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CRITICAL REVIEW

# Potentials of roots, stems, leaves, flowers, fruits, and seeds extract for the synthesis of silver nanoparticles

**Nurul Nazirah Saifuddin**[1] · **Shaidatul Najihah Matussin**[1] · **Qazi Fariduddin**[2] · **Mohammad Mansoob Khan**[1]

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## Abstract

Silver nanoparticles (AgNPs) have gained significant attention in various applications due to their unique properties that differ from bulk or macro-sized counterparts. In the advancement of nanotechnology, a reliable, non-toxic, and eco-friendly green synthesis has widely been developed as an alternative method for the production of AgNPs, overcoming limitations associated with the traditional physical and chemical methods. Green synthesis of AgNPs involves the utilization of biological sources including plant extracts with silver salt as the precursor. The potential of phytochemicals in plant extracts serves as a reducing/capping and stabilizing agent to aid in the bio-reduction of $Ag^+$ ions into a stable nanoform, $Ag^0$. This review provides insights into the potentials of various plant parts like root, stem, leaf, flower, fruit, and seed extracts that have been extensively reported for the synthesis of AgNPs.

**Keywords** Green synthesis · Silver nanoparticles · AgNPs · Plant extract · Phytochemicals · Reducing agent

## Introduction

Nanotechnology, predominantly associated with nanomaterials, has extensively contributed to numerous fields of research ranging from biomedical science [1], energy [2], textiles [3], and environmental science [4]. It deals with the production and manipulation of matter (i.e., bulk material, atom, or molecule) by controlling their size and shape into a nanoscale range of approximately 1–100 nm. These nanoscale materials, namely "nanoparticles" (NPs), can effectively enhance its physical, chemical, and biological properties compared to their bulk materials or macro-sized counterparts depending on the size, distribution, and morphology [5]. Generally, NPs can be categorized into metal, metal oxide, carbon based-NPs, and several others [6]. Among them, metallic NPs have drawn considerable attention from many studies due to their unique properties, especially those noble metals, namely silver, gold, and platinum, which have been utilized in a variety and wide-ranging applications, including drugs and medications [7], electronics [8], catalysts [9], and environmental remediation [10]. For instance, several unique properties of gold NPs like exceptionally small size, greater surface area-to-volume ratio, high stability, biocompatible materials, and non-cytotoxicity have led to their extensive application in many fields of biomedicine and targeted drug delivery as stated by Khan et al.[11] Other metallic NPs of platinum recently has shown significant impact in several biomedical applications including anticancer, anti-inflammatory, nano diagnostic, antibacterial, drug delivery, as well as bioimaging [12].

Among those noble metals, silver nanoparticles (AgNPs) are progressively gaining much attention as a prominent nanomaterial. In contrast to their macroscale or bulk particles, nanosized silver offers exceptional properties such as biocompatibility, high stability, good optical properties, and antibacterial, antifungal, and anti-inflammatory activities. This remarkably opens up its opportunity to be incorporated into diverse fields of nanotechnology [5]. A study of the antibacterial activity of synthesized cysteine-capped AgNPs (Cys-AgNPs) was conducted against two pathogenic bacteria, namely *Escherichia coli* and *Pseudomonas aeruginosa*.

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✉ Mohammad Mansoob Khan
mmansoobkhan@yahoo.com; mansoob.khan@ubd.edu.bn
https://scholar.google.co.kr/citations?user=ynzk598AAAAJ&hl=en

[1] Chemical Sciences, Faculty of Science, Universiti Brunei Darussalam, Jalan Tungku Link, Gadong, BE1410, Brunei Darussalam

[2] Plant Physiology and Biochemistry Section, Department of Botany, Faculty of Life Sciences, Aligarh Muslim University, Aligarh 202002, India

It was revealed that Cys-AgNPs acted as a potential antibacterial agent and successfully prevented the growth and reproduction of both bacteria. This opens the potential feasibility of NPs that could be applied in the medical and biotechnological fields [13]. Furthermore, synthesized AgNPs have promising potential in biomedical applications, specifically, for the healing of wounds and coating of biomaterials. This is because the AgNPs show effective antimicrobial activity against three pathogenic bacteria; *Enterococcus faecalis*, *Escherichia coli*, and *Proteus vulgaris* as reported by Wan Mat Khalir et al. [14]

This review aims to provide insight into general synthesis approaches for synthesizing NPs, specifically the AgNPs. The development of an eco-friendly, cost-effective, and biological method or green synthesis of AgNPs has also been emphasized which overcomes the negative effects of the physical and chemical methods. Among biological sources, the utilization of plant extracts has been predominantly reported owing to their active phytochemicals acting as a reducing/capping and stabilization agent for AgNPs of definite size and shape. Therefore, the potentials of different types of plant and plant parts for the synthesis of AgNPs are comprehensively highlighted in this review. Additionally, future perspectives of green synthesis of AgNPs using plant extract have also been discussed.

## Synthesis approach of AgNPs

Mainly, there are two fundamental approaches for synthesizing AgNPs, namely, top-down and bottom-up methods as illustrated in Fig. 1. The top-down approach can be referred to as a process of breaking down bulk material into tiny particles within the nanoscale size range. Conversely, the bottom-up approach refers to a nucleation and growth process of AgNPs from their atom or molecule components by reduction of silver salts with the help of a reducing and stabilizing agent. A control growth of desired AgNPs can be influenced by the use of stabilizers [15, 16].

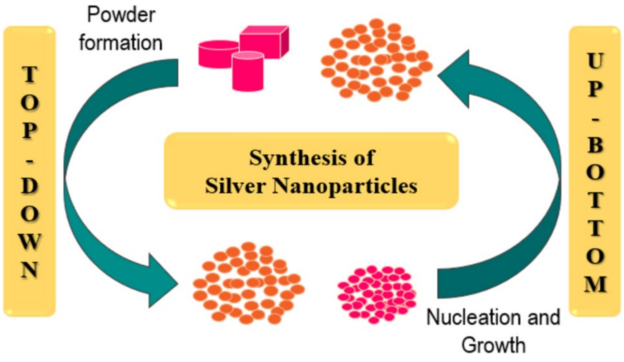

**Fig. 1** Two approaches for the synthesis of AgNPs: top-down approach involves a breaking down of bulky material into tiny particles, while bottom-up approach involves the construction of clusters from an atom or molecular components

As depicted in Fig. 2, there are three synthesis methods of AgNPs that are classified based on the aforesaid approaches, i.e., physical, chemical, and biological synthesis. The physical synthesis method is regarded as a top-down approach comprising various physical techniques such as ball milling [17], laser ablation [18], photoirradiation [19], spray pyrolysis [20], and thermal decomposition [21], to produce AgNPs. A spherical AgNP of size ranging from 2 to 5 nm was produced by irradiating a high laser beam of 532 nm to a target Ag precursor, which was initially immersed in pure water as reported by Pyatenko et al. [22]. Additionally, Pingali et al. reported that AgNPs were successfully synthesized via ultrasonic spray pyrolysis of very diluted aqueous $AgNO_3$ solution at higher temperature (650 °C) and produced NPs 20 nm in size [23]. Physical synthesis is seen as an outstanding method because of its high efficiency, high production rate of NPs, and most importantly an absence of chemical agents or additives. Nevertheless, this method involves high consumption of energy, pressure, and expensive equipment usage, causing a rapid rise in environment temperature, and also an alteration of NPs physiochemical properties may occur due to the absence of capping and stabilizing agents [5, 12, 24].

