

Brief review on recent outcomes of applications of green synthesis vs chemical synthesis of silver nanoparticles

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Abstract

Silver nanoparticles (AgNP) have been already proposed for many advanced research approaches in the fields of therapeutics and nanomedicine due to their non-antigenicity and more potent optical characteristics along with their respective antioxidant and antimicrobial properties in effective site specific targeted drug-delivery practices systems. In last few years, chemically synthesized metal based nanoparticles has been studied for their biological and delivery behaviours because of use of various chemical and bio-hazardous chemicals in their preparations. Various previous studies on green synthesis of silver metal based nanoparticles have been designed which involved biological sources like microorganisms, plants and herbal extracts as cost effective, eco-friendly and non-toxic approaches. So that, green synthesis of silver nanoparticles has been much exploited in wider range of applications in the field of biomedical, therapeutics, nanomedicine and pharmaceuticals as more potent and safe drug delivery vehicles as compared to chemically preparations of silver nanoparticles. Therefore, in this review, we recollected the comparative studies based on advantages of green approaches of silver nanoparticles over their respective chemical preparations.

Keywords: Silver nanoparticles, Green synthesis, Therapeutics, Nanomedicine, Drug delivery vehicles.

Introduction

These days, bionanotechnology and nanomedicine are considered major thrust areas for clinical and pharmaceutical application because of using various metals or metal based conjugates which in turn, have excellent optical, chemical and biological properties.¹ Nanoparticles synthesised in the range of 100nm have been considered most as drug-delivery agents in various therapeutical, nanodiagnosics, cosmetological, biomedical and pharmaceutical approaches as well as also considered in chemical industries and waste water treatment facilities.² Moreover, in the past few decades, silver nanoparticles also proposed for preparation of more sensitive and advanced biosensors.³

The green synthesis of metal based nanoparticles were carried out by using biotic entities like microorganisms, plants, algae and fungi.⁴ Nanoparticles prepared from herbal and fungal sources are found to more biocompatible with the living system due to presence of bioactive groups when compared with chemically synthesised nanoparticles.⁵⁻⁷

Recently, more advanced green approach have been considered for preparing silver nanoparticle as biological reducing, free radical scavenging and capping agents which found to reduce Ag^+ to Ag^0 .⁸ Hence, a broad range of various biological agents are considered for rapid, safe and green synthesis of silver nanoparticles by using bacteria, fungi/plant extracts, yeast and secondary metabolites.^{9,10} Cost effective standardization of silver nanoparticle size were found to achieve by using fungal agents in the range of 20-80nm.¹¹⁻¹³

Chemically synthesised silver nanoparticles are found to affect membrane permeability that result in the formation of harmful ROS (reactive oxygen species) and cause inflammation in the cells. On the contrary, biologically synthesised silver nanoparticles are biocompatible with the

living system and do not illicit any fatal immune response due to the presence of bioactive group acting as reducers and capping agents.¹⁴ Since these silver nanoparticles are majorly used in sunscreen lotions, ointments, toothpastes and cosmetic products as compared to chemically synthesised silver nanoparticles.¹⁵ Green synthesis of silver nanoparticles via plant extracts or microorganisms is rapid and quick. Secondary metabolites from various biological agents act as reducers and stabilisers thus reducing our dependency on toxic chemicals for preparing silver nanoparticles when their applications are to be subjected in clinical and pharmaceutical studies.¹⁶

Green synthesis of silver nanoparticles

Green Synthesis by using Plants and Phytochemicals

In the past few years, many reports have carried out which were based on use of algal plants, gymnosperms and angiosperms to prepare silver nanoparticles. A marine brown algae was used to prepare silver nanoparticle in the range of 0.5-50nm exhibiting shapes of spherical and polygonal as well as observed for their respective antimicrobial properties [17-20]. Silver nanoparticles prepared from extract of roots of *Delphinium denudatum* have been studied for their respective antibacterial and larvicidal activity against mosquito larvae.²¹ A recent study have been also proposed for green synthesis of silver nanoparticles by using a medicinal plant *Momordica charantia* which further subjected for targeted infections caused by earthworms (*P. posthuma*) and mosquito larvae *A. albopictus* and *A. aegypti*.²² Another study also carried out for the preparation of antibacterial and anticancer anisotropic silver nanoparticles by using leaf extract of *Dodonaea viscosa*.²³ Many other plants like *Azadirachta indica* (Neem), *Tinospora cordifolia* (Giloy) and *Catharanthus roseus* (periwinkle) have been widely used as

