



Synthesis and applications of plant based silver nanoparticles: A review

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Abstract

Plant-based silver nanoparticles have gained significant interest in recent years due to their unique properties and potential applications in various fields such as medicine, agriculture, and biotechnology. In this review, we discuss synthesis of Silver nanoparticles using different plant extract. The reviewed plant sources include, Aloe vera, Carica papaya, Ginkgo biloba, Ocimum sanctum, Prosopis juliflora, Punica granatum, Boswellia ovalifoliolata, Tilia argentea, Houltuynia cordata, Cannabis sativa, Aegle marmelos and Moringa oleifera. The paper believed that pH, temperature, concentration of Silver ions, reaction mixture, type of plant extracts, ratio of plant extract to silver nitrate solution, light exposure, growth conditions of the plant employed and presence of a reducing agent affect the synthesis processes. The current review indicated that catalytic applications of plant-based AgNPs demonstrated unique and eco-friendly catalytic systems that may be generated from plant extracts and used in a variety of chemical processes and plant-based AgNPs have shown promising results for water treatment among others.

Keywords: extracts, characterization, nanoparticles, silver, synthesis

Introduction

Nanoparticles are particles with a diameter of less than 100 nm. When compared to its constituent larger particles of bulk materials, NPs have new and improved attributes due to specific characteristics such as greater size, dispersion, and form. NPs have a higher surface-to-volume ratio due to their small size. Catalytic activity, as well as other associated features such as antibacterial capacity, require NPs to have a specific surface area (Rakib-Uz-Zaman *et al.*, 2022) [36]. NPs can be produced in a variety of ways, including physical and chemical processes. These processes are expensive and employ a variety of hazardous substances, making them difficult to scale for large production. Because NPs contain plant extracts, animal proteins, agro-waste, colors, bacteria, fungus, and small viruses that are difficult to handle using conventional techniques, green NP production is promoted (Dos Santos *et al.*, 2014) [14]. Plant molecules have been discovered in recent years to be substantially more efficient at performing the identical reduction reactions required for the formation of NPs (Rakib-Uz-Zaman *et al.*, 2022) [36]. Aldehydes, ketones, terpenoids, polyphenols, tannins, polysaccharides, flavonoids, proteins, amines, and alkaloids are examples of bioactive secondary metabolites found in plants. These substances act as stabilizing and capping agents and can reduce metal ions into metal nanoparticles and generate the necessary NPs with previously known advantageous properties (Jalal *et al.*, 2018) [26].

Subsequently, these synthesis procedures call for the employment of hazardous substances (Devanesan and AlSalhi, 2021) [12]. Several research have described the generation or synthesis of AgNPs employing microwave-

assisted, phase transfer, electrochemical, and photochemical methods. The environmentally friendly, straightforward, and simple green synthesis of AgNPs using medicinal plants results in NPs with great potency. Plant-mediated green biomimetic synthesis of AgNPs is regarded as a widely accepted technology for the production of silver nanoparticles quickly and successfully while reducing the generation of or production of hazardous substances to human health and the environment. Plants provide a variety of phytoconstituents that have antibacterial, anticancer, and antioxidant properties, and using plant sources to make AgNPs boosts efficacy while using less of them (Devanesan and AlSalhi, 2021) [12]. A successful synthesis of AgNPs using a green method has also been documented in the literature, *Jatropha curcas* latex was chosen as the reducing and capping agent. In addition, leaf extracts from *Acalypha indica*, *Aloe vera*, and *Garcinia mangostana* have also been used to produce AgNPs. As a reducing agent, *crataegus douglasii* fruit extract and a number of other plant extracts were used (Ghaffari-Moghaddam *et al.*, 2014) [19].

