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REVIEW

Biosynthesis of Silver Nanoparticles and their Antimicrobial Properties: A Review on Recent Advances

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Today, the world is witnessing the rapid advancement of nanotechnology in our everyday life, with numerous applications in energy, medicine, food, water, cosmetics and pharmaceuticals. Synthesis of silver nanoparticle is critical since their use is highly dependent on their form, size, and dispersion. The search for synthetic technologies which are safe for humans and the environment prompted researchers to employ locally accessible biogenic ingredients for silver nanoparticles. silver nanoparticles (AgNPs) are now employed as antimicrobial agents and produced using diverse procedures. This review article reports the green techniques for the synthesis of silver nanoparticles, which are eco-friendly, sustainable and energy-efficient that cause little pollution and pose no health risks. The goal of this article is to highlight and review the application of green synthesis methods that employ biological entities, specifically plants and microorganisms (bacteria, fungus and algae), for the formation of silver nanoparticles and their antimicrobial effect with an emphasis on research done in the previous five years.

Keywords: Nanoparticles, Metallic silver, Biogenic ingredients, Sustainable, Antimicrobial activity.

INTRODUCTION

Material science has fundamentally transformed human existence and got considerably more curiosity in the last decade as the most promising technical breakthrough in nanotechnology [1]. Because of their important characteristics owing to their shape, size and dispersion, nanoparticles play a crucial role in the building of nanotechnology [2]. Photochemicals [3], electrochemical [4], chemical reduction [5] and physical vapour condensation [6] all have been utilized to produce nanoparticles. The dimensions of nanomaterials are ranging from 1 to 100 nm and their major attraction is a high surface-to-volume ratio, which provides them with distinctive and improved characteristics. The shape, size and type of nanoparticles have a major impact on their characteristics and uses. Nanomaterials synthesis with the controlled size is greatly desired since its wide range of uses, most of which are size-dependent [7-9]. Synthesis on a large scale has several drawbacks, including poor stability and monodispersity [10]. Compared to bulk matter, nanomaterials generally have distinct physical, chemical and biological, characteristics. The gap between atomic or molecular structures and bulk materials is bridged by nanoparticles. Nanoparticles are used in nearly every field of research, including energy, space, defense, communication, agriculture and medical, due to their distinctive morphological and physico-chemical characteristics. Nanoparticles are increasingly being used in drug delivery, disease detection, imaging therapy, tissue engineering and cancer therapies [11]. The utilization of nanoparticles in living entities, particularly humans, is essential, and nanoparticles utilized in biomedical applications are preferred to come from natural sources [12]. The present trend of nanoparticles synthesis is going towards the safest option [13], taking into account different variables like bioavailability, biodistribution, biocompatibility and most significantly, biosafety of nanoparticles.

Inorganic and organic are the two types of nanoparticles that may be found in nature. Semiconductor nanoparticles (such as ZnS, ZnO, CdS), metallic nanoparticles (such as Cu, Ag, Au) and magnetic nanoparticles (such as Fe, Co, Ni) make up inorganic nanoparticles, whereas carbon nanoparticles make up organic nanoparticles like (fullerenes, carbon nanotubes, quantum dots). The two main techniques of nanoparticles synthesis are "Top-down" and "Bottom-up." In a top-down

approach, the appropriate bulk material is reduced into tiny particles using techniques such as pulse laser ablation, evaporation-condensation, ball milling and pulse wire discharge method, among others. For the bottom-up approach, nanoparticles may be made with the self-assembly of atoms into new nuclei, which develop into nanoscale particles, utilizing biological and chemical processes.

Among the noble metal nanoparticles, silver nanoparticles (AgNPs) are one of the most effective and most often utilized metal nanoparticles, with characteristics such as greater surface area, small size and good dispersion [14]. They have powerful antioxidant and antibacterial properties [15]. In tiny concentrations, silver metal is extremely toxic to bacterial cells but harmless to mammalian cells [16]. AgNPs are now widely utilized as a potent antibacterial agent against a wide range of bacteria, as well as antibiotic-resistant strains [17].

