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Synthesis and Characterization of Silver Nanoparticles: A Review

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Abstract

In the current century nanotechnology has gained great interest due to its ability to modify the size of metals to the nanoscale, which dramatically changes the physical, chemical, and biological characteristics of metals relative to their bulk counterparts. The approaches used to create nanoparticles (NPs) are physical, chemical and biological. The shortcomings in physical and chemical synthesis approaches, such as the generation of toxic by-products, and energy consume as they require high temperature, pressure, power and lethal chemicals, contributed to an increased interest in biological synthesis by plants. Scientists have created a new filed called as "green nanotechnology" by fusing the idea of sustainability with nanotechnology. By substituting plant-based materials, it aims to reduce the amount of chemicals used in the manufacture of nanoparticles. Silver nanoparticles (AgNPs) attract the most attention due to their great stability and low chemical reactivity in comparison to other metals. The present review describes the fabrication of nanoparticles (NPs) via chemical and physical methods, as well as the use of plants, bacteria, and fungi. The current review also discusses certain analytical methods used to examine AgNPs, including UV-Vis spectroscopy, FT-IR, SEM, TEM, AFM, XRD, DLS, and zeta potential analysis.

Keywords: Nanoparticles, silver nanoparticles, approach methods, green synthesis, characterization.

1. Introduction

Nanotechnology is an advanced technique that deals with nanometer-sized samples, which are referred to as nanoparticles (NPs). Nanomaterials are tiny, solid particles with sizes ranging between 1 and 100 nanometers[1]. Nanoparticles may be organic or inorganic, depending on the ingredients that were used in their synthesis. The first type (organic) is based on carbon, while the second type (inorganic) is a noble metallic or magnetic type [2]. Due to the many advantages of nanoparticles compared with bigger particles having the same chemical composition, they have gained great interest in overcoming the limitations of conventional therapies because of their improved and distinct physical, chemical, and optical properties, especially silver nanoparticles. There are many nanoparticles of great importance in the field of scientific research, including gold nanoparticles, copper nanoparticles, iron nanoparticles, zinc nanoparticles, and titanium dioxide nanoparticles [3]. Among these materials, AgNPs have drawn a lot of attention due to their exceptional biological activity. It has been demonstrated to have a potential candidate for biological activities that include anti-bacterial, anti-cancer, larvicidal, treatment of wounds, water purification, food preservation, wound healing, and cosmetics [4]. Moreover, AgNPs are playing an important role in a variety of applications, such as anti-oxidants, anti-microbial agents, nanomedicine, ointments, chemical sensing, the food industry, and information storage [5]. Despite the inconsistencies about the toxicity of silver nanoparticles (AgNPs), their efficacy as an antiseptic and antibacterial agent has received much praise. We decided to work on plant-mediated green synthesis because of the available documented data and community interest in this field [6]. The present review article is a comprehensive investigation of the environmentally friendly synthesis and characterization methods used for the synthesis of AgNPs by different biological sources using bacteria, fungi, and plants, and it provides an important database for researchers that may be useful in their future work. This review examines the published papers from 2012 to 2022.

2. Approaches for silver nanoparticles (AgNPs) synthesis

Silver nanoparticles can be prepared by three methods: physical, chemical, and biological, which result in various forms and sizes for usage in a variety of applications. These synthesis methods are classified into two categories: top-down and bottom-up approaches. Various top-down and bottom-up approaches for the manufacture of AgNPs are shown schematically in **Figure 1** [10].

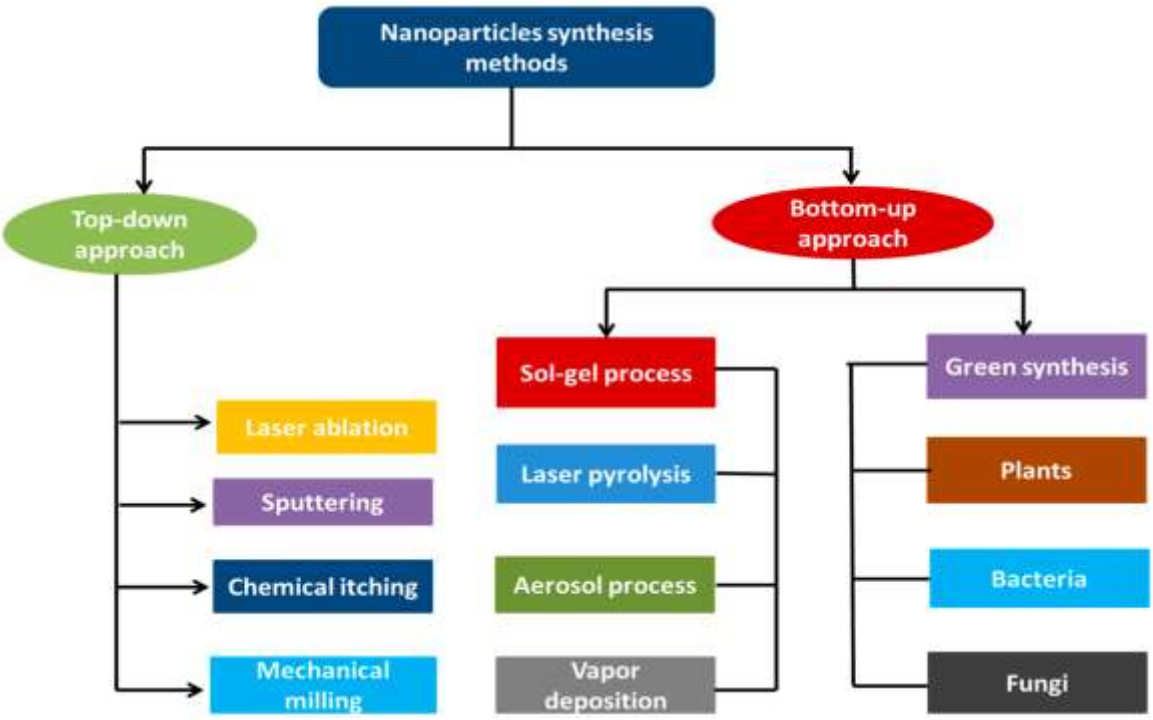

Figure 1. Systematically synthetic approaches of nanoparticles[2].