The ability for applications is increased but at the same time, their accurate and repeatable synthesis is essential due to the extreme sensitivity of NPs characteristics to their morphology (Jain *et al.*, 2020) [25]. Lower concentrations of AgNO₃ offer better intrinsic therapeutic prospects, catalytic activity, chemical stability, and biocompatibility than higher concentrations of silver, which are hazardous. AgNPs have been shown to have anticancer and antibacterial activities when compared to bulk metals and their salts (Adebayo *et al.*, 2019) [2]. The controlled and slow release of silver is one of silver nanoparticles' finest qualities. Additionally, Padnya *et al.* (2020) [34] acknowledged the popularity of AgNPs as a

less expensive alternative to pricey gold nanoparticles in their review. AgNPs, apart from being used for medical purposes, are being exploited for their redox stability in biosensors with the assistance of cyclophanes (Padnya *et al.*, 2020) [34].

Green synthesis of AgNPs

Plants are regarded as the inexpensive, low-maintenance chemical factories of nature. Due to the fact that small amounts of these heavy metal traces are toxic even at very low concentrations (Jadoun *et al.*, 2020) [24], plants have demonstrated exceptional potential in heavy metal detoxification as well as accumulation. When creating nanoparticles using plant extract, as opposed to other biological processes like microorganism-based synthesis (Jadoun *et al.*, 2020) [24], it is possible to preserve microbial colonies through a variety of complex processes. Plant-assisted NPs synthesis has the benefit that its kinetics are much higher than those of other biosynthetic methods that are comparable to chemical NP production. Due to the outstanding phytochemicals that different plant parts, including fruit, leaves, stems, and roots, generate, green production of NPs has been widely exploited (Jadoun *et al.*, 2020) [24]. The plant portion that needs to be employed in the formation of NPs can be cleaned and boiled in distilled water. The color of the solution begins to change when the appropriate solutions have been squeezed, filtered, and added, revealing the production of the NPs (Jadoun *et al.*, 2020) [24].

A novel approach to successfully synthesis AgNPs without the disadvantages of chemical and physical production methods has attracted a lot of attention. As a result, the concept of "green chemistry" has gained a lot of attention, especially the ideas that are primarily aimed at replacing the usage of hazardous chemicals (Rakib-Uz-Zaman *et al.*, 2022) [36]. Researchers are working to develop techniques and technologies that will lessen and eventually eradicate substances that are hazardous to the environment and human health (Rakib-Uz-Zaman *et al.*, 2022) [36]. Plant extracts for the biological synthesis of AgNPs have become extremely popular. This plant-based method can be used in place of the conventional chemical methods to assist the general synthesis of AgNPs because it is straightforward in its procedures, simple to monitor, easy to sample, and less expensive (Rakib-Uz-Zaman *et al.*, 2022) [36]. Because they can efficiently replace chemical reduction procedures in production and because the metabolites found in plant extracts may help with the reduction process, plant-based nanoparticles are thought to be environmentally beneficial (Rakib-Uz-Zaman *et al.*, 2022) [36]. Additionally, plants are accessible, simple to grow, as well as safe to handle.

From *Carica papaya* leaf extract, Ankamwar *et al.* (2010) [4] generated AgNPs. The scientists produced AgNPs with an average particle size of 25 nm using *Carica papaya* leaf extract. In a different study, Singhal *et al.* (2011) [43] produced AgNPs from *Ocimum sanctum* (Tulsi) leaf extract and evaluated their antibacterial capabilities. *Prosopis juliflora* bark extract was used in the environmentally friendly produce and characterization of AgNPs (Sivaraman *et al.*, 2012) [44]. The research showed how *P. juliflora* bark extract might be used to produce AgNPs with a size range of 20–40 nm. *Ginkgo biloba* leaf extract was used to characterize and produce AgNPs in a way that protects the environment (Arora *et al.*, 2013) [5]. The study produced

AgNPs with sizes ranging from 20 to 80 nm using *G. biloba* leaf extract. *Punica granatum* peel extract was used to produce AgNPs in a way that is environmentally friendly (Eshrati *et al.*, 2013) [17]. The researchers used *P. granatum* peel extract to produce AgNPs with particle sizes ranging from 10 to 50 nm.

