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Review Article

Biofabrication of Silver Nanoparticles and Current Research of Its Environmental Applications

R. R. Remya,[1] Angeline Julius,[1] T. Y. Suman,[2,3] L. Aranganathan,[4] T. Stalin Dhas,[4] V. Mohanavel,[1] Alagar Karthick,[5] and M. Muhibbullah[6]

[1]*Centre for Materials Engineering and Regenerative Medicine, Bharath Institute of Higher Education and Research, Chennai, 600073 Tamil Nadu, India*
[2]*Institute of Industrial Technology Changwon National University, Changwon, Gyeongsangnamdo 51140, Republic of Korea*
[3]*School of Civil, Environmental and Chemical Engineering, Changwon National University, Changwon, Gyeongsangnamdo 51140, Republic of Korea*
[4]*Centre for Ocean Research, Sathyabama Institute of Science and Technology, Chennai, 600119 Tamil Nadu, India*
[5]*Department of Electrical and Electronics Engineering, KPR Institute of Engineering and Technology, 641407 Coimbatore, Tamil Nadu, India*
[6]*Department of Electrical and Electronic Engineering, Bangladesh University, Dhaka 1207, Bangladesh*

Correspondence should be addressed to R. R. Remya; remya.praveen5@gmail.com

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In recent years, nanotechnology has received extraordinary attention as the demands of today's modern lifestyle are actively changing every day. The need for a sustainable environment and process is the prerequisite today for any advancement. Nanoparticles and its application have extended its wings into various fields. Researchers across the globe are constantly exploring the applications of NPs, especially those of metallic NPs. Among the metallic NPs, silver NPs has received special attention owing to their excellent physical and chemical properties. Nanobiotechnology has opened avenues for such a sustainable and environment-friendly progress. So, in this review, we have summarized the different methods employed in synthesising AgNPs, with special focus on the biological synthesis. This approach is of importance because of its advantages such as use of nontoxic compounds, inexpensive process, and high stability of products obtained in comparison to the other approaches. Several biomolecules of interest such as microbes and plant extracts that are used for synthesis are discussed in detail. The recent advancements in the environmental application of these biologically synthesised NPs include remediation of heavy metals and sensing, as catalysts in toxic dye degradation, remediation of waste water, and also, as a pesticidal agent for crop protection. Although AgNPs have been used in several sectors of research and industries, relevance to the environment is prominent owing to the impact it makes on the humans and all forms of life on earth.

1. Introduction

The term "Nano" is derived from a Greek word that indicates 10^{-9} (1 million) which equals three atoms in length. The concept of nanotechnology was invented by the Physics Noble laureate Richard P Feynman. Nanotechnology is known to produce particles in the form of solid with a size range of 10-100 nanometers (nm) [1]. These particles are termed as "nanoparticles" (NPs) produced in a variety of materials according to the researcher's need. The materials can be in different forms such as 0D, 1D, 2D, or 3D, based on their overall dimension. Several research groups have proposed different forms of definitions for NPs that is summarized in Table 1 [2–6]. NPs are composed of three layers such as surface, shell, and the inner core. The first layer of the NPs are composed of small molecules, the second layer of NPs are composed of chemically different material from the core layer, and the third layer is the predominant core layer, whose material defines the properties of the NPs [7].

Table 1: Definitions of NPs proposed by various research groups.

S. no.	Definitions	References
1	Nanoobjects with 3D in nanoscales	[2]
2	A solid colloidal particle whose size ranges from 10 to 100 nm	[3]
3	Structures designed with irrespective to the position of the particles	[4]
4	A short distance particle that is measured in nanoscale	[5]
5	Charged particles in nanorange	[6]

The three main features of NPs depending on the architectural type of the nanoparticle are [6]:

(i) The perspective and definition of a nanoparticle

(ii) Application of the nanoparticle

(iii) The physical/mechanical and chemical properties of the nanoparticle

Metallic NPs have gained more interests from researchers because of their potential application in industries and laboratories. Therefore, this review focuses on the importance of silver nanoparticles (AgNPs) and its environment-related applications.