Chemical reduction, the most common method for AgNPs synthesis in the bottom-up approach [18,19], in which reducing agents, both organic and inorganic such as ascorbate, sodium citrate, DMF, Tollen's reagent, sodium borohydride are used to reduce the metal salts. Capping agents are also employed to keep the size of the nanoparticles stable. One of the most significant benefits of this approach is the ability to synthesis a large amount of nanoparticles in a short interval of time. Due to the use of stabilizers, reducers, capping agents and solvents, which are all hazardous chemicals this approach has been proven to be extremely dangerous and costly for the environment. The use of alternative, ecologically friendly, cost-effective and non-toxic green techniques to synthesis nanoparticles is becoming more popular.

As a result, the development of green AgNPs synthesis is progressing as an important area of nanotechnology, where the use of biological organisms such as plant extract, microorganisms for the generation of nanoparticles could be an environmentally friendly alternative pathway to chemical and physical procedure [20]. While metal nanoparticles (MNPs) are biosynthesized, there are three opportunities to engage in green synthesis, which primarily involves the reduction of salt solution of related metal ion: i) solvent selection, (ii) a nucleation-initiating reducing agent, and (iii) use of capping agent for phase maturation and production of nanoparticles [21-23]. Noble metal nanoparticles can be synthesized using a one-pot approach, which has piqued the interest of many academics. This area is especially inexpensive, uses less energy, saves time and feasible way to manufacture eco-friendly materials which may be utilized in a variety of sectors. Any material's distinctive characteristics may be altered by shrinking its size to the nanoscale. As a result, the characteristics of a nanostructured material might differ dramatically from those of the bulk material, making it suitable for a wide range of applications.

Metal nanoparticles like Ag and copper nanoparticles, in particular, have been linked in a variety of applications, including bioengineering, agriculture and medicine [24-28]. In comparison to chemically produced silver nanoparticles, which require a significant quantity of expensive hazardous chemicals for stability and capping, green synthesis, on the other hand, does not necessitate the use of huge number of these chemicals. It has significantly higher optical stability also [29]. During biogenic synthesis, the capping formation and nanoparticle creation occur simultaneously using organism derived biomolecules, which were utilized in the synthesis, therefore no extra processes are necessary. With the advent of nanotechnology, there has been a surge in interest in silver nanoparticles' antibacterial capabilities as well as methods to employ them in ecologically beneficial ways. The creation of nanoparticles by reduction of metals biologically is a safe, non-toxic and ecologically friendly approach [30].

Researchers are interested in the antimicrobial properties of AgNPs against both fungus and bacterium since silver metal has been utilized as a wound-healing antiseptic. AgNPs have a lot of potential against bacteria and fungi which are multidrug resistant [31] and the antimicrobial function of AgNPs varies depending on the species, thus susceptibility varies as well. Many biomolecules are identified, which are engaged in the process of reducing metals to their nanoparticles. The possible corrective pathways based on these processes are also discussed. The emphasis of this brief review is on current work, mostly from the last five years, to focus and summarize the green synthesis methods, which employ biological entities like plants, bacteria, fungus and algae to fabricate nanoparticles and their antimicrobial applications.

Green synthesis: Green synthesis of AgNPs utilizing a variety of plants, microbes and algae, on the other hand, is natural, biocompatible and ecologically friendly technique. Green synthesis is the manufacture of nanoparticles in an environmentally friendly, non-toxic and cost-effective manner utilizing natural resources like plant extracts, microbes and energy saving techniques [32]. In comparison to the physicochemical techniques, this method produces more stable and efficient nanoparticles. They are environmentally friendly, long lasting, low-cost, and devoid of pollutants. Green nanoparticles are largely contaminant-free, which is a key concern for applications in biology and medicine. The simplicity of large-scale synthesis and the disposal of non-toxic waste products are also advantages [33]. Using natural materials such as enzymes, phytochemicals and biodegradable polymerase reducing and capping agents to substitute for potentially hazardous substances like sodium borohydride, solvent like water during the production of AgNPs concept of Green Chemistry is followed.

Characterization: Biological species functional groups (amine, hydroxyl, carbonyl and thiol) proteins and peptides help in the reduction of precursor salt and convert to nanoparticles, which are refered to as reducing as well as stabilizing agents [34]. They simultaneously cap and stabilize nanoparticles, making this type of production simple, reproducible and stable [35], which are very significant in biological applications [36]. Transmission electron microscopy (TEM), scanning electron microscopy (SEM), atomic force microscopy (AFM) and high resolution transmission electron microscopy (HR-TEM) [37,38] are the most widely utilized microscopic methods for determining the size and morphological characteristics of nanoparticles [39,40].

