
An Investigation into the Biosynthesis of Silver Nanoparticles by Fungi, Algae, and Bacteria

Anuj Rai¹, Akansha Singh², Pranjali Thakur³

Assistant Professor¹, Student^{2,3}

Department of Microbiology

Sundaram Institute of Medical Science, Pharmacy

Corresponding Author's Email: pranjalthakur_08@gmail.com

Abstract

*Silver nanoparticles are now widely considered as the industry's cornerstone. Silver, its compounds, and related salts have been around since the dawn of time. Although silver has long been known, it was only recently that the production of silver nanoparticles became a reality. It has several important uses in medicine, agriculture, and other industries. It has strong antioxidant, antibacterial, and antifungal properties. It is effective against a wide range of bacteria, including *Vibrio parahaemolyticus*, *Citrobacter koseri*, *Salmonella Typhii*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus*, as well as a few fungi, including *Candida albicans*. The interaction of silver ions with biomolecules found in cells might be the cause of the process. The entire system is assumed to work on the fact that it causes the formation of free radicals as well as the generation of ROS (reactive oxygen species), which finally results in an apoptotic scenario and therefore the cell's inability to reproduce. Food preservation and cosmetics are two examples of uses. However, physical and chemical Ag production has failed to fulfil demand while causing severe environmental harm. As a result, a more efficient, ecologically friendly, and cleaner method is necessary. The biosynthesis of Ag nanoparticles from plants, algae, and bacteria, among other things, has explored this topic. This review considers similar attempts in recent years.*

Keywords: *Silver nanoparticles; Algae; Bacteria; Fungi; Green synthesis; Toxicity mechanism.*

INTRODUCTION

The surface-dependent properties of nanoparticles differ depending on their shape, size, and morphology. These have a substantial influence on how nanoparticles interact with plants, animals, and microbes [1-7]. The silver nanoparticle has a high antibacterial and antimicrobial impact on bacteria and other microorganisms [8-11]. They are created in a variety of methods in order to investigate all of their facets of qualities [12]. Silver nanoparticles can be produced using a variety of methods, including physical, chemical, and biological methods. A microbe is used in the biogenic production of the nanoparticle, as are fungi, bacteria, yeast, and other plant components in extract form [13-15]. As a result, the properties of the particles formed vary greatly depending on the solvent employed, the intensity of the reducing agent, and the temperature at which metallic ions or compounds are treated to form nanoparticles [10, 11]. Ag and Au have a specific position in the creation of nanoparticles. Although the advantages of silver have long been recognised, it has not been commonly used. Each year, approximately 320 tonnes of silver nanoparticles are expected to be used in diverse applications [16, 17].

Because of negative advances such as the rise of multi-drug resistant bacteria and viruses as a result of multiple human activities such as pollution, which alters environmental circumstances and affects organisms to undergo mutation. Many metal salts and metal nanoparticles have been demonstrated to be antibacterial, but silver stands out [18, 19].

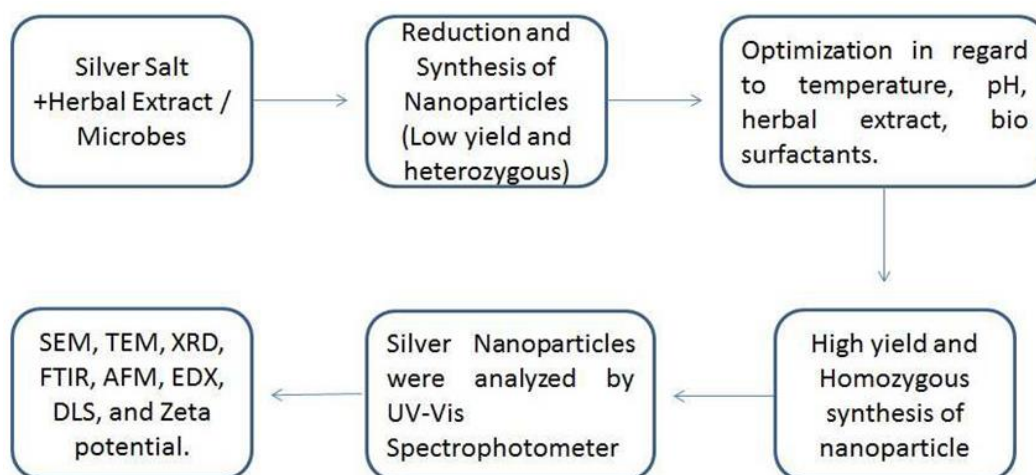


Figure 1. Biosynthesis of silver nanoparticle and their optimization techniques.