The benefits of NPs in modern science and technology are numerous and has acquired the attention of researchers and commercialists. NPs exhibit surprising properties when compared to the raw materials. This factor is considered as one of the most important reasons for the emphasis on the use of NPs over raw materials in terms of environmental protection [8]. The surface to volume ratio of NPs is higher; when the surface area of the particle increases, the radius of the particle decreases. This is one of the advantageous properties of NPs in the field of medicine for drug delivery [9]. The surface to volume ratio which influences the surface chemistry has resulted in more applications for AgNPs when compared to other metallic NPs [10]. When the stability of the NPs is high, they can be used as a good antimicrobial agent [11]. This stability is due to the zeta potential that gives the electrostatic mobility of NPs; this enables major application in pollution control or removal of any pollutant from the environment.

However, many research groups have raised a concern that the process of removing any pollutants may cause toxic effects to the ecosystem. In recent times, nanoparticles have also been incorporated into face masks for their antimicrobial property [12]. It is speculated that the particles that we use in this process may be easily taken up by plants and enters into the food chain. So, several researchers have studied the toxicity level of AgNPs and reported it to be comparatively low [13]. This search for a sustainable approach led to the literature search on the biosynthesis of nanoparticles. Biomolecules were found to be potent compounds with innate properties to act as an equivalent to other methods.

2. Types of Metal NPs and Synthesis of AgNPs

Varied types of metallic NPs have been used in different forms and types in different fields. The noble metal group comprises gold (Au), silver (Ag), and platinum (Pt), and the metal oxide group comprises silicon oxide (SiO_2) and zinc oxide (ZnO) [14]. Among the metal NPs, AgNPs have a wide range of application, and many research groups are currently working to explore more applications of AgNPs. Ag is considered as one of the basic elements on our planet, as it occurs naturally, and Ag is harder than Au. AgNPs have higher thermal and electrical conductivity when compared to Au. Metallic Ag is already used in many surgical procedures, also as fungicides and as preservatives. Thus, AgNPs have gained more interest than other metallic NPs, and some methods for synthesizing nanoparticles have been described in this review.

Palladium-based nanoparticles from plant extracts have been used as nanocatalyst in numerous catalytic reactions. Plant-assembled magnetic chitosan-copper nanocomposite, was used as catalyst for the formation of amino acid N-sulfonyl tetrazoles [15]. Palladium nanoparticles synthesized from *Euphorbia thymifolia* L. leaf extract exhibited significant catalytic activity for the Hiyama cross-coupling, cynation of aryl iodides, and ligand-free Stille reactions in water [16, 17]. Nasrollahzadeh and Sajadi (2009) synthesized Pd/Fe_3O_4 NPs from the root extracts of *Euphorbia stracheyi* Boiss, which demonstrated potential reductive amination of aldehydes.

Copper nanoparticles synthesized on graphene oxide/manganese dioxide using the leaf extract of *Cuscuta reflexa* showed catalytic activity towards the reduction of organic dyes and nitroarenes [18]. Copper oxide NPs formed from Chamomile flower exhibited antioxidant and DNA cleavage properties [19]. ZnO nanoshells were synthesized using urease enzyme at room temperature [20].

Gold nanoparticles with long-term stability was synthesized from red raspberry, blackberry, and strawberry [21]. UV light and red cabbage extracts were also used to synthesize AuNPs [22].

2.1. Physical Method for Synthesis of AgNPs. The predominant method in the physical synthesis of AgNPs is evaporation/condensation. In this method, the coating material is heated to its boiling point in the presence of a vacuum, and condensation occurs [23]. Recently, Park et al. (2020) have developed a novel method, solvent-free production of NPs using evaporation-condensation method in the presence of unipolar ionic flow to enhance the antibacterial effect of NPs [24]. Joseph and Matthew (2015) synthesized AgNPs rapidly using microwave irradiation from aqueous leaf extract of *Biophytum sensitivum*, to reduce the reaction time [25]. Fatimah (2016) investigated the formation of AgNPs

Table 2: Microemulsion technique for synthesis of NPs.

S. no	Microemulsion	NPs	References
1	Clove oil	Ag	[28]
2	Castor oil	Ag	[29]
3	Isopropyl myristate + poly(oxyethylene) sorbitan monooleate + sorbitan laurate (span 20) + ionic liquid	Au and Ag	[30]

Table 3: Electrochemical synthesis of NPs.

S. no	Reducing agent	NPs	References
1	Graphene oxide	Graphene nanotubes	[32]
2	Polyaniline-graphene	Graphene films	[33]
3	Tannin acid	Ag	[34]
4	Fruit peel extract	Ag	[35]

from the extracts of stinky beans pod using microwave irradiation technique [26]. The microwave-assisted synthesis of AgNPs using glucose as reducing agent and starch as capping agent was studied by Kumar et al. (2018) [27]. Microemulsion and isotropic technique is another physical method of NP synthesis; some of the sources used are summarized in Table 2 [28–30].