biological agents for green preparation of silver nanoparticle.²⁴ Phytochemicals like nimbin, salannin, phenols, triterpenoids, amino acids have also been proposed as capping agents for rapid and biodegradable silver based nanoparticle synthesis by involving more advanced techniques like electro-sonication.²⁵⁻²⁸

Green synthesis by using Bacteria

In many reports, bacteria are considered a safe, environment friendly and non-toxic bio-agents to produce silver based nanoparticles in which lesser amount of toxic by-products were found to reported by minimizing the cost of chosen downstream processing methods because Bacteria are highly resistant to extreme environmental conditions like extreme pH, temperature, salinity and pressure.²⁹⁻³¹ Silver nanoparticle preparations by using bacteria called *Pseudomonas stutzeri* and *Morganella* sp were reported whose particles size observed in the range of 5-20nm and chosen bacterial species produce silver nanoparticles intracellularly and extracellularly respectively.³¹ In another study, *Lactobacillus* strains present in dairy products like buttermilk produced crystalline silver nanoparticles when exposed to extracellular Ag⁺ ions in growth media.^{32,33} Intracellularly, anionic groups like carboxyl groups attached to bacterial cell walls and their organelles are attracted by Ag⁺ ions which undergo bio-reduction by intracellular proteins and co-enzymes to produce silver nanoparticles which reduces its purification processes and in turn reduces the labour cost.³³

Green synthesis by using Fungi

Fungal species have been widely used for synthesis of silver nanoparticles in the range of 4-90nm because of their ability to secrete large quantities of proteins, enzymes and extracellular secondary metabolites which results in rapid bio-reduction of dissolved silver salts resulted in extracellular synthesis.^{34,35} Fungal based green synthesis of silver nanoparticles also have higher metal and metalloid resistance and binding capacity as more potent antibacterial and anti-cancerous bio-agents when compared to bacterial green synthesis.³⁵ In a recent study, a known fungal species, *Botryodiplodia theobromae* was exploited for silver nanoparticles when exposed to silver-salt solution which observed to have ideal cytotoxic activity against breast and lung cancer cell lines.³⁶ Mycosynthesis of silver nanoparticles was proposed from *Fusarium solani*, a phytopathogen attacking onion, when exposed to a 1mM AgNO₃ solution.³⁷ Contrary to bacterial synthesis, reports have also suggested that silver nanoparticles are formed on the surface of the mycelia in mycosynthesis.^{39,40} In a recent study, mycosynthesized silver nanoparticles from *Penicillium oxalicum* were also studied for its use as substituents for conventional antibiotics against strains of *Staphylococcus* and *Salmonella*.⁴⁰ In another study, mycosilver nanoparticles from *Solanum nigrum* showed antifungal activity against plant fungal pathogens like *Fusarium graminearum*, *Fusarium udum*, *Rhizoctonia solani* and *Aspergillus niger*.⁴¹ Hence, scaling up of

extracellular mycosynthesis of silver nanoparticles is found to be easier and cost-effective due to ease in handling of fungal cultures which reduces their respective labour and downstream processing costs are reduced due to extracellular production.