2.1 Top- Down Approach (physical Approach)

In this method of synthesis, silver nanoparticles are created using a top-down approach. This approach starts by breaking down large silver particles into smaller units, and these units are then transformed into useful nanoparticles. The most popular physical approaches for the manufacture of nanoparticles are chemical itching, sputtering, mechanical milling, and laser ablation[3, 4]. The evaporation-condensation method is carried out using a tube furnace at atmospheric pressure. The sample is evaporated into a carrier gas within the boat positioned at the furnace. However, using a physical approach (tube furnace) to produce AgNPs has many drawbacks, including large area requirements, slow synthesis, raising the temperature of the environment around the source material, and low yield[5]. This method needs a long time to accomplish thermal stability. Additionally, a typical tube furnace needs a lot of energy and requires high concentration [5-7]. In the laser ablation method, AgNPs have been created using metallic bulk materials in solution. Their creation depends on a number of factors, including the wavelength of the laser, the duration of the laser pulses, the amount of the ablation time, and the liquid medium's efficiency. The nanoparticles that form in a solution with a high concentration of surfactants, with or without the presence of surfactants, are smaller than those that form in a solution with a low concentration of surfactants [8]. However, a benefit of using a laser to create colloids over other methods is that there are no chemical reagents present in the solution. In light of this, pure colloids will be beneficial for more applications.[9].

2.2 Bottom-up Approach

This approach is a constructive that involves arranging small units to form nanoparticles (NPs). In this approach nanoparticles (NPs) can be manufactured using green or chemical process[10].

2.2.1. Chemical Approach

This approach include various chemical methods such as chemical reduction, chemical vapor deposition (CVD), sol–gel process, hydrothermal, solvothermal, photo-chemical, chemical, laser pyrolysis, aerosol pyrolysis, plasma or flame spraying, templates, spinning[11]. The synthetic approach involves fabrication of metallic nanoparticles in solution by use three main components of the synthetic method: metal precursors, reducing agents and stabilizing agents or capping agents. In this approach sodium citrate, sodium borohydride (NaBH4), ascorbate, N,N,dimethylformamide (DMF), ascorbic acid , hydrazine (NH_2-NH_2), ammonium format (NH_4COOH), ethylene glycol and glucose, are the most frequently used reducing agents [12]. These reducing agents are accountable for the reduce metal ions (like, silver ions (Ag^+)) to the metal (Ag^0) followed by the nucleation stage and finally lead to the formation of metal nanoparticles (MNPs). Stabilizing agents like borohydride are added during preparation, as they help the growth of nanoparticles in addition to protecting nanoparticles from forming agglomeration[5]. The seed-mediated growth method, includes the adding of seeds into the growth medium to produce size-controlled metal nanoparticles, in this approach yields nanoparticles of various morphologies. Depending on the capping agent utilized[13]. The essential advantage of chemical method is producing particles that are easily distributed in organic media, which is acknowledged by scientists across a wide range of disciplines, but one of the disadvantages of this method is that it requires a high cost and high energy in addition to hazardous chemicals, so it was necessary to search for an environmentally friendly and economical technique for the production of nanoparticles. The green approach became inevitable and vital rather than other approaches, and it deserved extensive research [14].

2.2.2. Green Approach

The conventional methods (physical and chemical) used to produce nanoparticles (NPs) are costly, hazardous, and not environmentally friendly. To overcome these problems, researchers turned to biological methods in the production of nanoparticles because of their simplicity, environmental, and high productivity features, in addition to the fact that they do not require dangerous chemicals, high temperatures, or pressures [23–25]. Biological methods include biological microorganisms such as bacteria, algae, yeast, fungi, or plant extracts, which are precursors to the synthesis of metallic nanoparticles (MNPs) [26]. Green synthesis is a suitable approach when silver nanoparticles are synthesized using plant extracts and microbes. They contain reducing agents that reduce $1Ag^+$ to $1Ag^0$ and also contain capping or stabilizing agents that prevent the aggregation of the nanoparticles [27]. Especially with the green biological synthesis method that has attracted the interest of researchers recently due to its being environmentally friendly, in a short period of time a large amount of nanoparticles (NPs) can be manufactured, which is time-saving, cost-effective, less toxic, and produces different sizes of nanoparticles in comparison with other biological methods [23], which makes it preferred over

others. With the advancement of technology towards green chemistry, a lot of work has been done to synthesize a number of metallic nanoparticles like silver, gold, copper, zinc, platinum, and lead [28]. Interestingly, these nanoparticles have been exploited in a variety of environmental applications [29]. **Figure 2** shows different green approaches to the synthesis of AgNPs.

In general, the green synthesis of nanoparticles can be summarized as follows- :

- Biosynthesis; use of Microorganisms like Yeast, bacteria, fungi, and algae.
- Phyto synthesis; using plants (leaves, stems, latex, flowers, seeds, roots, fruits, and peel) and their extract
- Utilization of templates such as membranes, DNA, diatoms, and viruses [15].

The green synthesis via plants, bacteria, and fungi is described in the further sections.