2.2. Chemical Method for Synthesis of Ag NPs. For the production of ultrasmall particles, the most accepted process is the chemical synthesis of AgNPs by electrochemical method. In an aqueous solution, electrochemical synthesis of nanospheres and nanorods from their salts was demonstrated by Nasretdinova et al. (2017) [31]. Various electrochemical synthesis of NPs is summarized in Table 3 [32–35].

2.3. Biological Synthesis of AgNPs. Biological synthesis of NPs is a type of bottom-up approach as the reduction or oxidation is a major reaction of the process. The physical and chemical method of NP synthesis is expensive and energy-intensive, and the stability of the NPs is slightly low. Further, these methods employ the use of nonpolar solvents and toxic chemicals in the synthesis process. The use of capping agents and synthetic additives for stabilization of nanoparticles further limits their applications in biomedical and clinical fields [36], whereas biological approach for NPs synthesis is considered to be cost-effective, safe, biocompatible, natural, easily available, and ecofriendly, and stability of NPs produced is high [37]. The chemical approach may give rise to toxic substances during the processing of the source, which can be avoided in the biological process [38]. Microorganisms and plant extracts are used for the biogenic synthesis of nanoparticles. Bacteria, fungi, yeasts, actinomycetes, and viruses have inherent potential to produce metal nanoparticles, both intra- and extracellularly. However, use of microorganisms for synthesis of NPs has a major limitation on large scale; this is because of the maintenance of microbial cell cultures. Phytosynthesis of metallic nanoparticles is simple, scalable, and less-expensive compared to microbial process.

The extracts from the biological source acts as the reducing agent, and the synthesis of biogenic nanoparticles is confirmed by the color change of the aqueous extract and metal salt mixture. The yellow to brown coloration is a spectroscopic signature for AgNPs. The colour change was due to the surface plasmon resonance (SPR) phenomena. SPR is defined as the excitation of plasmon vibrations by light at particular wavelength, and this is one of the basic technique employed to confirm the presence of nanoparticles. The SPR phenomena enhance the absorption and scattering intensities of Ag and Au nanoparticles. The absorption maxima for AgNPs are reported in the range of 400–500 nm. The SPR frequency and shape of the spectra depends on the size and size distribution of Ag nanoparticles [39]. UV-Vis spectra of AgNPs from different plants is represented in Figure 1.

The biological method for the synthesis of AgNPs is considered a safe and eco-friendly method [40]. Since plant biomass is utilized for the synthesis, it is also cheap with simple processing. The different sources used for the biogenic synthesis of AgNPs is represented in Figure 2. Ghamipoor et al. (2020) reported a phytochemical extract from *Anthemis nobilis*-produced AgNPs by reducing silver nitrate and further studied the antibacterial activity of the NPs that were environment-friendly, simple process, less-toxic, and inexpensive [41]. There are challenges in nanotechnology while designing an NP such as tailoring the physical properties and controlling the configuration of the particles and the production cost. This may be achieved by an organized production method using bacteria. For instance, Allam et al. (2019) have used the extracts of some bacterial isolates *Bacillus pumilus*, *Bacillus paralicheniformis*, and *Sphingomonas paucimobilis* for producing AgNPs, which were characterized using different techniques and were used for the study of decontamination of wastewater from harmful dyes [42]. Baltazar-Encarnación et al. (2019) have proposed a novel method of producing homogenous shape and narrow size distribution of AgNPs from the supernatant of *Escherichia coli* top 10 cultures without any toxic residues and reported these AgNPs can be used for treating infections caused by nongrowing bacteria [43]. In the stationary metabolic states, the resistance of the bacteria will be higher; hence, it is more advisable in monitoring the growth phase of the bacteria during the production process.