Chemical synthesis of silver nanoparticles

Chemical synthesis of silver nanoparticle synthesis is the most conventional and commonly followed approach by all the leading chemical and pharmaceutical industries in which colloidal dispersions of silver solution is subjected in aqueous or organic solutions.^{42,43} But later, this methodology is found to be highly hazardous and costly due to usage of toxic chemical stabilisers, reducers, capping agents and solvents over the green approach of silver nanoparticles preparation by the scientific community when considered for clinical, biomedical, therapeutics, diagnostic, pharmaceutical and cosmetic applications.⁴³⁻⁴⁵ Chemical reduction is the most common chemical method of silver nanoparticle synthesis in which reduction of metal salts is carried out by organic and inorganic reducing agents like sodium citrate, ascorbate, N, N-dimethylformamide, toluene and sodium polyacrylate are used to reduce Ag⁺ to Ag⁰ to prevent agglomeration and stabilization.⁴⁴⁻⁴⁶ Among other reported chemical methods, microemulsion techniques were also involved for silver nanoparticles preparation by using two immiscible organic phases for separation of metal salt-reducer complex which stabilised by alkyl groups which required huge amount of chemicals.⁴⁵ So, green synthesis does not require huge amount of costly chemicals for stabilization and capping process as compared to chemically synthesized silver nanoparticles which require large amount of costly toxic chemicals. Green synthesis mediated silver nanoparticles are found to have considerable better optical stability as compared to chemically synthesized nanoparticles.⁴⁶ In a recent study, silver nanoparticles were prepared by electrolysis of pure silver-acetate solution and nanoparticles were dispersed in ethylene glycol solution.⁴⁷ And it was also synthesised from electrolysis of silver electrode in presence of a catalytic solution of hydrazine and formaldehyde.⁴⁸

Recent applications of green synthesis mediated silver nanoparticles

The green synthesis of silver nanoparticles has gained wide popularity due to non-toxic approach, its cost-effectiveness, environment friendly properties, biocompatibility, rapid synthesis and antibacterial/anti-parasitic characteristics when compared to chemically synthesized silver nanoparticles. So, Green synthesized nanoparticles have highly preferable for biomedical industry, human health care, textiles, bioremediation and automotive industry over chemically synthesized silver nanoparticles. In recent years, biologically synthesised silver nanoparticles have been proposed for biomedical applications like bio-labelling, magnetic separations, MRI contrast agents, implants and their use in accelerated wound healing.⁴⁹ A recent study has depicted that faster wound healing activity was achieved by

using silver nanoparticles synthesised from seaweed *Caulerpa scalpelliformis*.⁵⁰ These silver nanoparticles also found to have anti-angiogenic and anti-proliferative properties. Anti-proliferative activity was observed from silver nanoparticles obtained from *Derris trifoliata* against lung cancer cell line A549.⁵¹ Imaging application of these silver nanoparticles are also used for wide fluorescence imaging, surface enhanced raman spectroscopy to colorimetric imaging which a unique extinction spectra.⁵² Air disinfection and purification can also be enabled by the usage of these green silver nanoparticles. Development of silver nanoparticle based air filters has used for reduction of biological and particulate matter air contamination.⁵³ Nanoparticles synthesised from medicinal plants are found to have excellent with antimicrobial properties which increase the antimicrobial potential of silver as compared to chemically synthesized nanoparticles.⁵⁴⁻⁵⁷ In a recent study, catalytic degradation of reactive dyes was carried out by using silver nanoparticles which were synthesised from *Eriobotrya japonica*.⁵⁸ In another study, photocatalytic degradation of Methyl Orange and Methylene Blue were also carried out by silver nanoparticles synthesised from flower extract of *Passiflora edulis* which confirmed by spectrophotometric analysis.⁵⁹

Conclusions

This review is based on the most advanced and recent investigations of green and chemical preparation of silver nanoparticles. So, brief informations of this review may helpful to recollect the highlights on advantages of green synthesis of silver nanoparticles to be used as safer, non-toxic, cost-effective, biocompatible and eco-friendly approach over most conventional chemical synthesis of silver nanoparticles. Bacteria, fungi and medicinal plants and other herbal plants species are found to be cheaper sources as well as more potent, biodegradable, antimicrobial and anti-pathogenic agents to prepare silver nanoparticles as compared to chemically synthesized nanoparticles. Green synthesis also found to be economic viable over chemical methods due to minimal use of any hazardous chemicals, costly solvents, involvement of low-cost downstream processing techniques and low labour cost. Hence, green approaches used to prepare silver metal based nanoparticles can be more safe approach as compared to chemically synthesized silver nanoparticles in various applications in cosmetics, therapeutics, biomedical applications, clinical, pharmaceutical, air disinfection process, fumigation, bioremediation and biocatalysis.

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