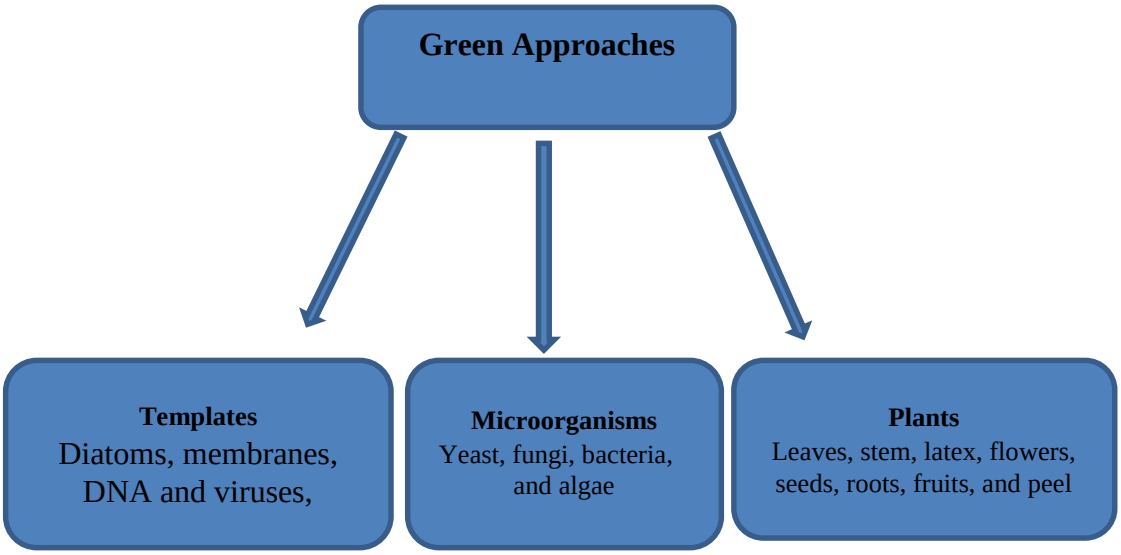

Figure 2. Different green approaches to synthesis of AgNPs .

3. Biosynthesis of silver nanoparticles (AgNPs)

3.1 Using Plant Extract

Plant extracts are a significant branch of biosynthesis processes, as plants have the ability to production metal nanoparticles in different ways inside and outside cells by reducing metal ions. Silver ion is converted into silver nanoparticles by biologically active molecules found in plants. Proteins, terpenoids, polysaccharides, phenols, alkaloids, flavonoids, amino acids, and enzymes of alcoholic substances are some examples of these biological molecules. The major variables that can affect the creation of the nanoparticles (NPs) are temperature , the concentration of the extract, metal salt, contact duration and acidic function (pH) [11]. The importance of using-plants in the synthesis of nanoparticles (NPs) because all parts of plants, including seeds, stems, roots, latex , and leaves, contain a variety of active ingredients that can be used to reduce silver ions (Ag^{+})[16]. When comparing green synthesis for nanoparticle, synthesis using plant extracts was considered several times faster than synthesis

using microorganisms (such as bacteria, fungi, algae and yeast). The latter is not feasible and requires more sterile circumstances, a laborious procedure, and a longer incubation period [17]. Therefore the use of plant extracts in green synthesis has attracted attention due to its quick development and ability to produce nanoparticles (NPs) in a single step at a low cost while being non-pathogenic and environmentally friendly protocol [17]. **Figure 3,** shows a schematic-diagram for the synthesis of silver nanoparticles using plants.

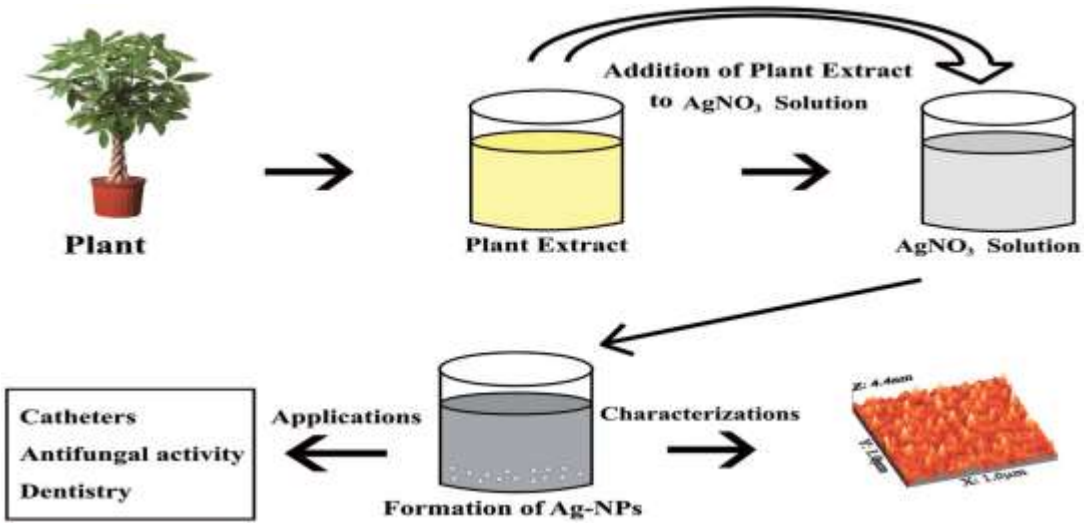

Figure 3. Schematic diagram for green synthesis of AgNPs by using plan/plant extracts[18].

The protocol used to prepare the plant extract and nanoparticles synthesize can be summarized as follows

- If the plant extract is made from the leaves or peels of some plants, a portion of the leaves or peels of the plant of interest is collected from the available sites and thoroughly rinsed two or three times in tap water to remove dust and soil particles, followed by distilled water to remove any accompanying debris. Clean, fresh leaves that are dried in the shade for (5-7) days and then crushed using a domestic blender. Finally, to prepare the plant broth, about 0.5–10 g of the dried powder is boiled with a suitable volume of distilled water [19]. The resulting extracts were then filtered using filter paper, and each filtrate was collected in a separate volumetric flask (250 ml) and kept at (4°C) for later use[20]. This extract was used for generating silver nanoparticles (AgNPs). This bio-extract is always used fresh[21].

- If the plant extract is made from fresh fruit, the fruit is thoroughly washed with tap water and then distilled water before being cut and squeezed through a fine nylon mesh to obtain the extract. Then, the obtained extract was centrifuged at 10,000 rpm for 10 minutes to remove any unwanted impurities. This extract was collected in a dark volumetric flask (100 ml) and stored at 4 °C for further experiments[22].

- To prepare the plant extract from the other plant parts, the required plant part must thoroughly washed, then mixed in distilled water, boiled for a short time, and filtered. Finally, the filtrate can be used immediately or stored at a low temperature for later use [23]. The solvent used also has an effect on the extraction rate. The phytochemical content of the

phenolic and alcoholic extracts increases [24]. Several studies summarized in **Table 1** have been carried out on the synthesis of AgNPs using different plant extracts.