On the other hand, chemical and biological synthesis is characterized as a bottom-up approach. Some chemical synthesis methods include chemical reduction [25], co-precipitation [26], microwave-assisted [27], and sol–gel method [28]. The most stable AgNPs were synthesized through chemical reduction with glucose and polyvinyl alcohol as reducing and stabilizing agents, respectively, resulting in the spherical shape of AgNPs with particle sizes ranging between 12.28 and 38.45 nm [29]. Nande et al. studied a chemical synthesis of AgNPs by the co-precipitation method, followed by sodium borohydride ($NaBH_4$) as a reducing agent [30]. They observed a color change in the $AgNO_3$ solution indicating a successful formation of AgNPs with a size of ~ 20 nm. In contrast to physical synthesis, the chemical synthesis method is more feasible and cost-effective and produces a high yield of AgNPs, but the exploitation of harmful and toxic chemicals raises a major concern, particularly for the environment and living organisms including human beings [12, 31, 32].

To counter the harmful effects of physical and chemical methods, AgNPs have been alternatively synthesized by a more reliable, non-toxic, and environmentally friendly biological method which is also known as a green synthesis method. As such, utilization of natural or biological materials like microorganisms, bio-wastes, and plant extracts has been used for the green synthesis of AgNPs as shown in Fig. 3. Consumption of safer and non-toxic chemical agents is also required to minimize

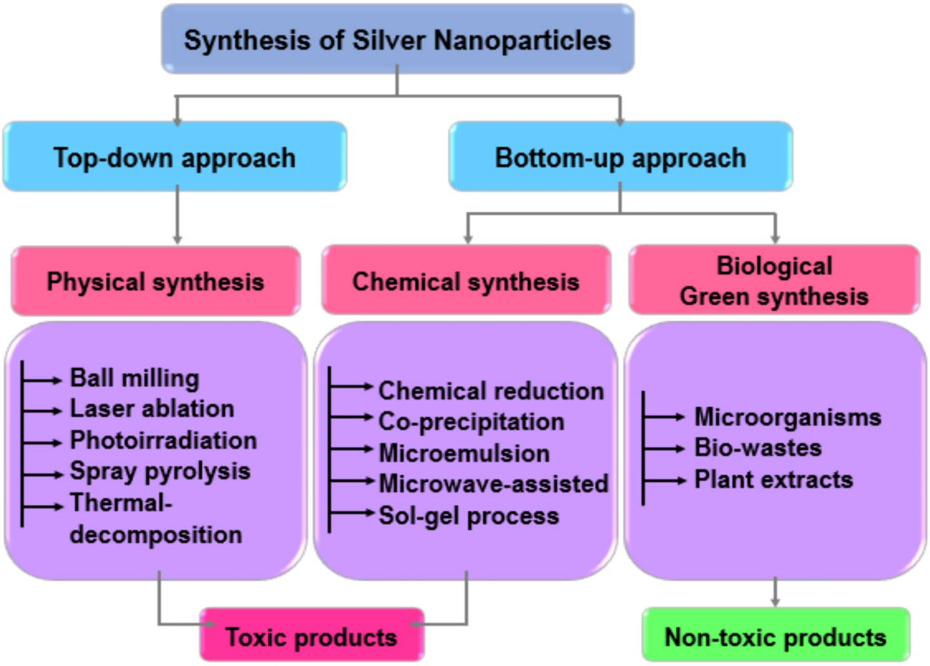

**Fig. 2** The methods used for synthesizing AgNPs based on two approaches. The top-down approach comprises physical synthesis, while the bottom-up approach comprises chemical and biological synthesis methods

the harmful effects of waste or pollution and enhance environmental friendliness as well as the remediation process [33]. Generally, components such as enzymes, proteins, and organic or inorganic substances actively available in the sources serve as reducing and stabilizing agents for silver salts, leading to the formation of the desired size and morphology of AgNPs [32, 34, 35].

Numerous types of microorganisms such as bacteria and fungi have also been used as a viable alternative method for green synthesis of AgNPs. Bacteria have the ability to reduce silver ions either intracellularly or extracellularly and form AgNPs [36]. Some of the bacteria are *Bacillus flexus*,[37] *Bacillus* sp. *AZ1* [38], *Bacillus thuringiensis*,[39] *Gluconobacter roseus*,[40] *Klebsiella pneumonia*,[41] *Lactobacillus bulgaricus*,[42] *Streptomyces hygroscopicus*,[43] *Sporosarcina koreensis DC4*,[44] *Streptacidiphilus durhamensis* [45], and *Staphylococcus aureus*.[46] The presence of proteins or enzymes in bacteria effectively serves as a reducing and stabilizing agent, thus enabling biogenic reduction of $Ag^+$ to $Ag^0$. Fungi, including yeasts, molds, and mushrooms, are eukaryotic microorganisms possessing extracellular proteins that also contribute to the reduction of silver salts and the stability of the developed AgNPs [47]. *Aspergillus tamari* [48], *Aspergillus niger* [49], *Beauveria bassiana* [50], *Cladosporium cladosporioides* [51], *Fusarium culmorum* [52], and *Trichoderma Reesei* [53] are some of the fungi that have been utilized to formulate AgNPs.

**Fig. 3** Some biological sources used in green synthesis of AgNPs: (i) bio-waste: animal waste, vegetables waste, and human hair. (ii) Microorganisms: bacteria, algae, and fungi. (iii) Plant extracts: flower, leaf, fruits, etc.

Moreover, bio-wastes are also among various biological sources that can be used as a source of green synthesis of AgNPs. Different types of bio-waste such as agricultural bio-waste, fruit, and vegetable waste, animal waste, and human hair have been commonly reported

[54–56]. As an example, Akintayo et al. conducted a novel study of biogenic and eco-friendly synthesis of AgNPs using fur extract from domestic goats [57]. They revealed that their synthesized AgNPs were spherical within the range of 11–32 nm. Other bio-wastes such as human hair extract also has been used and produced a spherical shape of AgNPs with variable sizes from 10 to 32 nm as reported by Rohullah et al.[58] Thus, applying bio-wastes for the synthesis of AgNPs is an eco-friendly method whereby reutilizing the wastes can effectively improve environmental sustainability and develop resistance against impacts such as air and water pollution, climate change, etc.[59, 60].

## Potential of plant extracts for green synthesis of AgNPs

Green synthesis using plant extract has gathered the most attention and interest in current research for synthesizing various nanomaterials including AgNPs. Plant extracts are most readily obtainable among other biological sources. It is a relatively simple, convenient, and feasible process to produce a higher yield of AgNPs with controlled size and morphologies. Figure 4 and Table 1 show different types of plants and plant parts that have been extensively used as potential sources for synthesizing AgNPs which are deliberated briefly in the present review.