Plant mediated synthesis: Plant materials may be more advantageous for nanosilver production than bacterial and

chemical techniques since they pose no risk of bacterial and hazardous chemical contamination, use less energy, broader implications and are easier to utilize. Furthermore, the inclusion of functional molecules such as phenol, terpenoids, flavones, ketones, aldehydes, carboxylic acids, amides and enzymes in plant extract-based green production of AgNPs reduces metal ions [41]. Furthermore, no research has been done on the plant-mediated impact of AgNPs with the rice pathogenic bacterium *Acidovorax oryzae*. The utilization of plant extract in biosynthetic reactions for nanoparticle generation was thoroughly explored and reported. Plants are an excellent medium for the production of metal nanoparticles, which form directly by reducing metal ions present in the absorbed soluble salt. At room temperature, aqueous solution of a metal nitrate is treated with plant extract and filtered [42]. A UV-visible spectrophotometer is used to monitor the colour change [43,44]. Fruit, leaves, stem, fruit peels, bark, root, flower and seeds are the components of the plant, which are known to be employed in the production of AgNPs. The fruit is extensively utilized in the production of AgNPs since it includes a lot of secondary metabolites. Fruit has the ability to act as a metal ion reducer and stabilizer [45]. The enormous plant diversity is naturally resourceful that may be used for rapid synthesis of diverse types of nanoparticles in a single-step procedure with a variety of antibacterial activity. Plant-mediated nanoparticles production is relatively quick (a few minutes to hours) and takes place mostly at room temperature, allowing for easy scaling.

Table-1 listed the individual components of several plants utilized in the production of AgNPs. Plant extracts have the benefit over other biological techniques, since they do not require extensive culture or the maintenance of cells. Several research publications and studies have documented the effectiveness of this approach in generating AgNPs with good antibacterial characteristics for a variety of applications [46-80].

Microorganism mediated synthesis: As the enzymes having a negatively charged carboxylate group, metal ions are trapped on the fungal cell wall due to electrostatic forces of attraction. The enzymes then reduce metal ions to produce noble metal nuclei, which then increase through additional aggregation and reduction [81]. Future studies in microbially driven biological production of nanoparticles with distinctive optoelectronics, electrical and physico-chemical characteristics will be necessary for applications in chemistry, medicine, agriculture and electronics. The interaction of metal microbes with released enzymes requires more research [82]. A deeper genetic knowledge of the microbial transformation process will result in the creation of innovative genetic tools to speed up bioremediation [83]. These processes, on the other hand, may aid in the understanding of antibiotic resistance. Antibiotic resistance has become a major problem for contemporary medicine across the world. The usage of metallic nanoparticles in conjunction with antibiotics is one of the most promising techniques for combating the bacterial resistance [84]. Co-existence of metal resistance and antibiotic resistance genes has recently been discovered [85]. Furthermore, metal-reducing microorganisms and mechanisms of extracellular electron transfer may have consequences in renewable energy electro-microbiological applications [86,87]. Redox membrane proteins are used by microorganisms like bacteria and fungi for surface synthesis and enzymes for extracellular synthesis to produce AgNPs [88]. The cell wall is connected to the fungal-mediated method of AgNP production, in which the cell wall, cell membrane and other macromolecules such as proteins and enzymes all play important roles in nanoparticle creation. In *Fusarium* spp., both intracellular and extracellular synthesis may be detected, where the silver ion is trapped by an electrostatic contact on the cell surface and the cell wall enzyme catalysis reduces the silver ions. Microorganisms such as fungus, yeast, and bacteria are used to synthesize nanoparticles because they are largely safe, non-toxic, dependable, clean and ecologically friendly [89-91] and can provide high yields [92-94]. Microbes aid in the production of nanoparticles with narrow size distribution and low polydispersity, as well as metal detoxifying reductase enzyme [95]. The generated AgNPs were stabilized by the electrostatic contact between free cysteine residues or amino groups in fungal proteins and peptides [96,97]. One of the exponential possibilities directed by nature's variant is microbial nano-synthesis to avoid poisonous chemicals and save massive amounts of energy. Yeast strains are preferred to bacterium strains due to their controllability in laboratory settings, availability of various enzymes and fast growth with the application of basic nutrients [98]. Fungi may consume extracellular food and release enzymes that hydrolyze complicated compounds to make them simpler. They produce nanoparticles from metal salts by serving as reducing agents through the release of proteins and enzymes. The mechanism might be extracellular or intracellular. This type of biosynthesis has a lot of potentials since it allows for large-scale manufacture of nanoparticles from a variety of fungus strains, and they can be produced *in vitro*. As intracellular nanoparticles synthesis necessitates additional processing steps, therefore extracellular synthesis is preferred in most microbiological methods. The generated AgNPs were stabilized by the electrostatic contact between free cysteine residues or amino groups in fungal proteins and peptides [96,97]. Microbial nanosynthesis is one of the exponential possibilities pushed by nature's divergence to avoid harsh poisonous chemicals and save massive amounts of energy. The intracellular production of nanoparticles relies heavily on the cell wall of microorganisms. Electrostatic interactions occur between negatively charged cell walls and positively charged metal ions. Metal ions are bioreduced to nanoparticles by enzymes found inside the cell wall and the smaller nanoparticles are then diffused out through the cellular wall. Nanoparticles were first synthesized by bacteria followed by fungi, actinomycetes and more recently by plants. The rate at which biological agents reduce metal ions is shown to be significantly quicker, even at room temperature and pressure. It was recently discovered that nanoparticle production may proceed without the use of the nitrate reductase enzyme [99]. This is intriguing since it opens up the prospect of synthesising nanoparticles utilising a variety of species without the reductase enzyme require-ment for efficient nanoparticle synthesis. There must be a good balance among the quantity of organic material produced by the fungus and the quantity of metal precursor [100,

