulting solution was stirred for 15 min more for complete reduction of silver ions. The AgNPs showed a dose-dependent bactericidal property against *E. coli* ATCC 25922 and MIC.

Dhayalan et al. [164] studied the green synthesis of silver and gold nanoparticles using the root extract of *Coleous forskohlii* as a capping and reducing agent. The size of colloidal gold and silver nanoparticles was found to be 10–30 nm and 5–35 nm, respectively. The synthesized gold nanoparticles were spherical in shape, whereas silver nanoparticles were elliptical. The stability of silver nanoparticles was checked by varying the pH ranging from 7 to 13. The optimum synthetic conditions were found at room temperature and pH 7. The volume of 0.4 mL of reducing agent (root extract of *C. forskohlii*) was found to reduce silver ions into nanoparticles. Silver nanoparticles were also synthesized using fruit extract of *Gmelina arborea* [165]. A total of 0.1 mL of fruit extract was added with 30 mL of aqueous $AgNO_3$ (1.0 mM). Then this mixture was heated at 60°C and 1,000 rpm for 5 minutes. Solution starts changing from colourless to yellowish-brown, and silver nanoparticles were confirmed by UV-visible spectra. The prepared AgNPs shape was spherical and crystalline in nature with average diameter of 17.0 ± 1.6 nm. Silver nanoparticles were synthesized by reduction of aqueous $AgNO_3$ using *Trachyspermum ammi* seeds extract [166]. The reduction rate of Ag^+ was increased by increasing Trachyspermum Ammi seeds extract concentration, and it also affected shape and size. The size of silver nanoparticles was found to be 10–30 nm. Silver and gold nanoseeds were synthesized from *Taxus baccata* extracted Taxanes as reducing and capping agents [167]. It was used to decorate silica-coated iron nanoparticle, which was used for cancer treatment. It has shown semispherical shapes and sizes between 200 and 500 nm. Gold and silver nanoseeds were also synthesized in the presence of *T. baccata* extract, as reported [167]. Silver nanoparticles were synthesized using the hull of *Vigna mungo* [168]. The SEM images suggested that the nanoparticles are 100 nm in dimension. Silver nanoparticles were synthesized using *Solanum tuberosum* extract as a reducing as well as stabilizing agent [169]. AgNPs were highly dispersed in the solution and found to be spherical with around 10 nm in size. Silver nanoparticles were also synthesized using *Butea monosperma* extract as reducing agents [170]. Transmission electron microscopy (HRTEM) showed that the nanoparticles had an average dimension of 35 nm. Silver nanoparticles were synthesized using *Cassia fistula* fruit extract [171]. Results confirmed spherical-shaped AgNPs with an average crystallite size of 69 nm.

Saha et al. [165] studied the formation of silver nanoparticles using *Swertia chirata* leaf extract. Synthesis of silver nanoparticles was observed by UV-visible spectrophotometer in 300–700 nm range. It was observed that the toxicity potentials could not be minimized by lowering the concentration of nanoparticles applied to the treated plants as the nanoparticles are equally reactive in low doses. Gold and silver nanoparticles were synthesized using *Paederia foetida* Linn [174]. Ag NPs owing to their small size (5–25 nm) could have easily penetrated into the cell membrane, disturb the metabolism, cause irretrievable damage, and finally lead to microbial cell death. Interestingly, biogenic gold nanoparticles did not show any antimicrobial activity. Silver nanoparticles were synthesized using the pod extract of *Cola nitida* [175]. The particles showed strong activities against multidrug resistant clinical bacterial strains and completely suppressed the growth of bacteria and fungi. Silver nanoparticles were synthesized using aqueous bark extract of *Terminalia cuneate*, and synthesized silver nanoparticles

were found to have a crystalline structure with a face-centered cubic geometry oriente [176]. The synthesized AgNPs were in size range of 25–50 nm with a distorted spherical shape identified from HRTEM analysis. The Silver nanoparticles were synthesized using Longan fruit juice as a reducing and stabilizing agent [177]. The synthesized AgNPs were in the size range of 4–10 nm.