**Fig. 4** Different plant types and plant parts that have been used for green synthesis of AgNPs: fruit, flower, leaf, etc.

**Table 1** Summary of plant extract used to synthesize AgNPs with their shape morphology and size

| Plant species | Plant extract | Shape | Size (nm) | Refs |
|---|---|---|---|---|
| *Areca catechu* | Nut | Spherical | 15–20 | [61] |
| *Citrus aurantifolia* | Juice | – | – | [62] |
| *Cornus officinalis* | Fruit | Spherical, polygonal | 50–60 | [63] |
| *Dracocephalum moldavica* | Seed | Spherical | 5–50 | [64] |
| *Entada spiralis* | Stem | Spherical | 18–19 | [14] |
| *Musa paradisiaca* | Peel | Spherical | 23.7 | [65] |
| *Persicaria hydropiper* | Leaf, stem, roots | Tetrahedron, spherical, oval | 32–77 | [66] |
| *Prunus africana* | Bark | Spherical | 17 | [67] |
| *Senna siamea* | Leaf | Triangular, hexagonal, rod shaped, oval, spherical | – | [68] |
| *Zingiber officinale*<br>*Curcuma longa* | Rhizome | Spherical | 42–61 | [69] |
| *Moringa oleifera* | Gum | – | 50 | [70] |
| *Malva sylvestris* | Flower | Spherical, hexagonal | 20–40 | [71] |

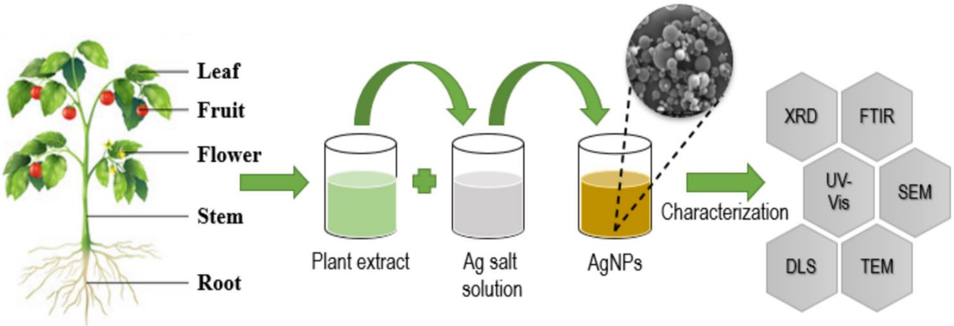

**Fig. 5** General procedures of the green synthesis of AgNPs using plant extracts

In producing AgNPs using plant extracts, the procedures can be summarized as shown in Fig. 5: preparation of an extract of plant sources using suitable solvent (water, methanol, or acetone), which is then mixed into a silver salt precursor based on various reaction conditions, for instance, solvent, both plant extract and Ag salt concentration, temperature, and pH conditions. A color change in the reaction mixture effectively indicates the presence of AgNPs. These could be further examined and characterized by their surface plasmon resonance peak, morphology, and size using several analysis instruments including UV–visible spectroscopy, FTIR spectroscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM), and several others.

## Phytochemicals in plant extracts

Plants, specifically diverse parts of plants, possess an abundance of different active biomolecules known as phytochemicals which play a vital role as a protective agent allowing proper growth and function for plants to live [72]. Phytochemicals can be categorized into several groups of organic and inorganic compounds depending on their biosynthetic classes: nitrogen-containing compounds (alkaloids), phenolic (flavonoid), terpenes, saponins, steroids, and several others. In terms of synthesizing AgNPs, the phytochemicals in plant extracts are shown to be a major part of the green synthesis process, whereby the compounds are actively responsible for the formation, reduction, and/or stabilization of AgNPs, metallic $Ag^0$, from silver salts, and $Ag^+$ ions. Table 2 displays several studies that reportedly found phytochemicals in plant extracts utilized in the green synthesis of AgNPs. However, none of these studies could clearly identify the exact mechanisms of AgNPs formation related to the compounds.

Despite that no studies have clearly stated the exact mechanism of the reduction of $Ag^+$ ions to $Ag^0$ NPs, it

**Table 2** Green synthesis of AgNPs using various plants extracts with their phytochemical compounds responsible for the reduction of Ag salts

| Plant species | Plant extract | Phytochemical compounds | Shape and size | Refs |
|---|---|---|---|---|
| *Acalypha wilkesiana* | Leaf | Phenols, triterpenes, saponins, flavonoids | Spherical; 10–26 nm | [73] |
| *Averrhoa carambola* | Fruit | Proteins, enzymes, polysaccharides, amino acids, vitamins, ascorbic acid | Spherical; 10–40 nm | [74, 75] |
| *Citrus aurantifolia* | Peel | Alkaloids, flavonoids, tannins, saponins, phenols, terpenoids, steroids, 1,2,4-benzenetricarboxylic acid, fumaric acid, nonyl pentadecyl, 4-methyl-2-trimethylsilyloxy-acetophenone | Spherical; 24.023 nm | [76] |
| *Chrysanthemum indicum* | Flower | Flavonoids, terpenoids, glycosides | Spherical; 37.71–71.99 nm | [77] |
| *Hagenia abyssinica* | Leaf | Alkaloids, tannins, flavonoids, saponins, cardiac glycoside, phenols, anthraquinones | – | [78] |
| *Jatropha integerrima Jacq* | Flower | Anthocyanin, carbohydrate, coumarin, glycoside, phenol, protein, saponin, and tannin | Spherical; 50.07 nm | [79] |
| *Piper chaudocanum* | Stem | Pentacosanoic acid, piperine, β-sitosterol, campesterol glucoside | Irregular; 8–12 nm | [80] |
| *Putranjiva roxburghii* | Seed | Alkaloids, flavonoids, amino acids, proteins, saponins, fats, oils | Spherical; 13–69 nm | [81] |
| *Sesamum indicum* | Seed | Alkaloids, phenols, steroids, flavonoids, diterpenes, glycosides, and tannins | Spherical; 14–48 nm | [82] |
| *Tropaeolum majus* | Leaf | Alkaloids, tannins, flavonoids, terpenoids, cardiac glycoside | Cylindrical; 25 nm | [83] |
| *Urtica dioica (Linn.)* | Leaf | Proteins, phenols,<br>diterpenes, and phytosterols | Spherical; 20–30 nm | [84] |

can be stated that the formation of AgNPs is due to the reducing capabilities of the phytochemicals. As compiled in Table 1, different phytochemicals are present in different parts of a plant. In one study, the authors proposed the mechanism of the formation of AgNPs using phytochemicals in two ways: with and without light [85]. With light, the formation and stabilization of AgNPs were most likely due to catechin-like polyphenolic tannins. In this pathway, catechin contains two different pharmacophores which are catechol and resorcinol. It was reported that the catechol group was more readily oxidized. On light exposure, the phenolic O–H bond undergoes homolytic cleavage and generates hydrogen radical, followed by electron transfer from hydrogen radical to $Ag^+$ ions resulting in the formation of AgNPs. However, the formation of AgNPs without light irradiation was simply due to the formation of phenolates from polyphenols in catechin. The phenolates are reported to be easily oxidized than phenol which aided in the reduction of $Ag^+$ ions [86]. Therefore, the types of phytochemicals are responsible for the reduction of $Ag^+$ ions to $Ag^0$ via different mechanistic pathways.