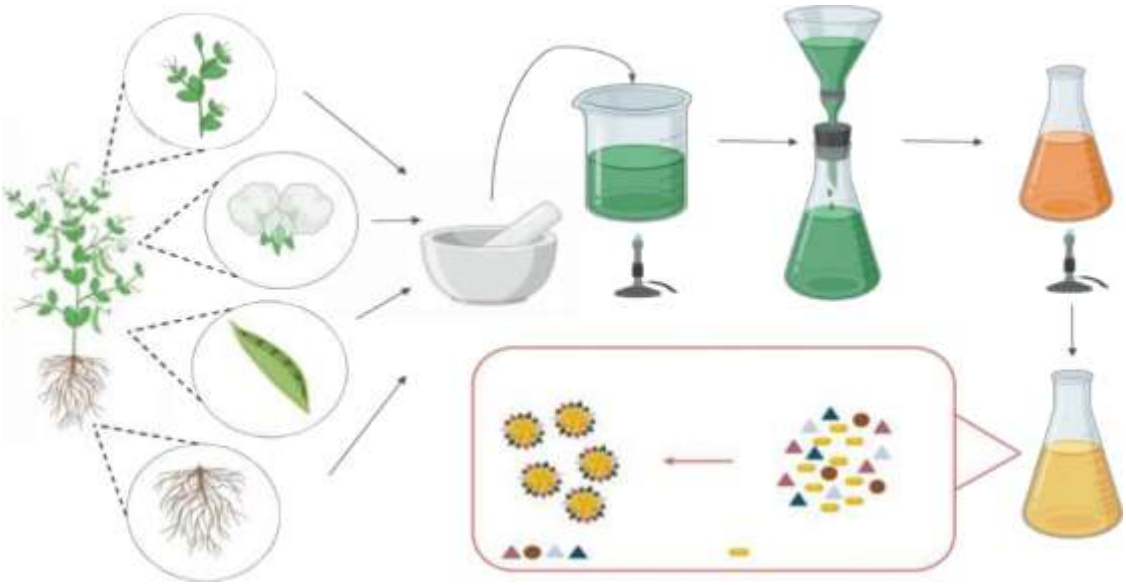

Figure 4. Green synthesis of metal nanoparticles by plant parts [25].

Table 1. Use of various plant extract in the synthesis of AgNPs

Name of plants	Part of plant used	Shape	Size (nm)	References
Angelicae- pubescenis	Extract of leaf	Spherical	12.48	[26]
Andrographis-echiodes	Extract of leaf	Cubic	68-91	[27]
Amomumvilosum	Extract of fruit	Spherical	5-15	[28]
Artemsia vulgaris	Extract of leaf	Round	25	[29]
Alium sativum	Extract of fruit	Spherical	3-6	[30]
Acacia- seyal	Gum	Round	81.45	[31]
Acalypha- hispida	Extract of leaf	Spherical	20–50	[32]
A. millefolium	Aqueous extract	Spherical /rectangular, and cubical	14-20.77	[33]
Barleria-buxifolia	Extract of leaf	Spherical	80	[34]
Butea -monosperm	Extract of leaf	Spherical, and triangular	20-80	[35]
Camellia- sinensis (green tea)	----------	Spherical	11	[36]
Coriandrum -sativum	Extract of leaf	Spherical	37	[37]
Cornus officinali	Extract of fruit	Quasi Spherical	11.7	[38]
Curcuma- aromatica		Irregular	10–30	[39]
Erythrina- indica	Extract of leaf	Spherical	20-118	[40]
Eucalyptus - chapmaniana	Extract of leaf	Spherical	Different sizes	[41]
Datura- stramonium	Extract of leaf	Spherical, and triangular	18	[42]

3.2 Using Bacteria

Bacteria is a type of microorganism, which are regarded as one of the best choices for the manufacture of AgNPs, the use of bacteria as environmentally sustainable precursors for the manufacture of nanoparticles such as gold and silver has been very successful. Due to their amazing capacity to reduce heavy metal ions and their relative simplicity in handling them.[18]. Nanoparticles (NPs) are manufactured, by bacteria either intracellular or extracellular, green synthesis is made flexible, reasonable, and appropriate method by the choice of bacteria[43]. **Figure 5** shows the schematic diagram for the synthesis of AgNPs by using different bacteria. The following are a few instances of bacterial strains that have been widely used to synthesize bio-reduced AgNPs with distinctive shape/size morphologies include: *Bacillus indicus, Antarctica, Pseudomonas, Escherichia-coli, Bacillus Amylolique-faciens, Arthrobacter 5gangotriensis, Bacillus-cereus, Aeromonas sp. SH10 Phaeocystis proteolytica, Bacillus cecembensis, Lactobacillus casei, Enterobacter cloacae, Geobacter spp.*, and *Corynebacterium sp. SH09* [44]. These species of bacterial are commonly utilized for commercial biotechnological applications including bioremediation,, bioleaching and genetic engineering [45]. According to some recent scientific studies , some types of bacteria including *Pseudomonas-aeruginosa* and P*seudomonas -stutzeri* possess a high skill in using defense mechanisms to combat stresses such as heavy metal ion toxicity and can even thrive and survive in the presence of high concentrations of heavy metal ions[46]. Also, several recent scientific reports confirmed that the ability of microbes to synthesize metallic nanoparticles mainly depends on several factors, including culture conditions, and the improvement of reaction parameters such as 33acidic function, temperature, and 2nutrient concentrations affects the production of microbial enzyme-activity[47]. The numerous studies have reported the production of AgNPs using bacteria. The first of these studies was the study conducted by Klaus et al. in which AgNPs were synthesized with specific structures and shapes well using Ag resistant bacterial strains *Pseudomonas stutzeri* (*AG259*). These cells accumulate AgNPs in large quantities up to (200) nm [48]. **Table 2** lists many other bacteria that can be employed in the synthesis of AgNPs. However, the main disadvantage of using bacteria as nanofactories is the slow rate of synthesis, the possibility of culture contamination, lengthy procedures, difficulty in controlling the nanoparticle size and reduction rate, and restricted morphologies compared to other biological sources such as fungi and algal species that contain many proteins that play an important role in the biosynthesis of metallic nanoparticles (NPs) of various shapes [9]. **Table 2** shows h green synthesis of AgNPs using different bacteria.