The silver nanoparticle has been used not only as a bacterial growth inhibitor, but also to minimise microbial infection in different cuts and wounds [20-22]. A second study found that water-soluble protein obtained from silkworms with a functional group such as hydroxyl, amino, or carboxyl might possibly act as a reducing agent for AgNO₃ solution reduction. Antibacterial experiments demonstrate that the MIC for both gramme positive and gramme negative bacteria is less than 0.001 mM [23-25].

SYNTHESIS AND CHARACTERIZATION OF SILVER NANOPARTICLE

The entire process of producing metallic nanoparticles may be divided into two categories: bottom-up and top-down. Agglomerating atoms and molecules to form nanoparticles is a bottom-up process. At the same time, the top-down method involves slicing or sequential cutting to achieve the nano range of 1 to 100 nm [1]. The bottom-up approach, which comprises a heterogeneous system and the use of several reducing agents and enzymes, is preferred over the top-down approach. The "top-down" strategy is employed when the sample is in bulk form; otherwise, various procedures such as physical ablations, cutting, sputtering, mechanical grinding, and so on are used to achieve a significant level of size reduction. It does, however, have a major imperfection in the form of a surface structural fault, which causes significant property loss. Silver nanoparticles may be produced by a number of methods, including the use of chemicals [26-29], physical breakdown processes [30-32], and biological systems [10, 11]. Several chemical processes, including pyrolysis, electrochemical reduction, chemical reduction, and irradiation, have been recorded to date [33].

In order to generate nanoparticles from solution, a reducing and a capping or stabilising chemical are required. As reducing agents, ascorbic acid, sodium citrate, a hydrazine molecule, and alcohol, among others, can be utilised. A second study demonstrated finely controlled silver NPs deposition over nanostructured SiO₂ [29]. At the same time, the physical methodology has several benefits over the chemical method, such as a narrow size distribution, the absence of dangerous and closely related compounds, and a short processing time, but only at high energy levels. Other methods that might be utilised include arc discharge, [31] physical deposition method, [30] magnetron sputtering [32], and energy ball milling method [34].

In the case of biological nanoparticle manufacturing, plant and microorganism have been

utilised as reducing and capping agents. Plants have been discovered to include a variety of lipids, nucleic acids, pigments, and secondary metabolites, necessitating the capacity to reduce and produce nanoparticles from metallic compounds while creating fewer hazardous by-products. In the case of microorganisms, reduction is caused by the presence of biologically active molecules as well as enzymes [1].

Table 1. List of different stabilizing/capping agent used in synthesis of nanoparticle from various strains of bacteria.

Strains of bacteria	Morphology	Stabilising agent	References
<i>Pseudomonas aeruginosa</i> BS-161R	15.1 ± 5.8 nm; spherical	Rhamnolipids	[35]
<i>Brevibacterium casei</i> MSA19	-	Biosurfactant	[36]
<i>Bacillus cereus</i> NK1	50-80 nm	URAK (a fibrinolytic enzyme)	[37]
<i>Gluconacetobacter xylinum</i>	5-40 nm	Cellulose	[38]
<i>Streptomyces coelicolor</i>	28-50 nm	Irregular Actinorhodin pigment	[39]
<i>Bacillus subtilis</i> MSBN	17-60 nm	Spherical Biofloculant	[40]
<i>Salmonella typhimurium</i>	3-11 nm	Flagellin	[41]
<i>Bacillus athrophaeus</i>	5-30 nm	Polydispersed Spores	[42]
<i>Lactobacillus rhamnosus</i> GG ATCC 53103	2-15 nm; spherical, rodshaped and hexagonal	Exopolysaccharide	[43]
<i>Nostoc commune</i>	15-54nm	Spherical Extracellular	[44]
<i>Pseudomonas aeruginosa</i>	10-13nm;spherical	Biosurfactant	[45]
<i>Ochrobactrum rhizosphaerae</i>	10nm;spherical	Glycolipoprotein	[46]
<i>Gordonia amicalis</i> HS-11	5-25 nm; spherical	Glycolipid	[47]
<i>Bacillus subtilis</i>	-	Surfactin	[48]