Fungi are considered to be the best biological control agents for any biological processes. Fungai are the most important class of microorganism in terms of industrial applications as they produce larger quantities of enzymes that are useful for processing in many industries. Feroze et al. (2020) have reported the antibacterial activity of AgNPs synthesised from the metabolites of *Penicillium oxalicum* [44]. Aziz et al. (2019) demonstrated the production of AgNPs from a novel fungal strain *Piriformospora indica* and reported their anticancer activity [45]. The most advantageous factors of using fungi for NP production are:

(i) Larger biomass production

(ii) Easy handling

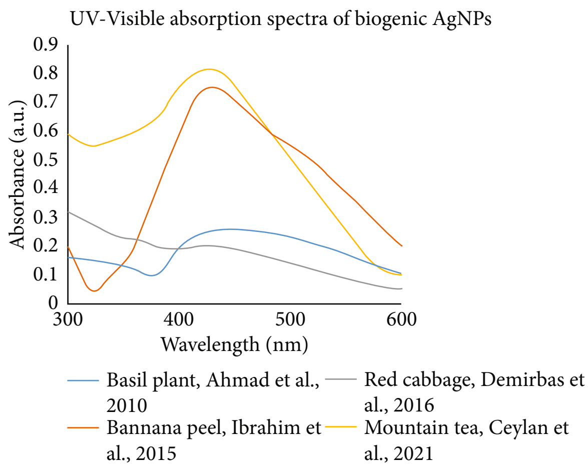


Figure 1: Characterization of the synthesis of AgNPs by UV-vis absorption spectra.

(iii) Their ability to digest or mineralize the compounds that are hazardous to our environment

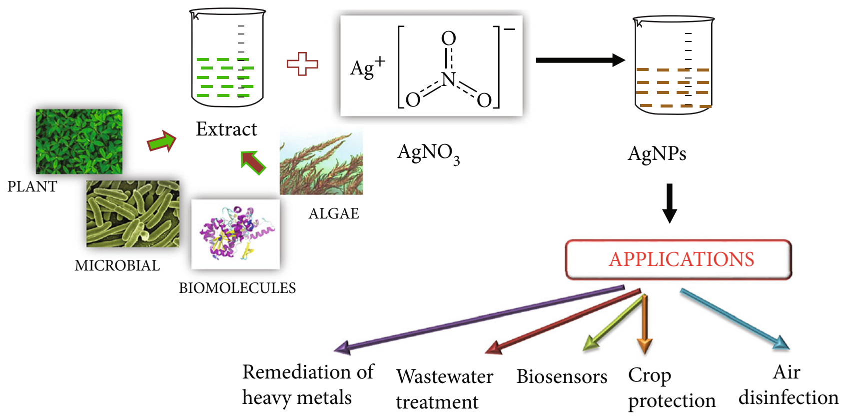
Algae as a source for the production of AgNPs have gained much interest in recent times. Algae involved in the synthesis of AgNPs are of two types, namely, microalgae and macroalgae. The cations within the cellular matrix of algae act as a reducing agent and are majorly responsible for the formation of NPs. For instance, El-Sheekh et al. (2020) have synthesized Ag and AuNPs using *Oscillatoria* sp. and *Spirulina platensis* and reported their *in vitro* antiviral activity against Herps Simplex (HSV-1) virus [46]. *Portieria hornemannii*, a red algal species which is a good antioxidant agent, was used to synthesise AgNPs and their antibacterial activity against a Vibrio species which is a fish pathogen was reported by Fatima et al. (2020) [47]. Seaweeds are a class of algae that comes under the macroalgal division. They are solid, structured organisms, which are found attached on the surface of rocks or sometimes under seawater and on shores. They are composed of a certain class of proteins, polysaccharides, and phenolic compounds. They have a wide range of bioactive compounds; hence, they are used as therapeutic and pharmaceutical agents [48]. For instance, Remya et al. (2016) used *Turbinaria ornata* for the production of AgNPs and evaluated its antitumour activity against retinoblastoma Y79 cells [49].

Phytochemical synthesis is the sought-after method considering availability of the source, ease, and nontoxic process involved. The use of plant-based extracts for the synthesis of silver nanoparticles has gained importance, owing to the production of environmentally friendly and highly stable AgNPs. Plant-based extracts act as both reducing and stabilizing agents. Ahmad et al. (2010) reported rapid synthesis of spherical-shaped AgNPs with an average size ~0 nm, using the broth of dried root and stem of *Ocimum sanctum* [50]. The phytochemicals, phenols, and flavonoids were responsible for the formation and stabilization of AgNPs. *Jatropha curcas* seed extracts have been used to develop an eco-friendly method to produce stable AgNPs [51]. The FTIR studies confirmed the presence of proteins on the surface AgNPs; hence, the proteins present in the seed extract were responsible for the stabilization of nanoparticles. Hydrothermal approaches in combination with green synthesis of AgNPs, using red cabbage extract, were employed by Ocsoy et al. (2017) to produce monodispersed AgNPs [52].