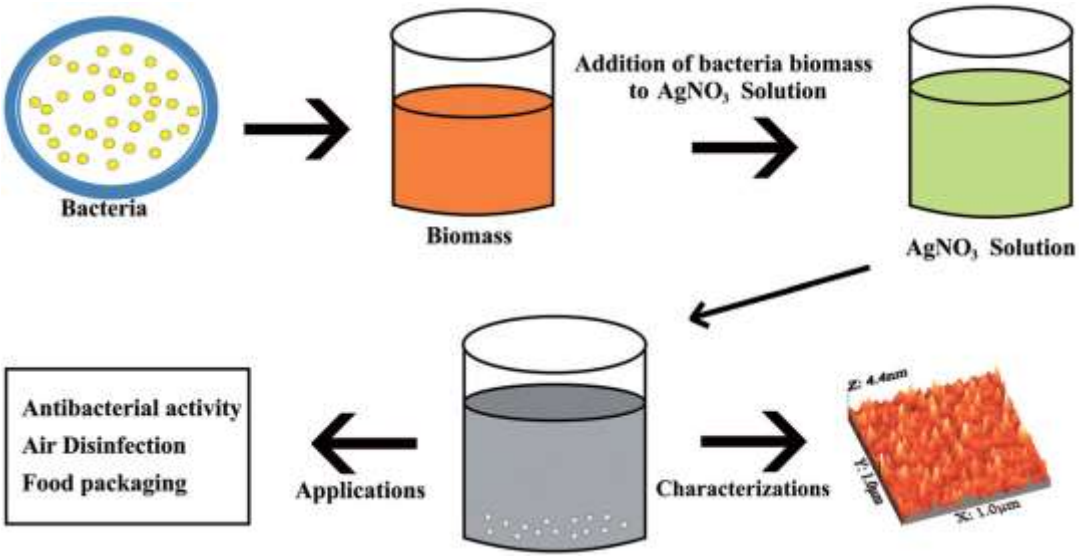

Figure 5. Diagram depicting the use of bacteria in the synthesis of AgNPs [18]**.**

Table 2. Green synthesis of AgNPs using different bacteria.

Bacteria Species	Intracellular/extracellular	Shape	Size (nm)	References
Esciheichia coli	Extracellular	Spherical	1.2–62	[49]
Bacilus- cereus	Extracellular	Spherical	20–40	[50]
Lactobcillus- casei	Extracellular	Spherical	20–50	[51]
Rhodococcus spp.	Intracellular	Spherical	5–50	[52]
Endosymbiotic Bacterium	Extracellular	Spherical, cubic, hexagonal, crystalline, and oval	10 –60	[53]
Aeromonas spTHG-FG1.2	Extracellular	Spherical, and FaceCentered Cubic	8 –16	[54]
Bacillus strainCS 11	Extracellular	Spherical and FCC	45 ± 0.15	[55]
Novosphingobium sp.HGC3	Extracellular	Spherical and crystalline,	8– 25	[56]
Bacillus-methylotrophicus	Extracellular	Spherical	10–30	[57]
Marine- Ochrobactrum sp	Intracellular	Spherical	38–85	[58]
Actinobacteria	Intracellular	Spherical	5–50	[59]
KinneretiaTHGSQ14	Extracellular	Spherical, Mono-disperse, FCC.	15–20	[60]
Nocardiopsis- spp.	Extracellular	Spherical	50 ± 0.15	[61]

3.3 Using Fungi

Fungi are good biological agents, it acts as a "Nano factory" for the biosynthesis of metal oxide /metal nanoparticles especially AgNPs and due to their high capacity for metal

bioaccumulation, their tolerance, high binding capacity with the metal ions in the intracellular region, and intracellular uptake[62]. Fungi are better than bacteria as biological agents as the specialized fungi can produce well-defined structured nanoparticles with good monodispersed compared to bacteria due to the presence of a variety of enzymes / proteins / reducing components on their surfaces and intracellular[63]. Which directly affects the higher productivity of nanoparticles [64]. The main advantage of nanoparticles manufactured from fungi is that they contain a large amount of pure enzyme and are free of cellular protein. In Fig.6. A schematic representation showing the synthesis of AgNPs using fungi. The expected mechanism for the synthesis of nanoparticles in fungi is due to the occurrence of electrostatic interaction between the negatively charged carboxylate groups in the enzymes and the positively charged Ag ions. This extracellular extraction simplifies biomass recovery in downstream procedures. This method was more beneficial than bacterial synthesis. It was observed that rapid reduction and extracellular formation of metallic nanoparticles occur within 10 minutes. Many studies which can be used for the synthesis of AgNPs from fungi are shown in **Table 3.**

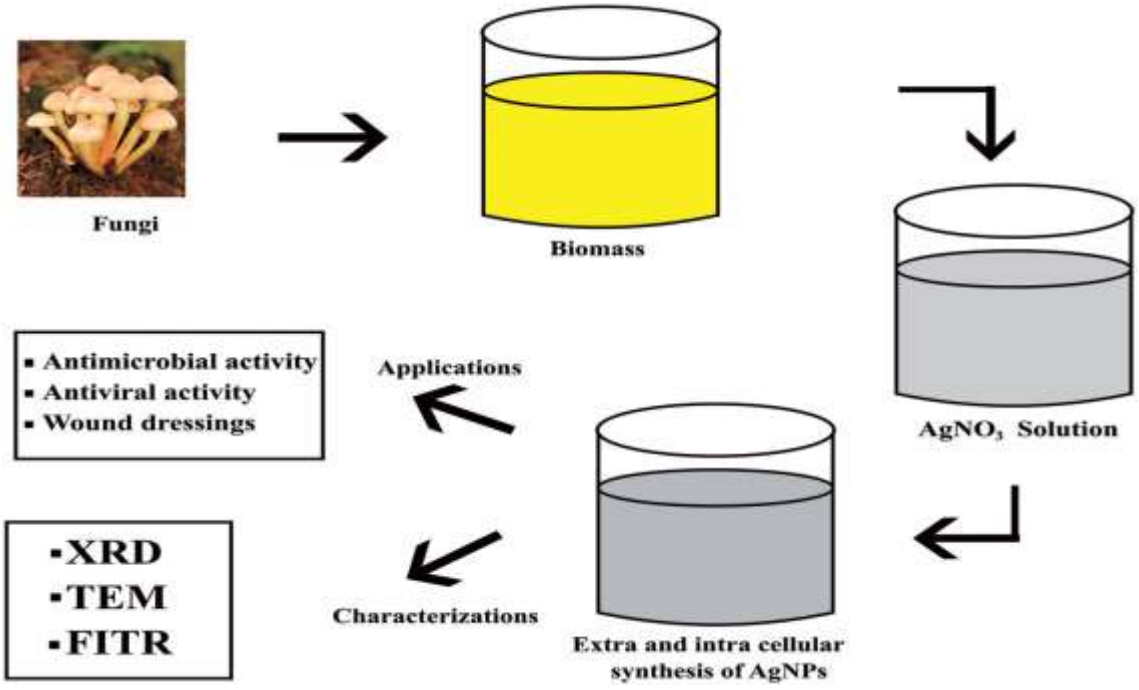

Figure 6. Schematic diagram for synthesis of AgNPs by using fungi[18].