NANOPARTICLES FROM BACTERIA

Much progress has been made in the biosynthesis of Ag nanoparticles since the conception of green nanotechnology. *Pseudomonas stutzeri*, isolated from a silver mine, was shown to

create intracellular silver nanoparticles [49], and several other bacteria have been employed to manufacture AgNPs in both extracellular and intracellular settings. *Bacillus calcoaceticus*, *Bacillus flexus*, *Bacillus megaterium*, *Bacillus amyloliquefaciens*, and *S. aureus* [50-53] Ag nanoparticles have been discovered in a range of forms ranging from spherical to cuboidal, hexagonal, and triangular. Nanoparticles might be created using aqueous cell-free extract, cells, and culture supernatant.

In a second investigation, it was discovered that the engagement of a bacterial strain S-27 from the *Bacillus flexus* group might result in the fast creation of silver nanoparticles [53-56]. Das et al. reported the production of silver nanoparticles from 1 mM AgNO₃ and bacteria at 25°C using *Bacillus* strain (CS11). Within 24 hours, a nanoparticle with a peak at 450 nm and a size range of 42 to 92 nm was developed.

NANOPARTICLES FROM FUNGI

Fungi have been widely employed in the manufacture of silver nanoparticles [57-59]. It has been observed that biosynthesis occurs in both pathogenic and non-pathogenic fungus. It causes the production of particles that are either extracellular or intracellular, or both. It has also resulted in silver nanoparticles that are stable in water [60, 61]. Syed et al. performed the synthesis in their study by employing the fungus *Humicola* sp. [62].

Owaidi et al. showed in their work that silver nanoparticles may be created from the yellow exotic oyster mushroom *Pleurotus cornucopiae* var. *citripileatus*. In this technique, basidiocarps are dried, pulverised, and boiled with water before the supernatant is transported for freeze drying. The presence of silver nanoparticles is established when the yellow hue changes to yellow-brownish. In the UV-vis range, the absorption peak is observed to be at 420 and 450nm. [63] *Aspergillus flavus*, *F. solani*, *Phytophthora infestans*, *A. fumigates*, *Phoma glomerate*, *Fusarium oxysporum*, *F. acuminatum*, *F. culmorum*, *Verticillium* sp., *Metarhizium anisopliae*, and *Trichoderma viride* all contribute to particle formation at both extracellular and intracellular levels.

Table 2. Silver nanoparticles synthesis with help of various microorganisms.

Microorganism	Morphology	Location	References
<i>Acinetobacter calcoaceticus</i>	8-12 nm; spherical	Extracellular	[64]

<i>A. haemolyticus</i> MMC8	4-40 nm	Extracellular	[65]
<i>Aeromonas</i> sp. SH10	6.4 nm	Intracellular	[66, 67]
<i>Bordetella</i> sp.	63-90 nm	Extracellular	[68]
<i>Enterobacter aerogenes</i>	25-35 nm; spherical	Extracellular	[69]
<i>Escherichia coli</i>	42.2-89.6 nm; spherical	Extracellular	[70]
<i>Geobacter sulfurreducens</i>	-	Extracellular	[71]
<i>Gluconobacter roseus</i>	10 nm	Extracellular	[72]
<i>Idiomarina</i> sp.	25 nm	Extracellular	[73]
<i>Klebsiella pneumoniae</i>	15-37 nm	Extracellular	[74]
<i>Klebsiella pneumoniae</i>	5-32 nm	Extracellular	[75]
<i>Morganella</i> sp.	10-40 nm; quasispherical	Extracellular	[76]
<i>Proteus mirabilis</i>	10-20 nm; spherical	Extracellular	[77]
<i>Pseudomonas aeruginosa</i>	6.3 ± 4.9 nm; spherical	Intracellular	[78]
<i>Pseudomonas aeruginosa</i>	8-24 nm; spherical	Extracellular	[79]
<i>Pseudomonas aeruginosa</i>	5-25 nm; quasispherical	Intracellular	[80]

NANOPARTICLES FROM PLANTS

Plant extracts derived from leaves, barks, stems, shoots, roots, and seeds, as well as their main and secondary metabolites, can be used for efficient biosynthesis [81]. Recently, extract from the seed of the plant species *Pongamia pinnata* was reported in a study for the green production of silver nanoparticles. The nanoparticles were confirmed further by measuring the absorbance maximum at 439 nm. Karatoprak et al. reported the production of silver nanoparticles from the extract of the plant *Pelargonium endlicherianum* in their work. Another study found that gallic acid, apocynin, and quercetin function together as a possible reducing agent. Moldovan et al. employed an extract from the diet of the plant species *Sambucus nigra* in what is known as phytomediated production of silver nanoparticles [82].

