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Current green synthesis for silver nanoparticles (AgNPs)

Bui Xuan Vuong*
Sai Gon University, An Duong Vuong Street, District, Ho Chi Minh City, Vietnam

Abstract
Silver nanoparticles are important because of their unique physicochemical and biological properties. Conventional methods for the production of AgNPs are toxic and non-environmental friendly. Therefore, development of the eco-friendly methods for the synthesis of nanoparticles is essential for nanotechnology. The biosynthesis of AgNPs has gained much attention due to the development demand of environmentally friendly technology. Microorganisms are widely used for the green synthesis of Ag NPs such as bacteria, fungi, and plants. This work provides some recent researches on the green synthesis of AgNPs.

Keywords: AgNPs, green synthesis, plant, bacteria, activity

Introduction

Nanoparticles (NPs) biosynthesis is an aspect that is under development for a long time. Nowadays, biosynthesis has attracted the interest of scientists because of the development requirement of eco-friendly environmental technology for material synthesis. “Top-down” and “bottom-up” are two approaches to synthesize NPs. The top-down approach involves the breaking down of the bulk material into nanosized structures or particles by different techniques such as pulse laser ablation, evaporation-condensation, ball milling, etc. Top-down approaches are normally simpler, however, the biggest problem of this method is the imperfection of surface structure. In the top-down approach, evaporation-condensation is the most popular method to synthesized NPs [1, 2]. An alternative approach, which are the potential of creating less waste and hence the more economical, is the “bottom-up”. The bottom-up approach refers to the build-up of material from the bottom: atom-by-atom, molecule-by-molecule, or cluster by cluster. Nanoparticles can be synthesized using chemical and biological methods such as organometallic chemical route, reverse-micelle route, sol-gel synthesis, colloidal precipitation, hydrothermal synthesis, template-assisted sol-gel, which are some of the well-known bottom-up techniques (Table 1). The conventional methods to synthesize NPs are expensive, toxic, and non-ecofriendly. On the other hand, biosynthesized NPs are non-toxic, friendly environmental, and low cost [4]. Therefore, biosynthesized NPs are more suitable for medical applications because of their compatibility compared to chemically synthesized ones. In general, Nanoparticles can be classified into 2 main categories as inorganic and organic NPs. Inorganic NPs are semiconductor NPs such as ZnO, ZnS, CdS; metallic NPs such as Au, Ag, Cu, Al; and magnetic NPs such as Co, Fe, Ni. While organic NPs are carbon NPs like fullerenes, quantum dots, carbon nanotubes [3]. Among different types of nanoparticles, Ag-NPs have received significant attention due to a variety of potential applications in catalyst, [5, 6] biological sensor, [7, 8] water cleaning treatment, [9] and biomedical applications [10–12]. This review describes the recent scientific publication in the green synthesis of Ag NPs and their applications.

Table 1: Different methods to synthesize Ag-NPs. Taken from Rafique *et al* [3].

Synthesis of nanoparticles		
Bottom-up approach		Top-down approach
Green methods	Chemical methods	Physical methods
• Using bacteria • Using fungi • Using plant and their extracts • Using yeast • Using enzymes and biomolecules • Using microorganism	• Chemical reduction • Sonochemical • Microemulsion • Photochemical • Electrochemical • Pyrolysis • Microwave • Solvothermal • Coprecipition	• Pulsed laser ablation • Evaporation–condensation • Arc discharge • Spray Pyrolysis • Ball milling • Vapour and gas phase • Pulse wire discharge • Lithography
Non-toxic	*Toxic*	

Synthesis of Ag-NPs by using bacteria

Rathor *et al.* [13] was successfully synthesized spherical Ag NPs by alkaliphiluc actinobacterium Nocardiopsisvalliformis, with a size range of 5-50 nm. The antimicrobial activity of Ag NPs against Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa, Staphylococcus aureus, and Bacillussubtilis was evaluated. Synthesized Ag NPs showed higher antibacterial activity against all the bacteria tested in the comparison with the commercial antibiotics. The cytotoxicity activity demonstrated a dose-response activity. Extracellular biosynthesis of Ag NPs using Pseudomonas aeruginosa was reported [14]. In this study, Ag NPs were spherical with the distribution size mainly between 25 and 45 nm. The evaluation of the antimicrobial activity of the biosynthesized Ag NPs against human pathogenic and opportunistic microorganism Staphylococcus aureus, Staphylococcus epidermidis, Enterococcus faecalis, Proteus mirabilis, Acinetobacter baumannii, Escherichia coli, P. aeruginosa, and Klebsiella pneumonia was reported. It is found that biosynthesized Ag NPs at picomolar concentration levels showing bactericidal activity against both Gram-positive and Gram-negative bacterial strains. Additionally, biosynthesized Ag NPs showed low toxicity to the host (Figure 1). Another green synthesis of Ag NPs from Escherichia coli was represented by Koiparambil *et al.* [15] The antibacterial activity was investigated using both pellet and supernatant against human pathogens Salmonella typhi, Vibrio cholerae, Bacillus subtilis and Klebsiella pneumoniae. Ag NPs produced by a pellet of Escherichia coli had the most activity.