Table 3. Green synthesis of silver nanoparticles (AgNPs) using different fungi.

Fungi Species	Intracellular/extracellular	**Shape**	**Size (nm)**	**References**
Penicillium italicum	Extracellular	Face-centered cubic lattice	39.5 nm.	[65]
Botryodiplodia theobromae	Extracellular	Spherical	62.77 –103	[66]
Schizophyllum commune	Extracellular	Spherical	51–93	[67]
Beauveria bassiana	Extracellular	Spherical, triangular, hexagonal	10–50 nm,	[68]

Beauveria bassiana	Extracellular	Spherical	40.14–289.13 nm	[69]
Aspergillus niger	Extracellular	Poly dispersed spherical	1–20	[70]
Trichoderma harzianum	Extracellular	Spherical	Different size	[71]
Guignardia mangiferae	Extracellular	Spherical	5–30	[72]
Arthroderma fulvum	Extracellular	Spherical	21	[73]
Candida glabrata	Extracellular	Spherical	2–15	[74]
Tritirachium oryzae W5H	Extracellular	Monodispersed and sphericalto ovular	7-75	[75]

4. Characterization of silver nanoparticle (AgNPs).

The first qualitative indicator for the synthesis of AgNPs is the color-change of the solution from yellow to brown [76].There are many techniques employed for characterization of nanoparticles, based on their size, shape, morphology, surface area, optical activity, thermal stability and dispersity. These techniques include UV-Visible spectrophotometry, Fourier Transform Infrared Spectroscopy (FT-IR), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Atomic Force Microscopy (AFM), X – ray diffraction (XRD), Dynamic Light Scattering (DLS), and Zeta-potential measurements [15]. **Figure 7** shows techniques for the characterization of AgNPs.

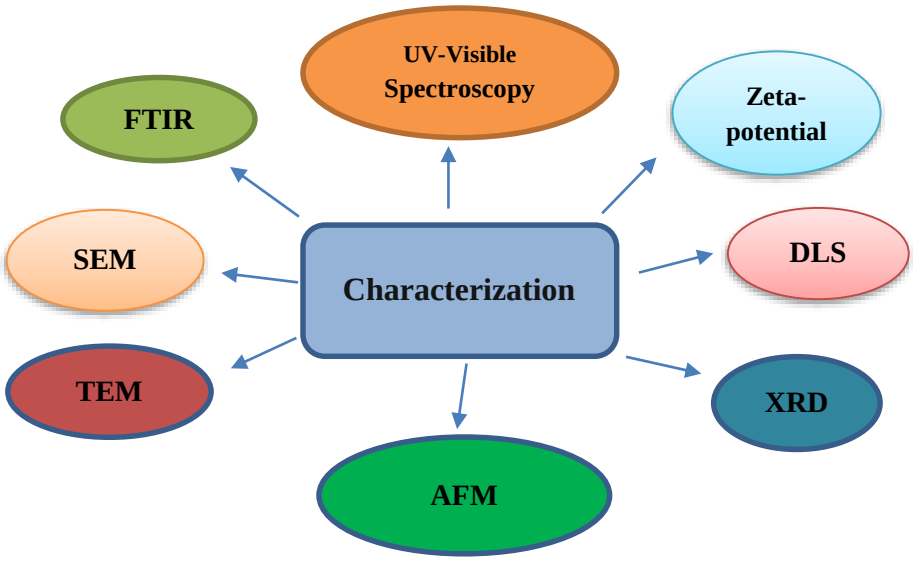

Figure 7. Characterization techniques of AgNPs[77].

4.1 UV–Visible Spectrophotometry

UV-visible spectrophotometry is one of the simplest and most reliable techniques that is also efficient and selective for many nanoparticles. The basis of spectroscopy is that light in the UV and visible spectrums is absorbed or scattered by metal nanoparticles. which results in a strong absorption band known as surface plasmon resonance (SPR) in the 400–500 nanometer, due to the interaction between light and mobile surface electrons of AgNPs. The concentration, form, and size of the metal ions investigated by UV-visible spectroscopy influence the degree of excitation[78]. **Table 4** showing green synthesis of AgNPs using plant extracts and a characterization method.

Table 4 . Showing green synthesis of silver nanoparticles using plant extracts and a characterization method.

1Plants name	Plant Part used	Shape	Size- (nm)	Characterization techniques used.	References
Alliumsativum	Extract of fruit	Spherical	3–6	Uv- Visible spectroscopy, FT-IR, XRD/EDX, and TEM.	[30]
Acacia -seyal	Gum	Round	81.45	Uv- Visible spectroscopy, FT-IR, AEM, and XRD.	[31]
Acalypha- hispida	Extract of leaf	Spherical	20–50	Uv- Visible spectroscopy, FT-IR, TEM, XRD, and GC-mass.	[32]
A. millefolium	Aqueous extract	Spherical, rectangular and cubical	14-20.77	Uv – visible spectroscopy, FT-IR, SEM, and XRD.	[33]
Barleria -buxifolia	Extract of leaf	Spherical	80	Uv- Visible spectroscopy, FT-IR, TEM, EDS, SEM, and XRD.	[34]
Buteamonosperma	Extract of leaf	Spherical and triangular	20–80	Uv- visible spectroscopy, FT-IR, TEM, DLS, TEXRD, and Fluorescence-Microscopy.	[35]
Alhagi -graecorum	Extract of fruit	Spherical	22- 36	Uv- visible spectroscopy, -FT-IR, and TEM.	[79]
Cornusofficinalis	Extract of fruit	Spherical	11.7	Uv- Visible spectroscopy, FT-IR, DLS, XRD/ EDAX, and FE-SEM.	[38]
Erythrinaindica	- Extract of root	Spherical	20-118	Uv- Visible spectroscopy, FTIR, TEM, XRD/ EDX, and DLS.	[40]
Eucalyptus - chapmaniana	Extract of leaf	Spherical	Different sizes	Uv-Visible spectroscopy, FT-IR, and XRD.	[41]
Datura-stramonium	Extract of leaf	-/ Spherical, and triangular	18	Uv- Visible spectroscopy, FT-IR, TEM, and XRD.	[42]