## Synthesis of AgNPs using leaf extract

As the most abundant, non-seasonal, and easily obtainable part of a plant, leaves have gained the attention of many studies and researchers. Among various parts of a plant, leaf extracts have been extensively selected as a great potential source in the green synthesis of AgNPs. Besides, an essential role of leaves is carrying out the photosynthesis process. Green leaves contain a higher concentration of chlorophyll, a most abundant light-absorbing pigment that significantly supports and derives photosynthetic processes [87]. Therefore, leaves are considered a fundamental part of a plant because bioactive pigments, phytochemicals, and other important nutrients for a plant to survive are mostly stored in the leaves than other parts of a plant.

The reducing agent of leaf extracts from diverse types of plants that have been utilized for AgNPs production are listed briefly in Table 3. Kaur et al. carried out a study of green synthesis of AgNPs from *Litchi chinensis* leaf extract (LCLE) as follows [88]. In short, 3.0 g of washed, dried, and powdered leaves were boiled in 50 mL of water for about 20 min and the resulting extract was filtered. Upon AgNPs synthesis, LCLE solution (15 µL) was added to 6 mL

**Table 3.** Various types of leaf extract used for the green synthesis of AgNPs

| Plant species | Plant extract | Shape | Size (nm) | Refs |
|---|---|---|---|---|
| *Aloe vera* | Leaf | Cubical, rectangular, triangular, and spherical | 70 | [91] |
| *Atrocarpus altilis* | Leaf | Spherical | 38 | [94] |
| *Azadiratcha indica* | Leaf | Spherical | - | [95] |
| *Cassia fitsula* | Leaf | Spherical | 40–50 | [96] |
| *Cinnamomum tamala* | Leaf | Spherical | 7–15 | [97] |
| *Crotolaria retusa* | Leaf | Spherical | 80 | [98] |
| *Croton sparsiflorus morong* | Leaf | Spherical | 16 | [99] |
| *Diospyros lotus* | Leaf | Spherical | 20 | [100] |
| *Grewia flaviscences* | Leaf | Spherical | 50–70 | [101] |
| *Holoptelea integrifolia* | Leaf | Spherical | 32–38 | [102] |
| *Leptadenua reticulata* | Leaf | Spherical | 50–70 | [103] |
| *Melia azedarach* | Leaf | Spherical | 23 | [104] |
| *Momodica charantia* | Leaf | Spherical | 16 | [105] |
| *Mukia maderaspatana* | Leaf | Spherical | - | [106] |
| *Myrsine africana* | Leaf | Spherical and oval | 28.32 | [107] |
| *Platycodon grandiflorum* | Leaf | Spherical | 19–21 | [108] |
| *Prosopis farcta* | Leaf | Spherical | 10.8 | [109] |
| *Prunus yedoensis* | Leaf | Spherical and oval | 20–70 | [89] |
| *Psidium guajava* | Leaf | Spherical | 40 | [110] |
| *Rhizophora mangle* | Leaf | Polydisperse | 30 | [111] |
| *Skimmia laureola* | Leaf | Spherical and hexagonal | 46 | [90] |
| *Tectona grandis* | Leaf | Spherical | 26.36 | [112] |
| *Terminalia chebula* | Leaf | Spherical | 10–30 | [97] |
| *Terminalia arjuna* | Leaf | Spherical | 8–16 | [113] |
| *Trigonella foenum-graecum* | Leaf | Spherical | 20–25 | [114] |

of 1 mM of an aqueous solution of $AgNO_3$ until a color change was observed signifying the formation of AgNPs. The study also assessed several experimental conditions by varying the reaction temperature, time, concentration of $AgNO_3$, and amount of leaf extract added. They concluded that 15 µL of LCLE effectively reduced 90% of $AgNO_3$ to AgNPs at 40 °C in 10 min. X-ray diffraction (XRD) analysis revealed a mean crystallite size of AgNPs of 22 nm through the Debye–Scherer equation. Besides, the NPs were mostly spherical shaped, approximately 43 nm in size as consecutively shown by dynamic light scattering (DLS), TEM, and SEM analysis. According to FTIR, *Litchi chinensis* leaf extract contains phytochemicals such as flavonoids, phenol, hydroxyl, and amide that were responsible for promoting the formation of AgNPs in the solution as potential reducing and stabilizing agents. They showed that the mechanisms involved the reduction–oxidation process of a polyphenol compound, epicatechin, which initially reacts with $Ag^+$ ion and forms a complex. The complex was then further oxidized to quinone, leading to the reduction of $Ag^+$ ions into Ag atoms.

Spherical and oval-shaped AgNPs with a mean size ranging from 20 to 70 nm were produced from an aqueous *Prunus yedoensis* leaf extract as described by Velmurugan et al. [89]. The green synthesis was performed by mixing the leaf extract with $AgNO_3$ precursor under ambient temperature. The initial pale-yellow color turned dark brown with a yellow shade within 10 min, confirming an effective reduction of silver ions in the mixture. The precipitate obtained was separated by centrifugation and the resulting pellet of AgNPs was repeatedly washed in nanopure water to remove any unwanted entities. For characterization, XRD analysis indicated a cubic crystal structure of their synthesized AgNPs that was crystalline in nature. The authors also found clusters of particles; mostly the AgNPs formed were spherical with smooth edges and some were irregular spherical in shape as visualized by Bio-TEM images. In addition, FTIR data showed that phytosterol, flavonoids, alkaloids, triterpenoids, and amino acids in the plant extract itself were found, which actively take part in the conversion of $Ag^+$ ions into nano forms due to the presence of functional groups such as –OH, –CN–, and C–N of the amide and amine groups.

Ahmed et al. conducted a study using *Skimmia laurolea* leaf extract which produced an irregular spherical and hexagonal shape of AgNPs with a mean size of 46 nm [90]. Based on FTIR analysis, the reduction of bands of the aqueous leaf extract after synthesis reaction at some frequencies confirmed that the corresponding phytochemical might serve as a main reducing and capping agent. They proposed that skimmidiol was one of the phytochemical constituents participating in the formation of synthesized AgNPs. This is because hydrogen atoms and electrons are released from the compound, effectively reducing $Ag^+$ ions into $Ag^0$. Furthermore, the ability of water-soluble phytochemicals in the leaf extract of *Skimmia laurolea* such as flavonoids and terpenoids to cap and stabilize the AgNPs at definite size and shape has also been mentioned. Medda et al. successfully prepared AgNPs from *Aloe vera* leaf extract with uniform distribution and particle agglomeration. SEM images found that the synthesized AgNPs were cubical, rectangular, triangular, and spherical in shape with agglomerated size within the range of 287.5 to 293.2 nm, whereas an individual particle showed a mean size of approximately 70 nm [91]. The presence of weak capping agents might be a reason that led to the formation of unstable AgNPs with different morphologies and agglomeration. On the other hand, the report found proteins to be the main capping and stabilizing agent for AgNPs formed as observed by FTIR spectra. Their amino acid residues strongly interacted with other bio-organic molecules via hydrogen bonds and subsequently absorbed the Ag metal strongly resulting in the formation of a layer [92, 93]. This further corroborates that proteins have the potential to provide stability and prevent further agglomeration of AgNPs.