TABLE-1
LIST OF PLANTS USED FOR SYNTHESIS OF NANOMATERIALS AND FOR ANTIMICROBIAL STUDIES

Name of the source for synthesis	Part of the source used for synthesis	Shape and size (nm)	Type of activity	Active against	Ref.
Grapefruits	Peel	Spherical 55.02	Antifungal	*Rhizoctonia solani*	[46]
Banana	Peel	Spherical 23.8	Antimicrobial	*E. coli* and *P. aeruginosa* *B. subtilis* and *S. aureus*	[47]
Citrus limon	Peel	Spherical 9-46	Antimicrobial	*S. aureus*, *E. coli*	[48]
Rosa indica	Leaves	Spherical 45-85	Antibacterial	*Bacillus subtilis* *Pseudomonas aeruginosa*	[49]
Dillenia indica	Leaves	Spherical 10.01	Antibacterial	*E. coli* and *Enterococcus faccalis*	[50]
Impatiens balsamina *Lantana camara*	Leaves	Spherical 24	Antimicrobial	*Staphylococcus aureus* and *Escherichia coli*	[51]
Plumeria obtuse	Leaves	Spherical and face-centered cubic 8.06	Antibacterial	*Pseudomonas aeruginosa* *Listeria monocytogenes*	[52]
Sesbania grandiflora (Avisa)	Leaves	Isotropic and spherical 24.1	Antibacterial	*Pseudomonas spp* *Staphylococcus spp*	[53]
Carica papaya	Leaves	Spherical 25	Antibacterial	*Acinetobacter baumannii* *E. coli*	[54]
Suaeda nudiflora Mangrove	Leaves	–	Antibacteriali	*Micrococcus luteus,* *Pseudomonas aeruginosa*	[55]
Neem	Leaves	Monodispersed 3	Antibacterial	*Bacillus thuringiensis kurstaki* *Xanthomonas*	[56]
Nervalia zeylanica	Leaves	Spherical 34.2	Antimicrobial	*Staphylococcus aureus* *Penicillium chrysogenum*	[57]
Artemisia monosperma	Fresh plant	Spherical 17	Antibacterial	*Pseudomonas aeruginosa*, *Satphylococcus aureus*	[58]
Green wheat spike	Grass or plant	Spherical 20	Antibacterial	*Klebsiella pneumoniae,* *staphylococcus epidermidis*	[59]
Salacca zallaca	Fruit	Face centered cubic 10	Antibacterial	*Staphylococcus aureus*, *Salmonella typhi*	[60]
Pomelo (*Citrus maxima*)	Fruit	Spherical 12.7	Antibacterial	*Acidovorax oryzae strain* RS-2	[61]
Phyllanthus emblica	Fruit	Spherical 39	Antimicrobial	*Acidovorax oryzae strain* RS-2	[62]
Momordica cymbalaria,	Fruit and Tuber	Spherical 20.35	Antibacterial	*Staphylococcus aureus,* *Pseudomonas aeruginosa*	[63]
Solanum tuberosum	Tuber	Semi-sphere	Antibacterial	*Streptococcus mutons* *Proteus vulgaris*	[64]
Arisaema flavum	Tuber	Spherical 20	Antibacterial	*E. coli* QH4	[65]
Olea ferruginea	Bark	Spherical 23	Antibacterial	*Pseudomonas aeruginosa* *Streptococcus pneumonia*	[66]
Fagus sylvatica L.	Bark	Polygonal and triangular 32	Antibacterial	*Escherichia coli,* and *Pseudomonas aeruginosa*	[67]
Picea abies L	Bark	Spherical 44	Antibacterial	*Staphylococcus aureus* *Pseudomonas aeruginosa*	[68]
Diospyros montana	Bark	Spherical 28	Antibacterial	*B. subtilis* and *S. aureus*	[69]
Illicium verum Hook. F	Extract and essential oil	Spherical 11.46	Antibacterial	*Staphylococcus aureus* *Escherichia coli*	[70]
Calotropis gigantean	Flower	–	Antibacterial	*Bacillus subtilis,* *Pseudomonas putida*	[71]
Abelmoschus esculentus	Flower	Spherical 16.19	Antimicrobial	*B. subtilis, S. aureus*	[72]
Jasmine flower	Flower	Fibre 22	Antimicrobial	*Staphylococcus aureus* *Escherichia coli*	[73]
Lepidium draba	Root	Spherical 24	Antibacterial	*Salmonella typhimurium* and *Escherichia coli*	[74]
Astragalus tribuloides	Root	Spherical 34	Antibacterial	*Shigella flexneri* *Bacillus cereus*	[75]