Silver nanoparticles were synthesized using *Caralluma edulis* extract [177]. HRTEM analyses and were found in the range of 2–10 nm, which were highly dispersion without any aggregation. Silver nanoparticles were also synthesized using aqueous *Abutilon indicum* leaf extract (AILE) [178]. Gold nanoparticles were synthesized using aqueous *Citrus paradisi* (grapefruit) extract, which was used as both the reducing and capping agent. Analysis of the sample shows FCC AuNPs with triangular, hexagonal, and spherical shapes [63]. Gold nanoparticles were synthesized using Kokum fruit extract, which was used as both catalytic and antioxidant agent [179]. Gold nanoparticles were synthesized using the *Elaeis guineensis* (oil palm) leaves extract [64].

2.5. Synthesis Using Waste Biomass and Pure Biomolecules. Biomass waste is a very good source of various organic and inorganic substances, and it can be further used in many process such as biosynthesis of nanoparticles. Biomass such as wheat straw and grass waste were used to synthesized silver and gold nanoparticles. Khatami et al. [180] used waste grass to synthesized silver nanoparticles. They reported anticancer, antifungal and antibacterial activity. The average size of silver nanoparticles observed in transmission electron images was estimated to be about 15 nm. Later, grape pomace extract was used to synthesized silver nanoparticles with size of 20–35 nm [181]. *Metarhizium robertsii* waste biomass extract used to synthesized silver nanoparticles [182]. Quercetin is a pure biomolecule, and it can be used for bioproduction. The minimal concentration was sufficient to reduce the same amount of silver salt as compared to tulsi extract. On increasing the concentration of quercetin further in aqueous silver salt, it was found that the colour of the solution turned blackish grey, and the formation of AgNPs was restricted. Also, the absorption peak got narrower with an increase in concentration [183]. The extract of orange peel has been studied for the silver ions reduction (Sararale et al.) [138].

2.6. Synthesis of Polysaccharides Nanoparticles. Polysaccharide NPs have received a lot of interest in the last decade, mostly for biological uses, but they have also been used in cosmetics and food. The polysaccharides used come from a variety of natural sources, making them ideal candidates for long-term nanotechnology. Furthermore, depending on their chemical structures, polysaccharides offer beneficial biological qualities and activities. The extraordinary biodegradability, biocompatibility, and low toxicity of polysaccharides are significant characteristics that promote their wide range of uses in the biological environment. Many researches were synthesized NPs using biopolymer from plant. Alginate, carrageenan (CRG), chitin (CH), chitosan (CS), cellulose (CL), dextran (DEX), starch, hyaluronic acid (HA), and pullulan (PL) are the common polysaccharides. Cellulose (CL) and starch are polysaccharides from plants.

3. Application of Ag and Au Nanoparticles

3.1. Application of Ag and Au NPs in Antibacterial, Antimicrobial, Catalytic, and Oxidant. Even though nanoparticles are formed from their parent element, they show a drastic change in properties due to quantum confinement, higher surface energy, and so on, which are unusual and unique qualities of the metals, giving rise to tremendous applications in various fields [8]. Living organisms have a vast potential for the production of nanoparticles or nanodevices for their wide applications [23]. Nanotechnology is currently utilized in everyday products such as beverages, cosmetics, clothing, and food category, including health and fitness products, containers, dietary supplements, bandages, sterile cloths, car wax, toys, and so on.

Silver nanoparticles were synthesized using *Caruluma edulis* extract [177]. The size of the silver nanoparticles were found in the range of 2–10 nm using HRTEM, which were highly dispersed without any aggregation. Silver nanoparticles were also synthesized using aqueous *Abutilon indicum* leaf extract (AILE) [178]. Gold nanoparticles were synthesized using aqueous *Citrus paradisi* (grapefruit) extract, which was used as both the reducing and capping agent. Analysis of the sample shows FCC AuNPs with triangular, hexagonal, and spherical shapes [184]. Gold nanoparticles were synthesized using Kokum fruit extract, which was used as both catalytic and antioxidant agent [179]. Gold nanoparticles were synthesized using the *Elaeis guineensis* (oil palm) leaves extract [64].