Nauclea -latifolia	Extract of fruit	Shape of irregular	12	Uv- visible spectroscopy, FT-IR, EDX, andSEM	[80]
Oryza- sativa L. (rice)	Extract of fruit	Different shape	346.4±36.8	Uv- Visible spectroscopy, FT-IR, and DLS.	[81]
P. subpeltata	Extract of leaf	Spherical	22.6	Uv-visible spectroscopy, FT-IR, FE-SEM, and XRD	[82]
Punica granatum L. (pomegranate	Extract of peels, leaves and seeds	Shape of spherical, and regular	50	Uv- Visible spectroscopy, FT-IR, SEM, and XRD.	[83]
Indigofera tinctoria	Extract of leaf	Spherical	9–26	Uv-visible spectroscopy, FT-IR, TEM, XRD/ EDX and AFM.	[84]
Seaweed *(S. swartzii)*	Extract of leaf	Spherical	20–40	Uv-visible spectroscopy, FTIR spectroscopy, XRD, TEM, FE-SEM, and AFM.	[85]
Sambucus ebulus	Extract of Aerial	Spherical, and cubic	35- 50	Uv- Visible spectroscopy, FT-IR, TEM, XRD, EDX, and HPLC.	[86]
Scindapsus officinalis	Extract of Fresh fruits	Spherical	Different size	Uv- Visible - spectroscopy, FT-IR, TEM, FE-SEM/EDX and XRD.	[87]
Hylocereus undatus	Extract of peel	Spherical	10- 50	Uv-visible- spectroscopy, FT-IR, SEM, XRD, and EDX.	[88]
Humulus lupulus	Extract of crushed	Spherical	17.40	Uv- Visible spectroscopy, FT-IR, TEM, XRD,DLS, BET, XPS, Raman Spectroscopy , SEM/EDAX, and AFM analysis.	[89]
Ixora brachypoda	Extract of leaf	Spherical	18 - 50	Uv- visible spectroscopy, FT-IR, TEM, XRD/FE-SEM, and EDS.	[90]

4.2 Fourier transform infrared spectroscopy (FTIR) Analysis

FT-IR technique is used to investigate and identify the functional groups (such as ketones, ammines, and aldehydes) of both plant extracts and AgNPs. The spectrum depends on the principle that particles absorb electromagnetic energy in the infrared region of the spectrum and reasons the subatomic particles to vibrate. The wave number ranges from (4000 - 400) cm^{-1}. The form of nanoparticles (NPs) based on the peak position, while the size of the nanoparticle (NPs) based on the intensity of the peaks measured in the (FT-IR) spectrum[91]. **Table 5** summarizes the FTIR data of the reviewed articles.

Table 5. FTIR data from chosen plant extracts.

Plant name	FTIR absorption bands (cm−1)	Possible functional group	References
Ixora brachypoda	3403	Stretching of COOH in group of carboxylic acids	[90]
	2923	Stretching - vibrations of C–H bond in alkane (CH4)	
	2853	Stretching-vibrations of C–H bond in aldehydes (CHO)	
	1603	Bending of N–H bond in primary amines	
	1403	Bending of C–H bond in alkanes	
	1384	bending of N=O bond in nitro compound (NO_2)	
	1318	Bending of S=O bond in sulfates	
	1262	Bending of esters (COOR)	
	1117	Bending of C-F bond in compound.	
	859, 620, 788, and 467	Stretching of C-X bond in aromatic compounds like (C-F, , C-Cl, C-Br, C-I).	
Seaweed *(S. swartzii)*	3748 and 3523	Stretching of O–H bond.	[85]
	2357 and 1737	Stretching of – C≡C– bond	
	1540	Stretching of -C–N-	
	1356 and 668	The bond related to C–H	
	1645	The bond related to (C = O)	
A. millefolium	1524, 1035 and 558	C-C bond in aromatic compounds	[33]
	3357	Stretching of – O–H bond	
	2917 and 2846	Stretching of C-H bond	
	3348.19	Stretching of O-H bond	[86]
	1623.95	Stretching of –C = O	
	1401.65	–C-H bend of alkanes or –C-C- the stretch of aromatics	
	1273.12	Bending of C-O bond in 8anhydrides group	
Acer oblongifolium	2865.16	The bond related to (C-H) in alkanes	[92]
	2031.92	The bond related to – C–H	
	1478.96	the N-C and N=C groups	
	845.35	The bond related to -C-O	
Alhagi graecorum	3294	The bond related to –N-H	[79]
	2178	Stretching of C-H	
	1631	for amide I	
	1488	The bond related to C-H-N	
	590 and 540	hydroxyl (-OH) group	
Barleria buxifolia	3410.15	Stretching vibration of -OH bond	[34]
	2926.06	stretching of -CH(Aliphatic)	
	1710	Stretching vibration of Carbonyl in the acid	
	1593.2	Stretching of C=O bond in amide,	
	2926	Stretch of C–H bond in (alkanes);	
	1348	Stretch of C=C bond in (aromatic ring)	
	1382	-C–H (aromatics)	