Kenaf seed	Seed	Spherical 15	Antimicrobial	*Escherichia coli* *Bacillus cereus*	[76]
Berberis aristata	Stem	Spherical 20	Antimicrobial	*Escherichia coli* and *Pseudomonas aeruginosa*	[77]
Garcinia mangostana	Stem	Spherical and monodispersed 30	Antimicrobial	*K. planticola* and *B. subtilis*	[78]
Carthamus tinctorius L	Stem	Spherical 10	Antibacterial	*Staphylococcus aureus* and *Pseudomonas fluorescens*	[79]
Chlorophytum borivilianum L	Calus	Spherical 52	Antibacterial	*Bacillus subtilis* *Candida albicans*	[80]

101]. The processes for the optimization synthesis should allow for large-scale nanoparticle manufacturing to be achieved quickly.

Fungi are appealing agents for the biogenic production of silver nanoparticles because they are metal-tolerant and simple to work with. They also produce enormous amounts of extracellular proteins helping in the nanoparticle's stability. Metabolism of fungus can be regulated by altering growth parameters like time, temperature, pH and biomass amount, in order to generate nanoparticles having the required properties, such as particular size and shape. Generally, the size is determined by the fungal strain, reaction temperature, pH, dispersion media and the capping agents. The fungus must first be cultured on agar before being transferred to a liquid media for the synthesis of silver nanoparticles [102,103]. The biomass is then transported to water, where the chemicals involved in the synthesis are released. The biomass is removed after filtering, and the filtrate is treated with silver nitrate.

Algae are becoming more popular for green synthesis since secondary metabolites, proteins, peptides and pigments are abundant, which may be used as nano-biofactories [104]. They are also ideal candidates for biological nanoparticles synthesis because of their rapid growth rate, ease of harvesting, and scale-up at a low cost [105]. Algae are the most basic creatures on earth, occupying a wide range of habitats and serving as the primary photosynthetic organisms. However, phyco nanotechnology or to synthesize nanoparticles is still in its early stages. Antioxidants, pigments, phycobilins, chlorophylls, oils, minerals, carbohydrates, polyunsaturated fatty acids, lipids, proteins and other phytochemicals are among the biological components found in algae, which help in the reduction of metal ion charge to zero-valent state. Depending on where the nanoparticles are generated, algae based nanoparticles biosynthesis might be intracellular or extracellular. The intracellular approach involves nanoparticles production occurring within the algal cell in a concentration-dependent manner. Reducing agents are NADPH and its depending reductase, which are produced during metabolic activities including photosynthesis, nitrogen fixation, and respiration [106,107]. Metal ions get linked to the surface of algal cells in the extracellular mode of production, and proteins, lipids, DNA, non-protein RNA, pigments, ions and enzymes are examples of metabolites that help in reduction at the surface [108]. Since nanoparticles can be easily purified, the extracellular method of production is more favorable, means it does necessitate certain necessary pre-treatments such as washing and mixing algal biomass [109].