The biosynthesized gold and silver nanoparticles as antimicrobial materials have been studied extensively [22, 28, 58–60, 73, 75, 98, 105, 124, 128, 149,
153, 154, 161, 164, 175, 177, 185–194]. The silver nanoparticle's antibacterial activities on four bacterial strains, namely, *Staphylococcus aureus*, *E. coli*, ampicillin-resistant *E. coli*, and *Salmonella typhus*, indicate its potential application to resist the growth of Gram-negative bacteria. The antibacterial activity on the above bacteria was concentration-dependent (for concentration less than 0.025 mg/ml of silver nanoparticles, there was no reduction in bacterial growth) and was important against Gram-negative bacteria compared to other microorganisms. The silver ions were released from silver nanoparticles impregnated fabrics continuously, thereby enhancing its antimicrobial activity [52]. The mechanism for interaction between silver nanoparticles and microbial cells needs to be explained for a better understanding of its antimicrobial activity. Silver has been used as an antimicrobial agent since ancient times. Now, silver nanoparticles have been found in applications such as wound dressings, surgical device coatings, silver-impregnated fabrics, and so on, because of the unique ability of silver nanoparticles to release silver ions continuously. Those silver ions bind to the tissue proteins and aids in the healing process. Also, the inner and the outer surfaces of the

Table 1: Silver nanoparticles from bacteria, fungi, plants and their size, shape and biological activity.

Species	Size and shape	Bioactivity	References
Bacillus clausii	150 nm	No activity reported	Mukherjee et al. [67]
Pseudomonas putida	5–16 nm, spherical	Antibacterial	Gopinath et al. [191]
Sporosarcina koreensis	102 nm, spherical	Antibacterial and catalytic	Singh et al. [105]
Actinomycete	5–25 nm, spherical	Antioxidant	Sowani et al. [109]
Metal-reducing bacteria	5–15 nm	Antibacterial	Kim et al. [200]
Salacia chinensis leaves	18.7 nm, spherical	Antimicrobial	Seetharaman et al. [59]
Phylloplane fungus	40 nm	Antibacterial	Nanda et al. [124]
Wasp nest soil fungi	33 nm	Antibacterial	Nayak et al. [126]
Fusarium oxysporum	34.6 ± 15.3 nm, spherical	Antimicrobial	Ballottin et al. [128]
White-rot fungi	15 nm, spherical	Antibacterial	Gudikandula et al. [129]
Trichoderma viride	2–5 nm, spherical 40–65 nm, rectangular 50–100 nm, penta and hexagonal	Antimicrobial	Kumari et al. [130]
F. oxysporum	—	Kinetics	Nair and panda [201]
Aspergillus terreus	1–20 nm	—	Li et al. [202]
Aspergillus clavatus	—	Antimicrobial	Saravanan and Nanda [203]
Angiosperms	3–20 nm, Spherical	Antibacterial	Iyer and Panda [137]
Terminalia bellirica fruit	Spherical	Antimicrobial and antioxidant	Anand and Mandal [147]
Phoenix dactylifera root fibers	21.65–41.05 nm, spherical	Antimicrobial	Oves et al. [149]
Fruits waste	9–46 nm, spherical	Antimicrobial and antioxidant	Annu et al. [151]
Palm date fruit	3–30 nm, spherical	Antimicrobial	Zaheer [153]
L. acidissima	21–42 nm, spherical	Antibacterial	Patil and Taranath [154]
Kokum fruit	<100 nm, spherical	Antibacterial	Sangaonkar and Pawar [155]
C. arvensis leaves	10–30 nm, spherical	Catalytic	Rasheed and Bilal [156]
Grape seed	54.8–128.9 nm	Catalytic	Yao et al. [157]
Anacahuita, cola de caballo and yerba mate	20 nm, spherical	Antibacterial	Barberia-Roque et al. [158]
Tulsi leaf	5–10 nm	Catalytic	Singh et al. [159]
N. nucifera flower	90 nm	No activity reported	Hitesh and Lata [160]
Soymida febrifuga	10–30 nm, spherical	Antibacterial	Sowmyya and Lakshmi [161]
Sonchus asper	13 nm, round shape	Antibacterial	Das et al. [162]
Spathodea campanulata leaf	18.4 nm	Antibacterial	Beg et al. [163]
Coleous forskohlii	91.03 nm, elliptical 20–30 nm, spherical	Antimicrobial and antioxidant	Dhayalan et al. [164]
Gmelina arborea	17 nm, spherical	Catalytic	Saha et al. [165]
Trachyspermum ammi	3–50 nm, cube	Catalytic	Chouhan et al. [166]
Taxus baccata	200–500, semi-spherical	Anticancer	Kajani et al. [167]
Taxus baccata	91.2-75.1 nm, spherical	Anticancer	Kajani et al. [167]
Seed hull of *Vigna mungo*	73 nm	Antioxidant and anticoagulant	Varadavenkatesan et al. [168]
Solanum tuberosum	10 nm, spherical	No activity reported	Ali et al. [169]
Butea monosperma	35 nm, spherical	Anticancer	Pattanayak et al. [170]
Cassia fistula fruit	69 nm, spherical	Antimicrobial and antibacterial	Rashid et al. [171]
Swertia chirata leaf	20 nm, spherical	No activity reported	Saha et al. [165]
Paederia foetida Linn.	5–25 nm, spherical	Antimicrobial	Bhuyan et al. [174]
Cola nitida	12–80 nm, spherical	Antibacterial and antioxidant	Lateef et al. [175]
Terminalia cuneate	25–50 nm, spherical	Catalytic	Edison et al. [176]
Longan fruit	4–10 nm, spherical	Antibacterial and antioxidant	Khan et al. [177]
Caralluma edulis	2–10 nm, spherical	Antibacterial and photo catalytic	Khan et al. [177]
Abutilon indicum leaf extract (AILE)	5–25 nm, spherical	Antibacterial	Mata et al. [178]