Philip (2010) reported synthesis of Au and Ag nanoparticles from the leaf extract of *Hibiscus rosa sinensis* [53]. The modulation in process variables like metal salt to extract ratio and pH of reaction medium led to the formation of different size and shapes of nanoparticles. Dogru et al. (2017) used different concentrations of *Matricaria chamomilla* flower extract and Ag^+ concentration to synthesize AgNPs of different sizes [54]. However, in another study, conducted by Cruz et al. (2010), the extract concentration, reaction time, and temperature did not cause any significant change in the size and shape of AgNPs synthesized using the aqueous leaf extract of *Lippia citriodora* [55].

Biogenic AgNP composites exhibit enhanced multifunctions as compared to AgNPs alone. Nanocomposite, Ag/HZSM-5 nanocomposite, was synthesized by using aqueous leaf extract of *Euphorbia heterophylla*, which showed excellent catalytic activity for the degradation of organic dyes such as Congo red, Methylene blue, 4-Nitrophenol, and Rhodamine B in water [56]. Ocsoy et al. (2017) reported an eco-friendly approach for the synthesis of AgNPs fabricated on magnetic graphene oxide (Ag@MGO). The Ag@MGO nanocomposites, at low concentrations, was highly effective against *Staphylococcus aureus*, *Escherichia coli*, and *Candida albicans* [57]. Colloidal suspensions of gold nanoparticles (AuNPs), AgNPs, and Au-AgNPs were synthesized using fruit peel extracts for the first time by Shankar et al. (2014) [58]. The nanoparticles exhibited antimicrobial activity and were biocompatible to C2C12 cell lines. Similarly, Khodadadi et al. (2017) used fruit extract of *Vaccinium macrocarpon* to synthesize AgNPs immobilized on the surface of clinoptilolite [59]. AgNPs obtained from banana peel extracts were found to be potent against representative pathogens of bacteria and yeast [60]. The high levels of tannins in the leaf extracts of *Caesalpinia coriaria* led to the synthesis of stable Ag nanoparticles and were potential antimicrobial agents against clinically isolated human pathogens [61]. The AgNPs obtained from dried leaves of *Vinca rosea* exhibited excellent antimicrobial activity against *Staphylococcus aureus*, *Lacto bacillus*, *Escherichia coli*, and *Pseudomonas fluorescens* [62]. AgNPs biofabricated from the extracts of inflorescence of the *Cocos nucifera* displayed enhanced antibacterial activity [63].

Vivek et al. (2014) synthesised AgNPs from *Annona squamosa* leaf extract, which demonstrated dose-dependent cytotoxicity against human breast cancer cell lines (MCF-7) [64]. Nasrollahzaden et al. (2015) used *Euphorbia helioscopia Linn* leaf extract to synthesize silver nanoparticles and was further used as a catalyst to synthesize propargylamine, which acts as a synthetic intermediate for the therapeutic drug molecule [65]. In China, *Cornus officinalis* is a medicinal herb, whose fruit is used to improve kidney function and treat cancer, diabetes, and shock. He et al. (2017) used the fruit of this magic herb to synthesize and biofunctionalize AgNPs [66]. Flavonoids and anthocyanins present



a) Plant sources such as leaves, stem, bark, roots, fruits etc.
b) Microbial sources such as bacteria, virus, fungi
c) Biomolecules such as sugars, enzymes, proteins etc.

Figure 2: Diagrammatic representation of the different sources used for the synthesis of AgNPs.

in the fruit extract played a vital role in synthesis and functionalization of AgNPs. The AgNPs showed cytotoxic activity against human liver cancer (HepG2) and human prostate cancer (PC-3) cell lines. Biogenic AgNPs synthesized from the leaf extract of mulberry, *Morus indica* L.V1, demonstrated antibacterial activity against *Bombyx mori* L. Interestingly, AgNPs did not demonstrate any significant toxic effect against human cell lines, namely, HepG2 and WRL-68, and showed beneficial effects on silkworms [67]. In 2020, Some et al. used leaf extract of *Morus alba* L to synthesize functionalized AgNPs, which displayed excellent antibacterial activity against multidrug-resistant (MDR) bacteria isolated from the gut of infected silkworm. Further, there was no significant change in the cell viability of HEK-293, WRL-68, HUH-7, and ACHN cell lines after treatment with AgNPs [68].