P. subpeltata	1050	Bending Strong of S=O bond	[82]
	1347	Stretch Strong C–F	
	1605	Bending of N–H Primary and secondary	
	2836	Stretch C–H amines and amides	
	3078	Stretch C–H Aldehyde	
7Fagonia- cretica	3864	The bond related to O-H	
	3729	The bond related to O-H	
	3626	Stretching of O-H	
	3467	The bond related to N-H	
	2916	Stretch of C-H in alkanes	
	2358	Stretching of N-H	
	1636	Stretching of C=O	
	1472	Bending vibration of N-H	
	1401	C-O-H	
	1114	C-O-C	
	1061	Stretching of C-O	
	869	Bending of C-C, C-OH, C-H (ring)	
	627 and 643	The bond related to C-H / bending	
Citrus tangerina, *Citrus sinensis*, and *Citrus limon*	2950 and 3670	The bond related to O-H/ stretching-frequency	[93]
	1636	Stretching of C=O, and aromatic C=C Stretching.	
	2115	alkyne group present in phytochemicals	
	597	Silver nanoparticles bonding with oxygen from OH group	
Tagetes -erecta	3415	Stretching-vibration of O-H in phenol and alcohol compounds.	[94]
	2922	The -C-H stretching mode in alkanes	
	1060, 1399, and 1829	Stretching of C-O, and Stretching of C=O in alcohol, ethers,and esters	
	1643 and 1564	Bending vibration of N-H in amides	
	1490	Stretching of C=C	
	670	Bending of O-H	
	609	Bending of C-H	

4.3 Scanning Electron Microscopy (SEM) Analysis

SEM is a common technique; it is used to determine the morphology and surface topology of nanoparticles. The principle behind scanning electron microscopy (SEM) is that when an electron beam incident on the surface of the sample, an interaction occurs between electrons and atoms inside the sample that leads to the emission of secondary electrons. The emission of these electrons depends on the surface geometry and composition of the sample [95]. This set of reflected electrons is captured by the detectors in the SEM and translated into images. SEM is paired with EDX. The advantage of using SEM is that it can resolve particles smaller

than 10 nm, but the disadvantage is that it cannot determine the interior structure of the particle [95].

4.4 Transmission Electron Microscopy (TEM) Analysis

Transmission Electron Microscopy (TEM) is one of the most common analysis and described as high-resolution techniques used to study themorphology of NPs. This analysis provides information about, particle shape, size, and distribution. The basic principle of this technique is that an electron beam is transmitted through the surface of the metal nanoparticles, and the interaction of the transmitted electrons produces in an image [47, 96]. Electron microscopy (EM) can be used to obtain a betterresolution on the sample. The (SEM) and (TEM) techniques are used to study topography and surface morphology for nanoparticles. The key distinction between (TEM) and (SEM) is that the former offers the good resolution and data of the internal structure than the SEM.

4.5 Atomic Force Microscopy (AFM) Analysis

Atomic Force Microscopy (AFM) is a microscopy technique used to describe topography, morphology, the surface texture, roughness, and particle -size distribution of nano particles[97]. A disadvantage of the atomic microscopy technique is that the lateral dimensions of the sample are overestimated, so it is necessary remove the error which requires more attention [98].

4.6 X- ray Diffraction (XRD) Analysis

XRD is the essential technique used to identify the crystalline nature of nanoparticles (NPs), polymers, various biomolecules, and superconductors. The basic idea behind the method is that when a monochromatic beam of X-ray is focused on a crystal, it produces a variety of diffraction patterns that can be analyzed using the Bragg's equation: $\mathbf{2d \sin\theta = n\lambda}$, where, **d:** Is the spacing between the diffracting planes, **ɵ:** Is the incident angle, n is any integer, and **λ:** Is the wavelength of the beam used to know the characteristics of crystalline or poly-crystalline material[47]. It is also used to determine the size of the crystal using the Scherrer equation: $\boldsymbol{D = 0.94\,\lambda/\beta\cos\theta}$.

D represent size of particles nm, ($\boldsymbol{\lambda}$**)** is the wavelength X-ray KCu (Kα = 15406 ˚), ($\boldsymbol{\beta}$) is the full width XRD peak, and **(**$\boldsymbol{\theta}$**)** is angle . The disadvantage of this XRD technique is that sometimes there is difficulty growing the crystals. This is the only disadvantage of the XRD technique [76].

4.7 Dynamic Light Scattering (DLS)

The most common simplistic technique used to determine the average size of nanoparticles in aqueous solution [99]. This method's basic idea is that it gauges the particle's hydrodynamic radius while it is in Brownian motion. The foundation of this technology is the interaction of light and particles. When exposed to laser light, the particle in the solution scatters the light in various intensities. Accordingly, the Stokes-Einstein equation was used to determine the corresponding particle sizes. This technique can be used to determine the size of nanoparticles ranging from 20 to 200 nm. When comparing the sizes of the particles

obtained by using DLS, TEM, and SEM techniques, it was noted that the size obtained from DLS was larger than the size obtained from TEM and SEM [95].

4.8 Zeta potential Analysis

Zeta potential analysis is one of an important techniques in interpreting the properties of nanoparticles, especially silver nanoparticles. This technique is used to determine the stability and aggregation of nanoparticles in a state of dispersion [100]. Also, zeta potential analysis allows detecting the surface charges of nanoparticles by giving information about those charges. The principle of this technique is the electrostatic attraction between the charges on the surface of nanoparticles with the oppositely charged ions present in the solution.

5. Conclusions

The present review describes methods for the synthesis of nanoparticles, especially silver nanoparticles, exemplified by the top-down and bottom-up approaches. This article also explained the shortcomings in chemical and physical methods, which increased the interest of researchers in biological synthesis by bacteria, fungi, and plants. The green synthesis of AgNPs mediated by many plant materials is more advantageous than alternative biological approaches because plant extracts are easy to handle, widely available, safe, and readily available. The present review, combining several recently published works, shows the significance of plant extracts facilitated bio-synthesis of AgNPs, and these studies are described as being cost-effective, environmentally friendly, and highly suitable for producing nanoparticles free of toxic contaminants needed in bio applications due to their unique properties. Silver nanoparticles will play a significant role in many nanotechnology-based processes, the present review also includes several analytical techniques that are utilized for the examination of these AgNPs, including UV-Vis spectroscopy, FT-IR, SEM, TEM, AFM, XRD, DLS, and Zeta potential analysis

Authors' declaration

The researchers declare that there are no conflicts of interest regarding the current manuscript.

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