The shape, size and aggregation of nanoparticles are influenced by certain physico-chemical parameters like temperature, pH, initial metal and substrate concentration [110]. Higher pH enhances the reducing capability of functional groups, which inhibits the nanoparticles agglomeration [111,112]. By reacting with the free amine and amino acids groups of surface-bound proteins, basic pH aids in the capping and stability of nanoparticles. AgNPs produced from several red algae strains have been found to be mostly spherical, with sizes ranging between 20 to 60 nm [113]. Red algae, which are members of the Rhodophyta family, are predominantly used as food due to their distinct flavour and high content of essential vitamins and proteins [114]. These proteins and vitamins may be the best candidates for reducing and stabilising the nanoparticles. Because of self-aggregation, sluggish crystallisation growth, and stability problems, the synthesis of nanoparticles from seaweed red algae is still in the developing phases [115,116]. Table-2 listed the individual components of several microorganisms utilized in the production of silver nanoparticles and its activities [117-142].

Antibacterial Properties : Nanomaterials are regarded as a modern pharmacological marvel. Anti-infection drugs are said to destroy around six different disease-causing bacteria, whereas nanoparticles can kill over 650 cells [143]. Most of the scientists believe AgNPs to have fantastic medicinal and pharmaceutical uses because of their remarkable features such as catalytic capabilities, biologic impacts and a high surface-to-volume ratio [144,145]. Several research has shown that AgNPs have significant anticancer and antibacterial properties. AgNPs cause cancer cells to die by destroying their mitochondria as well as their DNA. AgNPs also destroy the bacterial cell film, causing the cell to lyse [146,147]. Because of their high surface area, which allows for greater interaction with microbes and antibacterial activity of AgNPs is superior to that of other salts [148]. *Pesudomonas aeruginosa* Gram-negative bacteria cause infection as a result of prolonged hospitalization and resistant to many antimicrobials owing to its capacity to live in harsh environments. It was observed that the most suitable recognized agent for the control of nosocomial hospital infection is *Pesudomonas aeruginosa* [149,150]. AgNPs allowed for the reduction of antibiotic resistance, which has been a serious public health issue. Methicillin-resistant Gram-positive *Staphylococcus aureus* has the most powerful antibacterial action, along with methicillin-resistant *Staphylococcus epidermidis* and *Streptococcus pyogenes*. Gram-negative bacteria were shown to have moderate antibacterial action.