Dhivya *et al.* (2015) [13] investigated the production of AgNPs using stem bark extract of *Boswellia ovalifoliolata* in their study. The researchers employed *B. ovalifoliolata* stem bark extract for generating AgNPs with sizes ranging from 10 to 25 nm. Green synthesis and characterisation of AgNPs utilizing *Tilia argentea* leaf extract, as well as their biological activity (Larimi and Safavi, 2016) [30]. AgNPs with particle diameters ranging from 20 to 40 nm were synthesized using *T. argentea* leaf extract. The antioxidant, antibacterial, and anticancer effects of the produced NPs were established in the study. Wimalasena *et al.* (2016) [48] report on the green synthesis of AgNPs using *Houttuynia cordata* leaf extract and their antibacterial and cytotoxic properties. *H. cordata* leaf extract was employed in this study to synthesize AgNPs with diameters ranging from 20 to 80 nm. Asgarpanah *et al.* (2019) [6] report on the rapid green production of AgNPs using *Cannabis sativa* L. extracts and their antibacterial activities. AgNPs with particle diameters ranging from 10 to 30 nm were synthesized using extracts of *C. sativa* L. The use of *Aegle marmelos* leaf extract in the production of AgNPs, as well as its inhibitory effect on matrix metalloproteinase-2 and -9 activity, was demonstrated (Weerakkody *et al.*, 2020) [47]. - The study demonstrated the synthesis of AgNPs with a size range of 10-30 nm using *A. marmelos* leaf extract.

Conditions for synthesis of plant-based AgNPs

In the process of production of AgNPs, the pH of the reaction mixture is critical. Zhang *et al.* (2019) [50] discovered that alkaline pH levels ranging from 9 to 11 are appropriate for the synthesis of plant-based AgNPs. Another important factor in the formation of plant-based AgNPs is temperature. Lower temperatures ranging from 20-30°C have been reported to be suitable (El-Feky *et al.*, 2020) [15]. The reaction mixture's incubation time is critical in the synthesis of AgNPs. For example, a 48-hour incubation time is sufficient for plant-based production of AgNPs. The concentration of silver ions in the reaction mixture influences AgNPs production significantly. According to Hemmati *et al.* (2019) [21], lower silver ion concentrations ranging from 1 mM to 5 mM are ideal for the synthesis of AgNPs. The type of plant extract employed also has an impact on AgNPs production. *A. vera* leaf extract is an excellent biological agent for the synthesis of AgNPs (Al-Zahrani *et al.* 2020) [3].

A critical aspect is the ratio of plant extract to silver nitrate solution. According to Khan *et al.* (2019) [28], a mixing ratio of 1:10 is ideal for the synthesis of AgNPs. Light exposure is also an important factor in the plant-based synthesis of AgNPs. Debnath *et al.* (2020) [10] discovered that exposing the reaction mixture to direct sunlight speeds up the formation of AgNPs. Furthermore, the growth conditions of the plant employed for synthesis influence AgNP generation. Al-Zahrani *et al.* (2020) [3] discovered that plants cultivated in well-watered, sunny environments produce higher-quality AgNPs. A reducing agent is also required for the production of AgNPs. The presence of a reducing agent, such as ascorbic acid, is required for the production of AgNPs utilizing plant extracts.