Ponarulselvam et al. (2012) reported the synthesis of AgNPs using leaf extract of *Catharanthus roseus* Linn. G. Don, which exhibited antiplasmodial activity against *Plasmodium falciparum* [69]. AgNPs with an average size of 12 nm were synthesized from the flowers of *Achillea biebersteinii* extracts and showed therapeutic benefits against angiogenesis in the rat aortic ring model [70]. Maji et al. (2017) reported one-step process for the synthesis of AgNPs from the aqueous leaf extract of the medicinal plant, *Alstonia scholaris* [71]. They further studied the interactions between AgNPs and human serum albumin and proved that biogenic NPs are more biocompatible than the chemically synthesized NPs. Red cabbage extract was used by Demirbas et al. (2016) to biofabricate AgNPs, which in turn, decreased the antioxidant activity of anthocyanin towards organic chemical compound 2,2-diphenyl-1-picrylhydrazyl (DPPH) [72]. AgNPs synthesized using the aqueous extract of *Detarium microcarpum* served a dual purpose of sensing toxic heavy metals and also as an antioxidative agent [73]. The green synthesis of AgNPs from *Sideritis* species which demonstrated excellent inhibitory activity against acetylcholinesterase (AChE), butyrylcholinesterase (BChE), and tyrosinase enzyme was also reported [74]. Thus, the biosynthesized AgNPs can be used to treat Alzheimer and skin disease.

Ocsoy et al. (2018) reported biomolecules such as DNA, proteins, enzymes, and other functional groups isolated from living organisms which have been used in the synthesis of inorganic metallic nanoparticles [75]. Ocsoy et al. (2013) synthesized novel DNA-mediated metal NPs (Au/Ag/Cu/Pt) on graphene oxide. The DNA-directed Ag–GO nanocomposites were used to quantify dopamine using zeta potential measurements [76]. Further, it also exhibited significant antibacterial activity against *Xanthomonas perforans*. The same group further investigated the efficacy of Ag@dsDNA-GO nanocomposites in mitigating the bacterial spot disease in tomato, caused by *Xanthomonas perforans*. They found out that lower concentration, 16 ppm, of Ag@dsDNA-GO nanocomposites was effective against the bacteria [76]. In 2016, Strayer et al. used Ag@dsDNA-GO nanocomposites against the bacterial spot disease in tomato plants in greenhouse [77]. They found that 100 ppm of Ag@dsDNA-GO nanocomposite was best in terms of efficacy towards pathogen and less toxic to tomato plants. Karatoprakt et al. (2017) for the first time reported the biosynthesis of silver nanoparticles from *Pelargonium endlicherianum* Fenzl. root extracts [78]. They prepared two extracts, the first extract contained gallic acid and apocynin and the second extract constituted gallic acid, apocynin, and quercetin. The AgNPs prepared from both the extracts demonstrated enhanced antimicrobial activity against *Escherichia coli*, *Pseudomonas aeruginosa*, and *Staphylococcus epidermidis*.

2.4. Mechanistic Aspect of Biological Synthesis of AgNPs.

There are numerous reports on the biogenic synthesis of AgNPs, but only few papers have elucidated the mechanism behind the formation of nanoparticles. The understanding of the underlying mechanism of green synthesis would help in tailoring the size and shape of nanoparticles. However, elaborative studies are required because the exact mechanism is not yet known.

The biomolecules and phytochemicals present in the microbial and plant extracts act as reductant and stabilizer for the synthesized metallic NPs. The general scheme

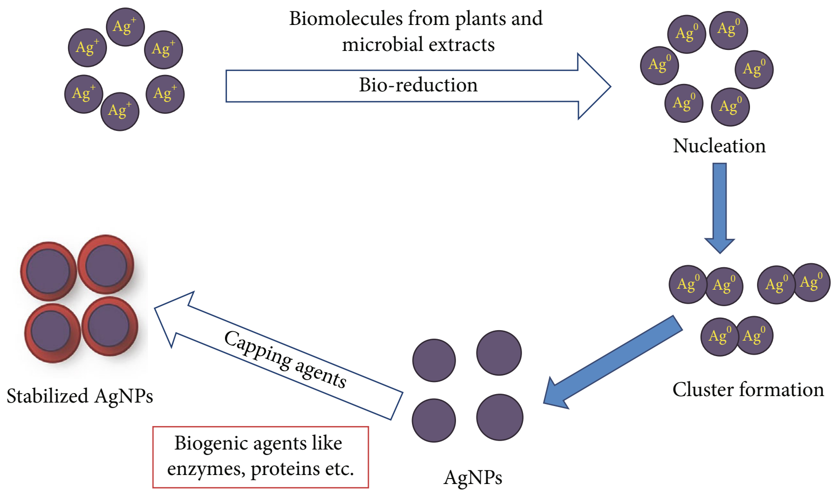


Figure 3: General mechanism of the synthesis of AgNPs.