TABLE-2
LIST OF MICROORGANISMS USED FOR SYNTHESIS OF SILVER NANOMATERIALS AND FOR ANTIMICROBIAL STUDIES

Name of the source for synthesis	Part of the source used for synthesis	Shape and size (nm)	Type of activity	Active against	Ref.
Trametes ljubarskyi and *Ganoderma enigmaticum*	Fungi	Spherical 25	Antibacterial	*Staphylococcus Pseudomaonas putida*	[117]
Penicillium oxalicum	Fungi	Spherical 60	Antibacterial	*S. dysenteriae* and *Salmonella typhi*	[118]
Fusarium oxysporum	Fungi	Spherical	Antibacterial	*Escherichia coli*	[119]
Phomopsis liquidambaris	Fungi	Spherical 18.7	Antimicrobial	*P. mirabilis M. luteus*	[120]
Alternaria sp.	Fungi	Spherical 28	Antibacterial	*Bacillus subtilis Staphylococcus aureus*	[121]
Aspergillus fumigatus	Fungi	Cube-shaped 0.681	Antimicrobial	*Klebsiella pneumoniae Staphylococcus aureus*	[122]
Aspergillus terreus	Fungi	Oval 16.54	Antibacterial	*Salmonella typhi Staphylococcus aureus*	[123]
Aspergillus oryzae	Fungi	7	Antibacterial	*Escherichia coli Bacillus subtilis*	[124]
Penicillium italicum	Fungi	Cluster 33	Antimicrobial	*Vibrio parahaemolyticus Candida albicans*	[125]
Ganoderma sessiliforme	Fungi	Spherical polydisperse 45	Antimicrobial	*Streptococcus faecalis, Listeria innocua*	[126]
Penicillium oxalicum	Fungi	Spherical 40	Antimicrobial	*Staphylococcus aureus Salmonella typhimurium*	[127]
Bacillus megaterium	Bacteria	Spherical 63.8	Antibacterial	*Escherichia coli* and *Staphylococcus aureus*	[128]
Lysinibacillus xylanilyticus	Bacteria	Spherical 30	Antimicrobial	*Vibrio parahaemolyticus Salmonella typhimurium*	[129]
Bacillus brevis	Bacteria	Spherical 41	Antibacterial	*Salmonella typhi Staphylococcus aureus*	[130]
Shewanella sp. ARY1	Bacteria	Spherical 38	Antibacterial	*E. coli* and *K. pneumoniae*	[131]
Sphingobium sp. MAH-11T	Bacteria	Spherical 22	Antibacterial	*Escherichia coli* and *Staphylococcus aureus*	[132]
Pseudoduganella eburnea MAHUQ-39	Bacteria	Spherical 24	Antimicrobial	*Staphylococcus aureus* and *Pseudomonas aeruginosa*	[133]
Terrabacter humi MAHUQ-38T	Bacteria	Spherical 24	Antibacterial	*Escherichia coli* and *Pseudomonas aeruginosa*	[134]
Bacillus subtilis	Bacteria	Spherical, hexagonal 20	Antimicrobial	*Bacillus cereus Candida albicans*	[135]
Gracilaria crassa	Red Algae	Spherical 60	Antibacterial	*Proteus mirabilis, Bacillus subtilis*	[136]
Galaxaura rugosa	Red Algae	Spherical 6	Antibacterial	*Acinetobacter baumannii* and *Staphylococcus aureus*	[137]
Gracilaria birdiae	Red Algae	Spherical 20.3	Antimicrobial	*Escherichia coli Staphylococcus aureus*	[138]
Pterocladiella capillacea	Red Algae		Antibacterial	*Staphylococcus aureus*	[139]
Padina pavonica	Macroalgae	Dendrimeric nanoflower	Antibacterial	*Staphylococcus aureus*	[140]
Hypnea musciformis	Red Algae	Spherical 42	Antibacterial	*Xanthomonas campestris Ralstonia solanacearum*	[141]
Enteromorpha compressa	Green seaweed	Spherical 24	Antimicrobial	*Aspergillus flavus Escherichia coli*	[142]

Salmonella typhi and *Klebsiella pneumonia* [151], possibly as a result of plasmon of the AgNPs in the bacteria's cell wall. *P. aeruginosa* had the greatest zone of inhibition, indicating that AgNPs had remarkable antibacterial action in comparison to Gram-negative rods which are more resistant [152]. These nanoparticles cling to microbe cell walls and membranes, potentially reaching the cell interior. They cause cellular damage, stimulate the formation of reactive oxygen species and disrupt signal transduction pathways. Due to variations in the cell wall structure and availability of functional groups on the cell surface of the various bacteria, the chitosan-Ag colloid exhibits better bactericidal effectiveness against *Escherichia coli* while having relatively moderate action against *Candida albicans* [153]. Due to variations in the cell wall structure and the amount of functional groups on the cell surface of the various bacteria, the chitosan-Ag colloid exhibits better bactericidal effectiveness against *E. coli* while having relatively modest action against *C. albicans*. Due to their greater negative zeta potentials,

oxidized AgNPs gain enhanced stability due to particle repulsion and demonstrate strong antibacterial action against Gram-positive bacteria [154]. The exact mechanism by which AgNPs operate on microbial cells is unknown. The process is thought to be similar to that of silver ions and it includes adhesion and disintegration of microbial membrane, interplay and disruption of biomolecules (nucleic acid, enzymes), and the production of ROS and free radicals, causing cellular oxidative stress.

Conclusion

The biosynthesis of silver nanoparticles (AgNPs) utilizing different plants and microorganism, as well as its reduction using bioactive molecules, has been explored. Since biosynthetic pathway is less harmful and more environmentally benign, the involvement of the reductive chemicals need more research to truly comprehend the surface morphology. The preparation of AgNPs with effective antimicrobial capability from different plants and microorganisms is also highlighted. Given the significance of cappings on the biogenic nanoparticles, more research into their compositions and biological activity is required. The synergy between nanometric silver and biomolecule cappings that are active against certain diseases is expected to be a future breakthrough. It is expected that this brief overview will assist researchers in investigating the prolonged advantages of AgNPs produced by biosynthesis.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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