Applications of AgNPs

Catalytic application of AgNPs

Because of their unique physicochemical features, nanoparticles have emerged as a critical catalyst. AgNP have received a lot of interest for their catalytic properties. Furthermore, plant-derived silver nanoparticles have demonstrated remarkable catalytic activity in a variety of chemical processes. El-Sayed *et al.* (2019) [16] successfully used AgNP generated from *Moringa oleifera* leaf extract as an efficient catalyst for the epoxidation of olefins such as alpha-pinene, beta-pinene, and styrene. Deghani *et al.* (2020) [11] demonstrated the efficacy of AgNP produced from *Ziziphus spina-christi* leaf extract for arylbromide amination under mild and green conditions. Hooshmand *et al.* (2019) [22] demonstrated the effective utilization of AgNP generated from *Cuminum cyminum* leaf extract as a catalyst for catalytic ozonation of phenolic chemicals. Abbas *et al.* (2020) [1] developed AgNP from *Camellia sinensis* leaf extract and used them as an efficient catalyst for nitroarenes to amines reduction. Jadhav *et al.* (2017) [23] demonstrated the effective usage of AgNP produced from *Syzygium cumini* leaf extract as a catalyst for alcohol oxidation to aldehydes and ketones. Singh *et al.* (2018) [42] developed AgNPs from *Aegle marmelos* leaf extract and used them as a catalyst for the allylic oxidation of olefins to allylic alcohols. Saleem *et al.* (2021) [38] demonstrated the effective utilization of AgNP generated from *Mentha piperita* leaves as a catalyst for the heterocyclization of dienones to produce a variety of bioactive heterocycles. Kadam *et al.* (2019) [27] generated AgNP from *Cassia fistula* leaves and used them as an excellent catalyst for converting sulfides to sulfoxides.

Antibacterial application of AgNPs

Nigella sativa-based AgNPs have shown effective antibacterial activity against drug-resistant bacteria such as Methicillin-Resistant *Staphylococcus aureus* (MRSA) and *Escherichia coli* (*E. coli*) through its phytochemical compounds. The AgNPs are non-toxic and have been used in the treatment of skin infections. Eucalyptus-based AgNPs have shown high antibacterial activity against urinary tract infections caused by bacteria such as *Pseudomonas aeruginosa* and *E. coli* (Singh *et al.*, 2015) [41]. The phytochemicals present in eucalyptus plants along with AgNPs have shown effective results in treating infections. *Aloe vera*-based AgNPs have shown significant antibacterial activity against wound infections caused by *Pseudomonas aeruginosa* and MRSA (Oluwaniyi *et al.*, 2015) [33]. The NPs have also been used for wound healing and tissue regeneration. Turmeric-based AgNPs have shown antibacterial activity against oral bacteria such as *Streptococcus mutans* and *Streptococcus sobrinus*, which are responsible for dental caries (Tamboli *et al.*, 2019) [45]. The NPs have also shown potential in the prevention of dental plaque formation.

Ginger-based AgNPs have shown significant antibacterial activity against skin infections caused by MRSA and *E. coli* (Chun *et al.*, 2017) [9]. The phytochemicals present in ginger along with AgNPs have shown effective results in treating infections. Tea tree oil-based AgNPs have been found to be an effective treatment for acne due to their antibacterial activity against *Propionibacterium acnes*. The NPs have also shown potential in treating other skin infections caused by bacteria (Mohamed, El-Shanawany and Ibrahim, 2019) [32]. Lemongrass-based silver nanoparticles have shown

significant antibacterial activity against foodborne pathogens such as *Salmonella typhimurium* and *E. coli* O157:H7. The nanoparticles have also shown potential in the prevention of bacterial contamination in food products (Rathore, Singh and Pandey, 2016) [37]. Garlic-based AgNPs have shown significant antibacterial activity against *Staphylococcus aureus*, which is responsible for many infections including wound infections, urinary tract infections, and skin infections. The NPs also shown potential in the treatment of drug-resistant bacteria (Sivakumar *et al.*, 2019). Neem-based AgNPs have shown significant antibacterial activity against the malaria parasite. The NPs have also shown potential in the prevention of malaria transmission (Mishra *et al.*, 2019) [31].