involved in the synthesis of AgNPs is represented in Figure 3. Huang et al. (2007) reported that polyols and water soluble heterocyclic components present in sun-dried *Cinnamomum camphora* leaves were responsible for bioreduction of silver and chloroaurate ions and stabilization of AgNPs and AuNPs [79]. Similarly, Dhas et al. (2014) through FTIR studies deduced the presence of functional groups on AgNPs surface, synthesized from mangrove leaves *Rhizophora apiculata* [80]. The spectral peaks of aldehydic C–H stretching (2,910 cm^{-1}), C=C group of the aromatic ring (1,600 cm^{-1}) and –OH plane (1,380 cm^{-1}), C–O stretch of phenols (1,226 cm^{-1}), benzene rings (between 1,200 and 900 cm^{-1}), and C–H bond in the phenolic rings (910–740 cm^{-1}). All the spectral peaks are characteristics of polyphenols. The leaves of *Rhizophora apiculata* are rich in polyphenols which act as both reducing and stabilizing agents.

The plausible mechanism for the biogenic synthesis of AgNPs could be explained in following way. The biomolecules present in plant and microbial extracts initiate Ag^+ reduction, followed by the formation of Ag^0 nuclei; this process is called as nucleation. The Ag^0 nuclei starts assembling, leading to the formation of silver clusters. The AgNPs continue to grow until the desired crystallite size is obtained; the size is controlled by the biomolecules present in the plant and microbial extracts. The biomolecules act as both reducing and passivating/stabilizing agents and control the nucleation and growth of Ag cluster [81, 82].The mechanistic aspect is represented in Figure 3.

2.5. Application of the Biogenically Synthesised Nanoparticles. Biosynthesis renders an environment friendly method and also has found its use in several areas of science ranging from sensing contaminants in food, water, soil, crop protection, pesticide applications, waste water treatment, and so on. Some of the relevant applications of the biosynthesised nanoparticles are discussed below.

2.6. Biosensors. Currently, the usage of AgNPs as biosensors has attracted various sectors such as environmental research, food, pharma, and healthcare units. Among these industries, food industries are more predominantly exploring the applications of AgNP-based biosensors. For instance, a protocol for calorimetric detection of caffeine in beverages using AgNP biosensors which were coupled with microspheres have developed [83]. Excess amount of caffeine consumption in human causes serious damage to the nervous system. Hence, these biosensors would be useful in detecting the exact amount of caffeine in beverages that we consume. Another research has developed a method for sensing mercury ions using biologically synthesized Ag nanosensor [84].

In the dairying sectors, these biosensors play a major role in detecting the pathogens that affect the production and storage time and chemical contaminants that affect the quality of dairy products. Apart from these applications, a wide range of biological analyses can be detected using these biologically developed biosensors. Few researchers have reported although the chemical stability of AgNPs is less when compared to AuNPs, AgNPs have excellent sensitivity as a biosensor as their Localized Surface Plasmon Resonance (LSPR) acts as a supporting feature [84].

2.7. Waste Water Treatment. AgNPs generally have a good optical and catalytic property; biologically synthesized AgNPs have even higher catalytic and electrical property. These catalytic properties are most widely used for treating wastewater. Biologically synthesized AgNPs using *Konjac glucomannan* extract which acts as both reducing agents and stabilizing agents and reported that its catalytic degradation of mono-azo and di-azo dyes in wastewater has been reported [85]. This catalytic activity of degrading the contaminants (dyes) can be employed in treating wastewater streams. This will control the release of toxic by-products during the chemical treatment of wastewater. The stem extract of *Coscinium fenestratum* was used to synthesize AgNPs for treating wastewater; the synthesized AgNPs were used in the detection of fungicide Thiram in wastewater by spectroscopic analysis. These AgNPs also reported an excellent property of degrading methylene blue, methyl orange, and naphthol green B acidic pollutants in wastewater [86].

Table 4: Catalytic activity of silver NPs in wastewater treatment.