Table 2: Gold nanoparticles from plants, size, shape, and biological activity.

Species	Size and shape	Bioactivity	References
Nuts exracts	13.7 nm, spherical	Catalytic and antioxidant	Rajan et al. [56]
M. calabura fruits	27 nm, spherical	No activity reported	Kumar et al. [60]
Mangifera indica seed	46.8 nm, spherical	Antibacterial and antiangiogenic	Vimalraja et al. [61]
A. bettzickiana	80–120 nm, spherical	Antibacterial and cytotoxic	M. et al. [48]
A. nigra leaves	21.52 nm, spherical	Antibacterial and antioxidant	Baruaha et al. [62]
Citrus paradise	25–325 nm, triangular 5–85 nm, spherical	No activity reported	[184]
Coleous forskohlii	35.5 nm, spherical	Antimicrobial and antioxidant	Desai et al. [179]
Oil palm leaves	35–75 nm, spherical	No activity reported	Ahmad et al. [64]
Elettaria cardamomum	15.2 nm, spherical	Antioxidant and antibacterial	Rajan et al. [57]
Rhazya stricta	30–60 nm	Antibacterial	Ahmad et al. [58]
Crescentia cujete L. leaf	32.9 nm, spherical, triangular, hexagonal	Anticancer	Seetharaman et al. [59]
Paederia foetida Linn.	10–50 nm, irregular	Antimicrobial	Bhuyan et al. [174]
Cannonball fruit	25 ± 6 nm, spherical	Antioxidant	Sathishkumar et al. [204]
Mimosa pudica	12.5 nm, spherical	Anticancer	Suganya et al. [205]
Coleus aromaticus	28 nm, spheroid	Antibacterial and antiradical	Vilas et al. [188]
Areca catechu nut	13.7 nm, spherical	Antibacterial and antioxidant	Rajan et al. [56]

medical devices can be coated with silver ions for the continuous release of silver ions, enhancing their antimicrobial efficiency. Scar-free healing is a noted advantage of silver nanoparticles in healing wounds. Silver and gold nanoparticles synthesized using callus and flower extracts of *Michelia champaca* L. were studied for their antimicrobial activity [50]. The biosynthesized silver and gold nanoparticles as catalytic material has been studied extensively [99, 159, 161, 165, 166, 176, 188, 195].

One of the amazing properties of silver nanoparticles is that it attaches to HIV 1 virus. Thus, it puts a stop to the virus from attacking the host cells [69]. Nanomaterials can also be used as catalysts instead of using toxic chemicals. Nanomaterials and nanodevices can be used in air and water filters to reduce pollution. They can be used in solar and fuel cells for more efficient alternative energy production [15, 196–198]. Silver nanoparticles affect the physiology of plants, which may be extended to application in weed control [199]. Sensor with silver nanoparticles coated graphene was used. This composite gave high sensitive analysis of avian influenza virus [6]. A detailed list of silver/gold nanoparticles from different bio-sources, nanoparticle size, shape, and their biological activities is compiled in the tables. Table 1 documents silver nanoparticles from bacteria, fungi, and plants, and Table 2 gathers the gold nanoparticles from plants.