According to Logaranjan et al., Aloe vera extract may be very effective in the formation of silver nanoparticles with very limited morphology and variable in shape and size. It has an absorption peak at 420 nm, confirming the creation of silver nanoparticles. After microwave irradiation, silver nanoparticles in the 5-50 nm range were discovered, each with its own thriving octahedral structure.

Table 3. Synthesis of silver nanoparticles with the help of fungus.

Fungus species	Morphology	Location	References
<i>Humicolasp.</i>	5-25nm;spherical	Extracellular	[83]

<i>Macrophominaphaseolina</i>	5-40nm;spherical	Cellfreeextract	[84]
<i>Penicilliumbrevicompectum</i>	58.35 ±17.88nm	Cellfreeextract	[85]
<i>P.nalgiovenseAJ12</i>	25 ±2.8nm	Cellfreeextract	[86]
<i>Phaenerochaetechryso sporium</i>	5-200nm;pyramidal	-	[87]
<i>Phomaglomerata</i>	60-80nm;spherical	-	[88]
<i>Pleurotusostreatus</i>	< 40nm; spherical	-	[89]
<i>P.sajor-caju</i>	30.5 ± 4.0nm; spherical	Extracellular	[90]
<i>Trichodermaasperellum</i>	13- 18nm;nanocrystalline	Extracellular	[91]
<i>T.reesei</i>	5-50nm	Extracellular	[92]
<i>T. viride</i>	5-40 nm	Extracellular	[93]
<i>T. viride</i>	2-5 nm; spherical 40-65 nm; rectangular 50-100 nm; penta/hexagonal	Cell free extract	[94]

CYTOTOXICITY OF SILVER NANOPARTICLES

Cytotoxicity of any nanoparticle or nanomaterial is a consequence of its size, shape, as well as the stabilising or capping agent, and is notably impacted by the pathogen under study. When compared to their counterpart, biosynthesis is thought to have improved the toxicity of silver nanoparticles against pathogens. Because of the ionic state in which Ag NPs are present, the pathogen is discovered to be more susceptible to silver nanoparticles than other nanoparticles. Initially, Ag NPs will just encapsulate the infection before breaking through and eventually acting as an inhibitor for numerous cellular elements [95-99]. The cytotoxic impact being caused by liberated Ag ions or Ag NPs is still a contentious issue, with opinions divided on both options [100-103].

The cytotoxicity of silver nanoparticles has been attributed to the generation of ROS, which results in a decrease in glutathione levels and an increase in ROS levels [104]. Silver nanoparticles have been shown to be effective against a wide range of pathogens, including

Vibrio parahaemolyticus, *Citrobacter koseri*, *Salmonella Typhii*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and even a few fungi, like *Candida albicans*. It is due to the fact that it has a bigger surface area that allows it to breach the cell membrane and bind to different intracellular locations dependent on its size. Size reduction is inversely related to antibacterial efficacy. Many explanations have been advanced in support of this, but the most compelling is the creation of free radicals, which is supported by absorption at 336.33 in the ESR (electron spin resonance) band of Ag NPs. In another study, it was claimed that because Ag⁺ is smaller in size, it can pass through the cell wall, causing it to rupture, resulting in protein denaturation and death [105-110].

CONCLUSION

Silver nanoparticles have a wide range of applications in both research and development and commercial applications. It has been used in a variety of industries including medicine, agriculture, biosensors, and many more. It has been shown to be cytotoxic to both gramme positive and gramme negative pathogens. It might be used to treat a variety of illnesses, and when combined with an antibody, it could be active against numerous bacteria that have been identified as drug-resistant. Ag NPs have been combined with polymers to provide an effective drug delivery system that is intended to improve medication solubility, stability, and distribution inside the body. Aside from all of the benefits of silver nanoparticles, there are some drawbacks. The long-term effect of these nanoparticles is a wild assumption that must be investigated.

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