Applications of AgNPs in water treatment

Plant-based AgNPs have been used for various environmental applications such as water treatment, waste water treatment, and soil remediation. It has been extensively used for water treatment applications due to their ability to disinfect water and remove contaminants. It has been reported that the plant-based AgNPs possess higher efficiency compared to chemically synthesized silver nanoparticles for water treatment applications. A study by Singh *et al.* (2021) reported that the green synthesis of AgNPs from *Azadirachta indica* leaf extract could remove various heavy metal ions such as lead, cadmium, and arsenic from wastewater. Khan *et al.* (2014) [29] reported that AgNPs synthesized from plants such as *Azadirachta indica* were found to be effective in removing heavy metals such as lead and copper from aqueous solutions. Similarly, AgNPs derived from the plant extract of *Ocimum tenuiflorum* were shown to successfully remove chromium from contaminated water (Gurunathan *et al.*, 2009) [20]. Plant-based AgNPs have been used for the disinfection of water as an alternative to traditional disinfection methods such as chlorination. AgNPs synthesized from the extract of *Eucalyptus camaldulensis* showed significant antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* in water (Tayel *et al.*, 2016) [46]. Plant-based AgNPs have also been found to be effective in the remediation of organic pollutants from water. In a study, AgNPs synthesized from the leaf extract of *Melia azedarach* were used to remove phenol from water with a removal efficiency of 91%.

Plant-based AgNPs have also been used for the removal of dyes from water. In a study, AgNPs synthesized from the leaf extract of *Moringa oleifera* were found to be effective in removing methylene blue dye from contaminated water (Rajakumar *et al.*, 2016) [35]. AgNPs synthesized from the aqueous extract of *A. indica* leaves were found to be effective in reducing the turbidity of water by acting as coagulants and flocculants (Sarijo *et al.*, 2015). AgNPs derived from the plant extract of *Cicer arietinum* were found to be effective in reducing microbial contamination in water by inhibiting the growth of *E. coli* and *S. typhi* (Sharma *et al.*, 2018) [40]. AgNPs synthesized from the extract of *Psidium guajava* leaves have been used in membrane filtration for water treatment. The AgNPs coated membranes showed significant antimicrobial activity against bacteria and fungi.

Plant-based AgNPs have also been used for the treatment of industrial wastewater. A study showed that AgNPs synthesized from the leaves of *A. indica* were capable of degrading textile dye effluent with a removal efficiency of

up to 90% (Sengodan *et al.*, 2015) ^[39]. AgNPs derived from the extract of *Eucalyptus globulus* were found to be effective in reducing the viability of waterborne parasites such as *Cryptosporidium parvum* and *Giardia intestinalis* in water (Farkya *et al.*, 2017) ^[18]. Plant-based AgNPs have been used for the removal of fluoride from contaminated water. In a study, AgNPs synthesized from the extract of *Hydrilla verticillata* showed a high adsorption capacity for fluoride with a removal efficiency of up to 97% (Zhan *et al.*, 2017) ^[49].

Conclusion

Ultimately, plant-based AgNPs are developing as a viable nanomaterial for medicinal, environmental, and agricultural applications. Plant-based synthesis of silver nanoparticles has various advantages over conventional synthesis processes, including being environmentally friendly, cost-effective, non-toxic, and biocompatible. Several factors, including the plant extract selection, solvent, concentration, pH, temperature, and stabilizing agents, have been shown to influence the size, shape, and stability of the synthesized AgNPs. The current review indicated that catalytic applications of plant-based AgNPs demonstrated unique and eco-friendly catalytic systems that may be generated from plant extracts and used in a variety of chemical processes. Overall, plant-based AgNPs have shown promising results for water treatment through a variety of mechanisms, including heavy metal removal, disinfection and removal of organic pollutants and dyes, turbidity and microbial contamination reduction, membrane filtration, industrial wastewater treatment, parasite reduction, and fluoride removal. These plant-based AgNP applications are important in efforts to assure access to clean and safe water for human consumption and industrial use.

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