Based on the compilation above, it was found that the particle sizes of AgNPs are small. This suggests that the presence of the phytochemicals acted as the capping agent which controlled and reduced the particle growth [90, 115]. As discussed in "Phytochemicals in plant extract", the phytochemicals are responsible for reducing $Ag^+$ ions to $Ag^0$. Apart from that, the phytochemicals also act as the stabilizing and capping agents. Varying the concentration of plant extract would influence the particle size and shape as reported in one comprehensive study [116]. For instance, at higher concentrations of plant extract, larger clusters of particles were formed. This might be due to a very high localized concentration of reducing reagents in the solution. Moreover, these larger clusters appeared as irregularly shaped particles. It can be concluded that the concentration of the plant extract plays a crucial role in determining the particle size and shape of AgNPs.

## Synthesis of AgNPs using fruit extracts

Fruit can be defined as a ripened ovary or edible part of a flowering plant, essentially providing protection and successful dissemination of seeds [117]. Apples, avocados, cucumbers, peaches, and tomatoes are some of the examples. Fruits are also considered a vital component in providing a healthy effect and preventing diseases due to nutrients, minerals, fibers, and bioactive phytochemicals, predominantly, carotenoids, phenolics, polyphenols, flavonoids, and several others [118]. With regard to NPs synthesis, these compounds may also potentially contribute to the reduction and formation of AgNPs. Table 4 shows some fruits that have been used for green synthesis of AgNPs.

**Table 4** Various types of fruit extract used for the green synthesis of AgNPs

| Plant species | Plant extract | Shape | Size (nm) | Refs |
|---|---|---|---|---|
| *Abelmoschus esculentus (L.)* | Fruit | Spherical | 3–11 | [129] |
| *Anacardium occidentale* | Fruit | – | 51.9 | [130] |
| *Azadirachta indica L* | Fruit | Spherical | 23.44 | [119] |
| *Cordia obliqua Willd* | Fruit | Spherical, monodisperse | 7.13 | [131] |
| *Crataegus pentagyna* | Fruit | Spherical | 25–45 | [128] |
| *Emblica officinalis* | Fruit | Spherical | 15 | [132] |
| *Forsythia suspensa* | Fruit | Irregular spherical | – | [133] |
| *Garcinia indica* | Fruit | Spherical and hexagonal | 5–30 | [134] |
| *Mimosa pudica* | Fruit | Irregular | – | [135] |
| *Momordica charantia* | Fruit | Irregular spherical | 78.5—100 | [136] |
| *Nothapodytes nimmoniana* | Fruit | Spherical | 60–80 | [137] |
| *Panax ginseng* Meyer berries | Fruit | Spherical | 10–20 | [138] |
| *Rosa canina* | Fruit | Spherical, isotropic in structure | 13–21 | [122] |
| *Salmalia malabarica* | Fruit | Spherical | 7 | [139] |
| *Sambucus nigra L* | Fruit | Spherical | 26 | [120] |
| *Solanum trilobatum* | Fruit | Spherical | 12.50–41.90 | [140] |
| *Syzygium alternifolium* | Fruit | Spherical | 21–25 | [141] |
| *Tamarindus indica* | Fruit | Spherical | – | [142] |

Alharbi and Alsubhi studied the evaluation of the biological methods using *Azadirachta indica* fruit extracted with cisplatin as a reducing agent to facilitate the formation of AgNPs (AgNPs-cis) [119]. Initially, the fruit was washed, dried, and reduced in size to a fine powder. To obtain an extract, 5.0 g of the powdered fruit was mixed with 100 mL of water, stirred, and heated at 100 °C for 10 min. The fruit extract was added to 1 mM $AgNO_3$ at a ratio of 1:9, which was exposed to sunlight for 3 min until a color transformation occurred from yellow to brown, and then maintained at room temperature for 1 h. For the AgNPs-cis synthesis, 10 mL of cisplatin and 10 mL of fruit extract were mixed into 90 mL of $AgNO_3$. The reaction mixture was also allowed to stand under sunlight and at room temperature. On the other hand, they also analyzed phytochemical tests on the aqueous extracts of *Azadirachta indica* fruit based on the observed color and/or precipitated form. The fruit extracts tested positive for flavonoids, phenols, and terpenoid compounds. Thus, they suggested that these compounds, including polyphenol and proteins, were indeed responsible for the reduction and formation of AgNPs based on the corresponding peaks observed by FTIR spectra. The exact mechanism associated with the bio-reduction of AgNPs is still not fully clear. According to field emission-SEM (FESEM), both synthesized AgNPs were spherical and 27 nm in size. However, DLS analysis showed that the particle size of AgNPs and AgNPs-cis were 249 nm and 260 nm, respectively. This is because the presence of cisplatin particles might contribute to the larger size of AgNPs-cis as compared to AgNPs from fruit extract only.

Moldovan et al. reported the use of European black elderberry, *Sambucus nigra* fruit extracts as a reducing agent, and aq. $AgNO_3$ solution as a precursor for the production of AgNPs. A fruit extract was obtained by mixing the ground fruits in water with constant stirring for 1 h at room temperature. After filtration, the extract was then mixed with 1 mM $AgNO_3$ followed by an addition of 0.1 M NaOH to adjust the pH. Subsequently, the obtained AgNPs were subjected to centrifugation for purification. XRD analysis found the AgNPs calculated a mean crystallite size of 25 nm. A polydisperse spherical shape of AgNPs of 26 nm in size was also further confirmed by TEM images [120]. Besides, from the images, it was also clearly observed that the surface of synthesized NPs was covered by a faint thin layer. The authors suggested that the presence of organic molecules originated from the fruit extracts that potentially capped and stabilized the NPs. In another study, *Sambucus nigra* fruit extracts were used and reported to have an abundance of phytochemicals such as polyphenols, anthocyanins, and flavonoids, proving as the main bioactive and free electron-donating molecules for the reduction of metallic AgNPs from $Ag^+$ ions [121]. The mentioned phytochemicals were compatible with characteristic peaks observed in the FTIR analysis.