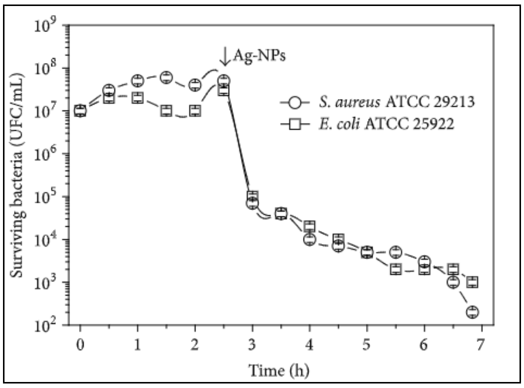

Fig 1: Antimicrobial activity for S. aureus ATCC 29213 and E. coli ATCC 25922 using 0.6 Pm Ag-NPs biosynthesized.[14]

Synthesis of Ag-NPs by using fungi

Feroze *et al*. [16] reported a green synthesis of Ag NPs from fungal metabolites of Penicillium oxalicum. Synthesized Ag NPs were nearly spherical with the average size from 60 to 80 nm. Antibacterial activity of synthesized Ag NPs was checked against Staphylococcus aureus, S. dysenteriae, and Salmonella typhi with the maximum zone of inhibition ± SD 17.5 mm ±0.5, 17.5 mm ± 0.5, and 18.3 mm ± 0.60 respectively at 5 mM dilution of 40 µl. The biosynthesized Ag NPs of Penicillium oxalicum showed excellent activity against these pathogenic microbial strains. Silver NPs were synthesized from dental fungi Candida albicans.[17] The size range of particles was from 50 to 100 nm. Antimicrobial test against pathogens Escherichia coli, Klebsiella sp, Salmonella sp, Pseudomonas sp, and Staphylococcus aureus. The maximum antimicrobial activity was observed for Staphylococcus aureus. An extracellular Ag NPs using Entomopathogenic fungus (Beauveria bassiana) was presented by Tyagi *et al*.[18] Different morphologies of Ag NPs (triangular, circular, hexagonal) with size ranging from 10 to 50 nm were achieved (Figure 2). Optimal conditions for synthesis were also investigated such as temperature, and pH. Antimicrobial activity was checked via growth kinetic of microbes Escherichia coli (gram-negative), Pseudomonas aeruginosa (gram-negative), and Staphylococcus aureus (gram-positive) in control (C) and presence of Ag NPs. Results indicated that Ag NPs exhibited an inhibitory effect on the growth of tested microbes.

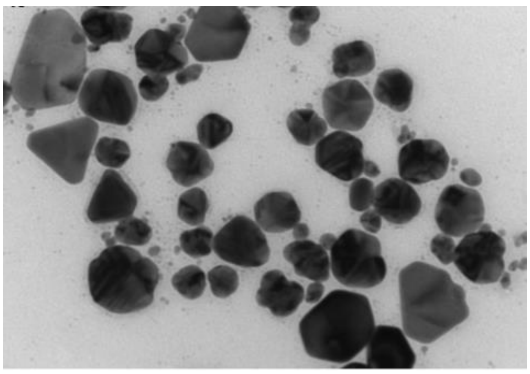

Fig 2. TEM image of Ag NPs synthesized from Entomopathogenic fungus (Beauveria bassiana). Taken from Tyagi *et al*.[18]

Another extracellular synthesis of Ag Nps was studied by Hamad *et al*, [19] using two filamentous fungi Penicillium citreonigrum Dierckx and Scopulariopsis brumptii Salvanet-Duval, isolated from east of Lake Burullus. Ag NPs are mostly uniform in a spherical shape, size range from 6 to 26 nm, and 4.24 to 23.2 nm for Penicillium citreonigrum Dierckx and Scopulariopsis brumptii Salvanet-Duval, respectively.