S. no.	Research group	Source	Pollutant	References
1	Atarod et al., 2016	*Euphorbia heterophylla*	Organic dyes	[87]
2	Veisi et al., 2018	*Thymbra spicata*	Organic dyes	[88]
3	Shaikh et al., 2018	*Azadirachta indica*	Congo dyes	[89]
4	Pawan et al., 2018	Pomegranate fruit peel	Aniline blue dye	[90]
5	Soha et al., 2019	*Duranta erecta*	Nitrophenols and dyes	[91]
6	Lubna et al., 2020	*Terminalia bellerica*	Anthropogenic water pollutants	[92]
7	Gehan et al., 2020	*Anabaena variabilis* and *Spirulina platensis*	Malachite green	[93]

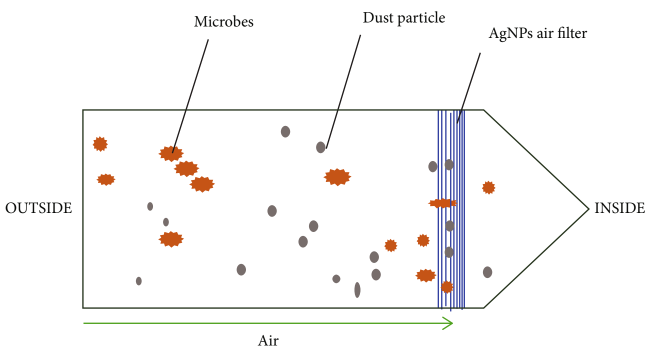


Figure 4: Air disinfectant using AgNPs.

Various catalytic activity of AgNPs is summarized in Table 4 [87–93].

Extracellular production of AgNPs from a cocktail of fungal extract and characterization was performed. During characterization, a functional group has reported antimicrobial activity and was used for disinfection of water during the water purification process [94]. In this study, polyurethane foam, which can be used for large scale industries, was utilized to coat the AgNPs against the pathogens in water. AgNPs have a wide range of physical and chemical properties, which are utilized by many industries and group of researchers for many applications.

2.8. AgNPs for Crop Protection. AgNPs have excellent photocatalytic and antimicrobial activity. Owing to these properties, AgNPs are involved in agricultural industries for crop protection. For instance, Nilavukkarasi (2020) has synthesized AgNPs using *Capparis zeylanica* extract and reported against *Staphylococcus epidermis*, *Enterococcus faecalis*, *Staphylococcus paratypi*, *Staphylococcus dysenteriae* bacteria, and fungi *Candida albicans* and *Aspergillus niger* [95]. Another study has reported the bactericidal and sporicidal activity of AgNPs synthesized using *Litchi chinensis* extract [96]. This study reported that these AgNPs may be commercially utilized as bactericidal and sporicidal agents for protecting the crops and give better yield. The synergistic antifungal activity of the AgNPs synthesized by a biological method using *Ligustrum lucidum* leaf extract and characterized the AgNPs using different techniques [97]. A various group of researchers has been involved in the exploration of AgNPs in the field of agriculture with the help of modern tools and technologies.

2.9. Air Disinfectant. The clean air environment system is gaining more importance after this coronavirus 19 pandemics. It is necessary to filter the air that enters into our environment where we live. Current research on using the antimicrobial ability of AgNPs has grabbed the attention of a various group of researchers and healthcare industries. The mechanism of the silver nanoparticle air filter is shown in Figure 4 [98].

3. Conclusion

Biosynthesis of metal nanoparticles has been of prime importance in the past decade. This review addressed the general views of nanotechnology, types of metallic NPs, different approaches for biosynthesizing AgNPs, and a few environmental application of the AgNPs. AgNPs have unique properties, and thus, they have wider applications. Literature suggested that the size and shape of the AgNPs can be influenced by various parameters that are involved during the synthesis. The ability to control the morphology of the NPs offers the flexibility to construct the nanoparticles according to the researcher's needs. AgNPs were found to be one of the potential metallic NPs for the treatment of wastewater by removing heavy metals and dyes. They are commonly accepted for their antimicrobial property and hence used in the treatment of waste water to eliminate microbes. It has also found wide application as biosensors in the food industry and heavy metal sensing. These biosensors based on nanoparticles are also incorporated in the storage of packed foods. Apart from these applications, they are also used in the agricultural field for protecting the crops by their excellent pesticidal and larvicidal activity. Current research, in controlling the morphology, distribution size of the particle, and other general characteristics of the NPs may further lead the researchers to explore the commercial applications of NPs.

Data Availability

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

Conflicts of Interest

The authors declare no conflict of interest.

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