Fruit extracts of *Rosa canina* have been utilized for a green synthesis of AgNPs as reported by Gulbagca et al. [122]. They successfully formed a spherical isotropic structure of AgNPs with a particle size range from 13 to 21 nm. Similarly, Cardoso-Avila et al. studied the same plant species, an aqueous extract of *Rosa canina* fruit as a reducing and stabilizing agent for both AuNPs and AgNPs with different amounts of plant extracts and metal salt concentrations previously studied [123]. In regard to AgNPs synthesis, TEM and SEM analysis revealed the presence of quasi-spherical and anisotropic NPs with a mean size of 34 nm. FTIR data showed *Rosa canina* fruit extracts comprised phenolic compounds. Previous literature also mentioned the presence of flavonoids, proanthocyanidins, ellagic acid, catechin, gallic acid, and caffeic acid [124–126]. They may present as the main active phytochemicals that potentially participate in green synthesis. The reactions may involve an oxidation of the hydroxyl functional group compounds into a ketone form, leaving protons and electrons that effectively reduce the metal ions into metallic nanoparticles. However, the exact mechanism is still unclear [127].

A green synthesis using *Crataegus pentagyna* fruit extracts was successfully performed by Ebrahimzadeh et al. [128]. They also investigated the effect of optimization of parameters to produce the best characterization of AgNPs. According to the UV–Vis analysis of individual parameters, 20 mM $AgNO_3$, pH 12, reaction time of 2 h, and temperature at 45 °C were chosen as the optimum parameters used in this experiment. DLS analysis found the particle size of synthesized AgNPs (of sample with optimum parameters) in a range from 15 to 60 nm. SEM images visualized a uniform, low agglomeration, spherical shape of AgNPs size ranging between 30 and 50 nm, while TEM also found uniform spherical AgNPs of size range from 25 to 45 nm. Furthermore, the assigned absorption peaks in FTIR spectra represent the presence of compounds such as alkaloids and flavonoids in *Crataegus pentagyna* fruit extract interacting with the stabilization of AgNPs.

## Synthesis of AgNPs using flower extract

Flower is one of the essential reproductive organs of plants, whereby the color, texture, as well as freshness, are generally seen as a symbol of “beauty”. According to the literature, flower produces multiple colors due to organic molecules called pigment derived from photosynthesis in plants [143]. This pigment can be categorized into tetrapyrroles, carotenoids, flavonoids, anthocyanins, and betalains, interrelated to the most common bioactive phytochemicals [144]. Many studies have published the utilization of flowers in potentially wide-ranging applications owing to their antioxidant properties, nutritional values, and phytochemical compositions. Therefore, diverse types of flowers have been extensively used in the green synthesis of AgNPs.

Green synthesis using *Argemone mexicana* and *Turnera ulmifolia* flower extracts displayed a spherical AgNPs size from 23 to 38 nm, respectively [145]. An aqueous extract of individual flower blooms was continuously stirred with 90 mL of 5 mM $AgNO_3$ solution for 20 min at ambient temperature. The initial golden yellow color turned dark brown after the mixture was left for 24 h, attributed to the effective formation of AgNPs. The report also assessed phytochemical screening analysis on both flowers. They confirmed that the flowers contained flavonoids, alkaloids, phenols, tannins, cardiac glycosides, saponins, amino acids, and terpenoids, which played a major role in the green synthesis of AgNPs. FTIR spectra analysis also corroborated the results. XRD calculated the average crystallite size of synthesized AgNPs using *Argemone mexicana* and *Turnera ulmifolia* of 29.13 nm and 31.47 nm, respectively. Comparable results were also shown by SEM: 29.34 nm using *Argemone mexicana* and 32.42 nm using *Turnera ulmifolia*.

Phytochemicals such as phenolics, flavonoids, tannins, terpenoids, saponins, and phlobatannins act as reducing and capping agents for AgNPs and were found in an ethanolic extract of *Nyctanthes arbortristis* flower [146]. Initially, the ground flower was extracted in 10 mL of ethanol. 5% (v/v) ethanolic flower extract was mixed with 1 mM aq. $AgNO_3$ and stirred at 80 °C until a brown color appeared in the mixture. The synthesized AgNPs were found to possess a size of around 5–20 nm with uniform spherical and oval shapes. In addition, ultrahigh-resolution TEM (UHRTEM) discovered lattice fringes on the surface, signifying the AgNPs were successfully capped and stabilized which prevented them from secondary nucleation or agglomeration.

A recent study on green synthesis of AgNPs using *Moringa oleifera* flower extracts (MOFE) was conducted by Bindhu et al.[147] A light-yellow extract was obtained by heating the flower in water at 100 °C and separated by centrifugation, followed by filtration. Upon synthesis of AgNPs, 1 mM of $AgNO_3$ was mixed into different volumes of flower extracts (2, 4, 6, and 8 mL). A reddish-brown color was observed in the solution, indicating an effective reduction of AgNPs. In UV–Vis spectra, it can be seen that increasing the concentration of MOFE also increases the intensity of absorption peaks. According to TEM images, 8 mL of MOFE exhibits a small monodispersed spherical shape of AgNPs with a mean size of 8 nm. While, 2 mL MOFE showed a similar morphology of AgNPs, but the mean particle size was 13 nm, slightly bigger than 8 mL MOFE. This is because only a few phytochemicals are present at lower concentrations of extracts, which is insufficient to reduce $Ag^+$ ions, leading to the formation of bigger particles of AgNPs compared to higher concentrations [148, 149]. These are also further confirmed as calculated by XRD analysis: 16 nm for 2 mL and 11 nm for 8 mL. Besides, the presence of phytochemicals such as flavonoids, phenolic, antioxidant vitamins, cysteine, tocopherols, calcium, β-carotene, potassium, and proteins in *Moringa oleifera* flower has been previously reported [150, 151]. Some compounds were confirmed to exist in MOFE and serve as reducing/capping and stabilizing agents from characteristic absorption bands observed in FTIR. The ability of those compounds to donate electron pairs and provide electrostatic interactions on the surface of AgNPs prevented the particles from aggregation, as was proved by TEM.

## Synthesis of AgNPs using seed extract

Seed defines the beginning of a plant. The growth and germination process of a plant commences from a seed. On fertilization, the ovary of a flower matures into a fruit, enclosing a developed ovule or a seed that is also capable of growing into a new plant. Fundamentally, the seeds store all resources and nutrients including carbohydrates, starch, proteins, minerals, as well as phenolic compounds [152, 153]. This is necessarily required to promote proper life and healthy growth of plant. It is evidently found that a seed contains numerous potential compounds which may have the ability to play a part in the synthesis of AgNPs.

AgNPs were rapidly synthesized using seed extracts of *Alpinia katsumadai* [154]. To obtain the extract, 25 g of ground seeds of *Alpinia katsumadai* were sonicated in 300 mL water at 30 °C for 50 min. Then, 15 mL of seed extract was mixed with 150 mL of 10 mM $AgNO_3$ in a dark condition. DLS analysis proved that the synthesized AgNPs were roughly quasi-spherical with a mean diameter of approximately 12.6 nm. The aggregation of clusters formed led to variations in the size of AgNPs. This might be associated with decreasing the volume of the extract during sample preparation [155]. However, FETEM visualized a faint thin layer around the synthesized AgNPs, reflecting that the phytochemicals in *Alpinia katsumadai* seed extracts possibly capped and stabilized the AgNPs from aggregation. These are further confirmed by FTIR analysis. The observation of the characteristic peaks of free amine groups and carbonyl functional groups indicates the presence of active proteins and flavonoids, respectively.