3.2. Application of Ag and Au NPs in Biosensing. Many compounds such as heavy metals used in different fields of industry. Even if it is not so sensitive, the method for detecting heavy metal traces using biosensors has a dynamic trend. In the past few years, they also become more and more a synergetic combination between biotechnology and microelectronics. Dedicated biosensors were developed for offline and online analysis. Ghodake et al. reported colorimetric detection of Cu^{2+} based on the formation of peptide-copper complexes on silver nanoparticle surfaces [206]. Ghodake et al. used gallic acid-functionalized silver nanoparticles for detection of Al^{3+} [207]. The three essential components of a biosensor are depicted in Figure 2. These components, which are bioreceptor, transducer, and detector in terms of the conceptual and basic mode of operation, are bioreceptor, transducer, and detector. A biosensor's principal function or goal is to detect a biologically unique substance.

4. Practical Applications, Future Research Perspectives and Challenges

AgNPs have been widely employed as antibacterial and anticancer agents, as well as for biomedical applications in the healthcare business, due to their inherent cytotoxicity. The surface charges of AgNPs determine the degree of toxicity against cells. Efforts have been made to explore their attractive properties and utilize them in practical applications, such as antibacterial and anticancer therapeutics. When it comes to green synthesis, AuNPs and AgNPs are straightforward and easy to make. The reaction can be carried out in mild conditions with no increase in temperature or pressure. The rate of reaction is influenced by the presence of a green reducing agent, such as plants. When compared to other green materials, a plant-based reducing agent usually produces the fastest reaction, ranging from minutes to hours. Despite the benefits of green synthesis, additional research is needed to market and scale up AuNPs and AgNPs production. Unlike physical and chemical synthesis, there are still a number of unknown variables preventing this technique from gaining acceptance in medicine. Green materials have been used in many studies due to the presence of organic molecules and functional groups in the materials. The mechanism of manufacturing, however, remains unknown. The characteristics of the reducing agents should be studied in more depth. It is necessary to determine the major reducing components or organic groups in order to develop a precise and reproducible technique. The mechanism and bonding of the reaction should also be investigated in order to give knowledge for the nanoparticles use. Before applying nanoparticles to diverse sectors, it is necessary to grasp the details of their

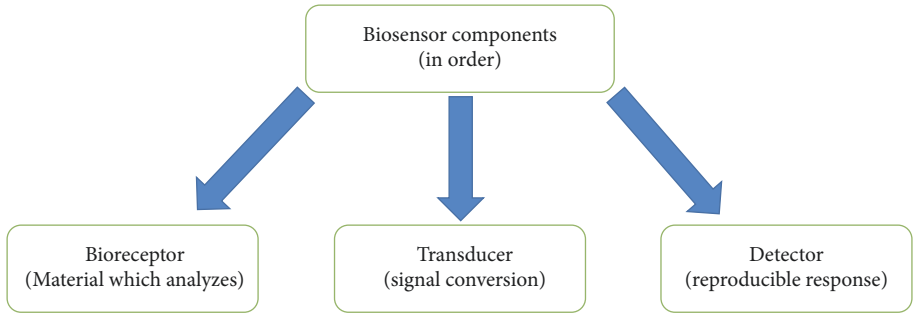

Figure 2: Depiction of the block diagram of a biosensor (adapted from Malik et al. [208]).

creation. Since nanotechnology-based applications require the use of specified shape, size, surface charge, and stability of NPs, a major problem associated with biologically synthesized Au and Ag NPs is that these NPs display variability in all these factors. This is a major drawback of biologically synthesized Au and Ag NPs compared to the physicochemically synthesized NPs.

5. Conclusion

This review looks at the latest research on silver and gold nanomaterials in order to better understand the synthesis methods and mechanisms, as well as the characterization of physicochemical properties and possible toxicity, and to find new applications in oncology, personalised healthcare, and pharmacology. The antifungal and antibacterial properties of silver and gold nanoparticles have been described separately. The biosynthesis, mechanism, and biomedical applications of the NPs, especially silver and gold, are reviewed. The characterization techniques such as SEM, TEM, XRD, FTIR, and UV-visible spectrophotometer proved that the particles produced in nanodimensions would be equally effective as that of antibiotics and other drugs in pharmaceutical applications. In the presence of nanoparticles, the absorption of medicine increases several times. Therefore, Ag NPs may be used as a drug delivery system. The ongoing research efforts should be focused on evaluating the safety of nanomedicine and formulating the international regulatory guidelines for the same, which is critical for technology advancement. Hence, the NP synthesized via the biosynthesis route possesses great potential for many applications.

Data Availability

All data used to support the findings of the study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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