Antibacterial activity was checked at two concentrations of Ag NPs solution (550.7 and 676.9 mg/l). Silver NPs with the concentration of 676.9 mg/l showed the highest antibacterial activity against fecal coliform.

Hulikere *et al*. reported a green synthesis of Ag NPs by using marine endophytic fungus- Cladosporium cladosporioides which are isolated from brown algae, Sargassum wightii [20]. Particles size ranged from 30 to 60 nm. Ag NPs were monodispersed. Silver NPs could inhibit the growth of bacterial pathogens such as S.aureus, S.epidermis, B.substilis, E. coli, and fungi C.albicans.

Synthesis of Ag-NPs by using plant and plant extracts

Dada *et al*. [21] described a single pot synthesis of Ag NPs using medicinal plant extract of Acalypha wilkesiana. In this study, five parameters including concentration, contact time, volume ratio, pH, and temperature were investigated to find out the optimal condition. Obtained Ag NPs exhibited significant antimicrobial activities against Escherichia coli and Staphylococcus aureus. The zone of inhibition varied from 16 mm to 20 mm. The green synthesis of Ag NPs from Annona reticulate leaves aqueous extract was represented by Parthiban *et al* [22].

XRD analysis confirmed the success of this processing for Ag NPS synthesis (Figure 3). Morphology of NPs was face-centered cubic structure. The size ranged from 6.48 ± 1.2 to 8.13 ± 0.18 nm. Interestingly, synthesized Ag NPs are biocompatible with red blood cells, leading to further investigation in the multidiscipline of biomedical applications.

Zarei *et al* [23]. reported the synthesis of Ag NPs from Caralluma tuberculate extract. Nanoparticles were spherical, with an average diameter of 32 nm. The half-maximal inhibitory concentration in the Caralluma tuberculate extract was 4.722 mg/ml. Antimicrobial activity was tested against S. aureus, B. cereus, P. aeruginosa, and E. coli. The antimicrobial activity of Ag NPs increased at a higher concentration of Ag NPs solution. The inhibition zone strongly depended on the concentration of Ag NPs. In the study of Prajwala *et al*. [24] silver NPs were prepared from Tinospora cordifolia leaf extract. Silver nanoparticles showed a good inhibitory effect on gram-positive and gram-negative bacteria such as Escherichia coli, Pseudomonas syringae, Staphylococcus aureus and Enterococcus faecalis. Agarwal *et al*. [25] synthesized Ag NPs using lemongrass (cymbopogon citratus). The average size ranged of 75 nm. Particles were spherical.

Aggregation of Ag NPs can be occurred because of long incubation period with aggregate size of 138 nm. Anti-diabetic activity of Ag NPs was demonstrated via alpha-amylase inhibitory assay and glucose diffusion retardation assay. The results proved that Ag NPs clearly showed anti-diabetic activity.

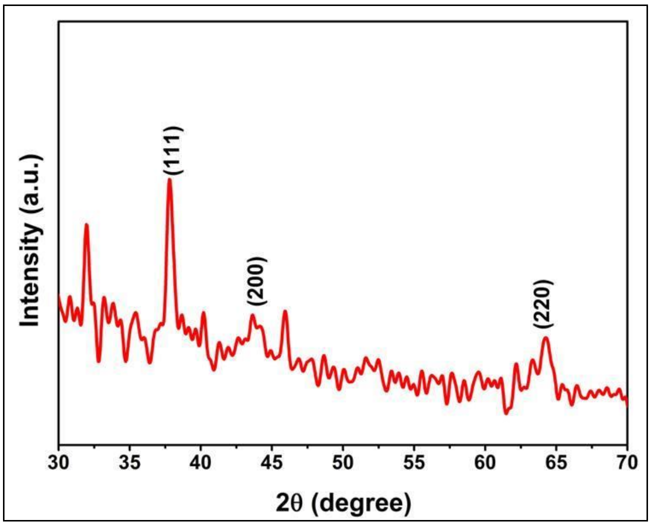

Fig 3: XRD diagram of AgNPs synthesized from Annona reticulate leaves aqueous extract. [22]

Conclusions

Silver NPs have been widely used in a variety of applications. However, their accumulation in the environment negatively impacts humans and animals. Increasing awareness toward green chemistry for Ag NPs synthesis led to a demand to develop eco-friendly methods. Using microorganisms for the green synthesis of Ag NPs is an emerging and attractive area of nanotechnology. In this review, we summarize some recent studies on the green synthesis of Ag NPs. It is worthy to note that biosynthesized Ag NPs are promising candidates for biomedical applications due to their antimicrobial effect.

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