*Persea americana* seed extracts were utilized as a reducing agent for AgNPs formation. Girón-Vázquez et al. studied the effect of different concentrations of *Persea americana* seed extracts. 0.25, 0.50, and 2.0 g of dried seed powder was boiled and stirred in 50 mL of water for 1 h at room temperature and 1 h at 65 °C [156]. The prepared extracts were added to three separate beakers containing 5 mL of 0.01 M $AgNO_3$ and 2.5 mL of ammonium hydroxide until the volume reached 50 mL. Each mixture was stirred for 5 h. All three mixtures successfully showed a color transformation from pale yellow to brownish yellow. UV–Vis and TEM analysis indicated that an increasing amount of extract affected the size and shape of the synthesized NPs from mostly semi-spherical to larger elongated particle size.

Another aqueous seed extract of a different plant, *Descurainia Sophia,* was studied to produce AgNPs from the reduction of $AgNO_3$ solution [157]. TEM images clearly revealed a spherical shape of AgNPs with diameter size ranges between 1 and 35 nm, while DLS analysis indicated the NPs size of around 30 nm. Moreover, spherical-shaped AgNPs with particle size of 55–99 nm range were also synthesized using *Sinapis arvensis* seed as performed by Khatami et al. [158]. According to FTIR spectra, carboxyl, hydroxyl, and amine functional groups present in *Sinapis arvensis* seed extracts are the main active phytochemicals that may be involved in the bio-reduction of $Ag^+$ ions into AgNPs.

## Synthesis of AgNPs using root extract

Few studies have been published on the potential of roots as an alternative plant source utilized for the green synthesis of AgNPs. The root is one of the major organs of most plants aside from leaves and stems. As an underground part, it is responsible for anchoring and attaching the plant's body to the ground or soil. It also primarily absorbs nutrients, water, or minerals from the soil, transporting them through stems and leaves [159, 160]. This is crucial in sustaining the proper growth of a plant, as it supports photosynthetic processes. Over the last decades, chemical products produced in roots have been explored. Generally, the major products of a plant's root contain alkaloids, terpenoids, flavonoids, phenol compounds, anthraquinones, quinones, glucosinolates, lignans, proteins, etc.[161].

Rao et al. investigated a green method of synthesizing AgNPs using methanolic root extracts from *Diospyros paniculata* and silver precursor of Ag acetate. The root powder was extracted with methanol using Soxhlet extraction, concentrated under reduced pressure, and then dissolved in dimethyl sulfoxide. The study assessed the effect of varying concentrations of Ag acetate while fixing the amount of root extracts and vice versa with a constant reaction time of 2 h at room temperature. UV–Vis spectra concluded that increasing the concentrations led to a rapid formation of AgNPs with larger sizes and particle agglomeration as confirmed by SEM. In addition, TEM images presented spherical-shaped AgNPs with a mean size of 17 nm, which is also consistent with the average crystallite size estimated by XRD [162].

Roots of *Alpinia calcarata* were selected as a reducing and stabilizing agent for the synthesis of AgNPs by Pugazhendhi et al.[163]. To obtain the extract, a dried root powder was initially heated and stirred at 75 °C in water for 30 min. Four analyses of different root extract concentrations were prepared: 3, 4, 5, and 7 mL of *Alpinia calcarata* root extracts was added into 50 mL of 0.2 mM $AgNO_3$, respectively. The reaction mixture was continuously stirred for 24 h. The formation of AgNPs can be seen by the appearance of a light pale-pink color within a few minutes. High-resolution-TEM (HRTEM) analysis revealed a quasi-spherical shape of AgNPs with smooth edges and varied particle size from 5 to

15 nm. The formation of AgNPs clusters is also observed in the image. The authors concluded that a higher amount of *Alpinia calcarata* root extracts decreases the particle sizes. More phytochemicals effectively capped and stabilized the synthesized AgNPs in higher amount of extracts, forming smaller particle sizes. According to FTIR, the presence of flavonoids, terpenoids, proteins, cysteine, and thiamine compounds may participate in the reduction as well as the formation of AgNPs.

Garibo et al. revealed the presence of alkyl halides, proteins, phenolic, and aromatic compounds in an aqueous stem and root extracts of *Lysiloma acapulcensis* as potential reducing and stabilizing agents for AgNPs formation [164]. TEM and HRTEM characterization indicated spherical and quasi-spherical AgNPs with an average size of 5 nm. On the other hand, Oves et al. produced a uniform spherical shape of AgNPs using an aqueous *Phoenix dactylifera* root fiber extract [165]. The result of particle sizes is in accordance with that indicated by FESEM, TEM, and XRD analysis, ranging from 21.65 to 31.05 nm, 27 nm, and 25.1 nm, respectively. Predominantly, FTIR data peaks indicate that the contribution of protein functional groups capped and stabilized the obtained AgNPs.

## Synthesis of AgNPs using stem extract

Stems, including main stems, branches, and twigs, are also one of the major tissues of a plant that have been studied for the green synthesis of NPs, particularly for AgNPs. Like roots, stems are also responsible for nutrient uptake, holding, and supporting the growth of a plant. The nutrients are transported throughout the plant's structures initially from roots to the stems and, finally, the leaves. In addition, there is a wide range of substances evidently found in stems such as carbohydrates, proteins, amino compounds, soluble and insoluble compounds containing essential elements, etc. [166]. The utilization of flower, seed, root, and stem extracts from different types of plant to potentially synthesize AgNPs is shown in Table 5.

**Table 5** Several plant extracts (flower, seed, root, and stem) used for the green synthesis of AgNPs

| Plant species | Plant extract | Shape | Size (nm) | Refs |
|---|---|---|---|---|
| *Argemone mexicana* | Flower | Spherical | 29.34 | [145] |
| *Canna indica* L | Flower | Spherical | 43.1 | [172] |
| *Cosmos bipinnata* Cav | Flower | Spherical | 36.1 | [172] |
| *Lantana camara* L | Flower | Spherical | 24.5 | [172] |
| *Moringa oleifera* | Flower | Spherical | 5–2 | [147] |
| *Nyctanthes arbortritis* | Flower | Spherical and oval | 5–20 | [146] |
| *Syzygium aromaticum* | Flower | Spherical | 23 | [173] |
| *Tecoma stans* | Flower | Spherical | 50–60 | [174] |
| *Turnera ulmifolia* | Flower | Spherical | 32.42 | [145] |
| *Alpinia katsumadai* | Seed | Quasi-spherical | 12.6 | [154] |
| *Carum copticum* | Seed | Spherical | – | [175] |
| *Descurainia sophia* | Seed | Spherical | 1–35 | [157] |
| *Dracocephalum moldavica* | Seed | Spherical | 5–50 | [64] |
| *Hibiscus cannabinus L* | Seed | Spherical | 7–11 | [176] |
| *Persea americana* | Seed | Spherical | – | [156] |
| *Pimpinella anisum* | Seed | Spherical | 3.2–16 | [177] |
| *Salvia hispanica L* | Seed | Spherical | 7 | [178] |
| *Sinapis arvensis* | Seed | Spherical | 14 | [158] |
| *Trigonella foenum-graecum L* | Seed | Spherical | 33.93 | [179] |
| *Alpinia calcarata* | Root | Quasi-spherical, polydisperse | 5–15 | [163] |
| *Diospyros paniculata* | Root | Spherical | 17 | [180] |
| *Lysiloma acapulcensis* | Root | Spherical, quasi-spherical | 5 | [164] |
| *Phoenix dactylifera* | Root | Spherical | 15–40 | [165] |
| *Potentilla fulgens* | Root | Spherical | 10–15 | [181] |
| *Boswella ovalifoliolata* | Stem bark | Spherical | 30–40 | [170] |
| *Chasmanthera dependens* | Stem | Cubic | 24.53–92.38 | [171] |
| *Momordica charantia* | Stem | – | – | [136] |
| *Litsea glutinosa L* | Stem | Spherical | 10–40 | [182] |
| *Piper chaba* | Stem | Spherical, homogenous | 26 | [167] |

AgNPs were synthesized by Mahiuddin et al. using a fresh extract from *Piper chaba* stem [167]. 4 mL of an aqueous stem extract was heated and stirred with 80 mL of 1 mM $AgNO_3$ in an oil bath at 60 °C for 30 min. The colorless mixture turned reddish brown, resulting in a successful formation of AgNPs. In the study, the authors determined that lower concentration of both $AgNO_3$ (1 mM, 40 mL) and stem extracts (2 mL), reaction time for 1 h at 60 °C, and pH of 7 were the optimum parameters to yield a quality product of AgNPs. These were used for further characterization. FTIR data evidently confirmed the capping substances present in the extracts such as polysaccharides and other organic molecules. They can form and interact on the surface of synthesized AgNPs by hydrogen bonds. Thus, SEM and TEM found a spherical shape of AgNPs with an average size of 26 nm and 19 nm, respectively. These results were also approved by XRD analysis.

Olabemiwo et al. conducted a study of green synthesis of AgNPs using *Annona senegalensis* stem barks [168]. According to previous literature, similar spectral data in this study corresponds to the presence of polyphenolics and proteins responsible for the reduction of $Ag^+$ ions to $Ag^0$ [169]. The synthesized AgNPs were found to be spherical in shape with agglomeration and size range from 11 to 24.76 nm. Apart from that, an extract of *Boswellia ovalifoliolata* seeds was also used to biologically synthesize AgNPs [170]. A 1 mM of $AgNO_3$ was added with the stem bark extracts until a total volume of 200 mL was reached. The solution was subjected to centrifugation and the resulting supernatant was heated at 50–95 °C. Spherical AgNPs with a diameter range from 30 to 40 nm was discovered by SEM images. Furthermore, a large quantity of cubically shaped AgNPs with a size range between 24.53 and 92.38 was successfully produced using *Chasmanthera dependens* stem extracts by Aina et al. [171]. It was reported that FTIR data spectra characterized several organic functional groups, such as carbonyl, amide, and hydroxyls, on the surface of AgNPs. These organic compounds might play a key role during the synthesis.

## The parameters affecting the particle size and shape of AgNPs

Similarly, the particle size and shape of AgNPs are the results of the chosen plant parts and types as well as the concentration of the plant extract. Moreover, the phytochemicals present in the fruit extract might be different from those present in leaf extract as reported in this study [183]. Hence, the present bioactive compounds are responsible for reducing $Ag^+$ ions as well as controlling the size and shape of AgNPs. Researchers mostly emphasized the potential of plant extracts as a reducing and stabilizing agent for the green synthesis of AgNPs owing to their phytochemical contents. They successfully formed AgNPs with average sizes ranging from 3 to 90 nm according to SEM, XRD, and TEM analysis. Leaf extracts are a most potential source of synthesizing AgNPs. This is because leaves are the most abundant and obtainable part of a plant compared to others. However, there are no general plant extracts that are ideal and each plant's part is exceptional in their phytochemical content responsible for the formation of AgNPs. The size and shapes of AgNPs were significantly influenced. Synthesis using leaf extracts mostly showed uniform spherical shape of AgNPs, while the fruit, flower, seed, root, and stem extracts showed irregular shapes with particle agglomeration. This could be due to different phytochemicals present in each part of the plant, controlling the shapes of the synthesized AgNPs. Different amounts of plant extracts were used as one of the factors, as the phytochemical contents were also varied in amount. In this review, it also can be concluded that an aqueous or water extract of plants mostly formed AgNPs with spherical shape compared to other solvents. Hence, those factors or others like reaction time, temperature, and pH should be taken into consideration to form an efficient size and morphology of AgNPs.

## Future perspectives

Undeniably, a great number of syntheses using a variety of types of plant and plant parts for the production of different shapes and sizes of AgNPs have been studied like those discussed in the review. However, there are many areas of research that have not been further explored in the potential of those plant parts such as leaf, fruit, flower, seed, root, and stem extracts for the synthesis of AgNPs:

- The mechanisms related to phytochemical compounds present in plants that are responsible for the production of AgNPs have not been extensively studied.
- The optimum parameters and compositions between plant extracts and silver precursors such as concentration, incubation time, pH, temperature, etc., must be clearly examined, for instance, for large-scale production of AgNPs in industries.
- The factors and optimization of experimental conditions should be taken into consideration. Efficient control of the size and morphology of AgNPs is required, as most of the produced AgNPs are spherical in shape.
- Plant extracts of the same species collected from different countries have not been extensively considered as the factor that may lead to variation in results.
- There is a need to consider the limitations behind the green synthesis of AgNPs using plant extracts.

## Conclusion

AgNPs have been broadly explored and incorporated in diverse fields of nanotechnology owing to their unique properties that differ from their bulk materials. The AgNPs can be prepared by physical, chemical, and biological synthesis methods. Out of all three, biological or green synthesis for AgNPs is significantly used as it is a safe, cost-, and time-effective, environmentally friendly method. Green synthesis using various biological sources including microorganisms, bio-wastes, and plant extracts could serve as reducing and stabilizing agents for the formation of AgNPs. Among biological sources, plant extracts have significantly gained interest in many studies. This review highlighted a variety of plant and plant parts reportedly utilized in the synthesis of AgNPs. Numerous phytochemicals exist in the plant extracts that are said to have great potential as a reducing/capping and stabilization agent for AgNPs, metallic $Ag^0$, from silver salts, and $Ag^+$ ions. The size and shape of AgNPs were significantly influenced by the amount of phytochemicals present in the plant extract. Most AgNPs were found to be spherical in shape with size ranging from 1 to 100 nm. Other experimental factors can also affect the final physiochemical properties of AgNPs including solvents, reaction time, temperature, and pH.

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## Declarations

**Conflict of interest** The authors declare that there is no conflict of interest.

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