



## Review Article

# A Review on Synthesis, Optimization, Mechanism, Characterization, and Antibacterial Application of Silver Nanoparticles Synthesized from Plants

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Developments in nanotechnology and natural product research toward the search for novel antibacterial agents have drawn the interest of many scientists to the synthesis of silver nanoparticles (AgNPs) from natural product (especially plants) due to its numerous benefits over other methods of synthesis such as been easy, economical, convenient, and environmental friendly. Aside from the aforementioned advantages, the synthesis of AgNPs from medicinal plant has been reported as the best approach of synthesizing AgNPs with great biological activities due to the numerous biomolecules found in plants. Recently, the number of researches toward the improvement of the yield, morphological properties, analytical techniques, and the development of optimal conditions and exact mechanism for synthesizing AgNPs from plants have been increasing tremendously. In this review, we present a comprehensive report on the recent development in the synthesis, optimization conditions, mechanism, and characterization techniques of AgNPs synthesized from plant extracts. Furthermore, a thorough discussion on the recent advances in the application of AgNPs synthesized from plant as therapeutic agent against bacterial infections was made.

## 1. Introduction

Bacterial infections had remained a major threat facing medical industry since the occurrence of antibiotic-resistant bacterial strains [1]. The overdosage of antibiotics in treating infectious diseases coupled with other side effects (like strain, diagnosis, and treatment, hypersensitivity, immune-suppression, and allergic effects) has been linked to the causes of drug resistance. Reports on the usage of AgNPs as a therapeutic agent in curing bacterial infection or as an alternative to antibiotic drugs showed good effect on multi-drug resistant bacteria [2]. The presence of protein caps on AgNPs has been observed to be a great advantage in promoting the binding and stabilization on bacterial cell surface

which promote the binding and absorption of drug on human cells [3].

Nanotechnology is the scientific approach of synthesizing particles of nanoscale in the range of 1 to 100 nm [4]. The large surface area to volume ratio exhibited by nanoparticles has been reported to enhance their optical properties to confine their electrons and yield quantum effects that are easily detectable. Diverse application of AgNPs in pesticide [5, 6], food sensing [7], textile [8], medical [9], DNA detection [10], water [11] and pharmaceutical industries has been reported to increase its demand.

Limitation of the chemical method of synthesizing AgNPs has been traced down to the health and environmental implications associated with the organic solvents

such as ascorbate, trisodium citrate, hydrazine, sodium borohydride, and sodium borohydride used as reducing and stabilizing agent in chemical synthesis of AgNPs [12]. In addition, literatures had also made it clear that chemical reduction method also produces low yield, high purity, require high energy, and expensive [13, 14].

Quest to eradicate this problem as demand for AgNPs increases had led to the synthesis of AgNPs from biological substances (microorganisms and plants). Intracellular and extracellular synthesis of AgNPs from microbes such as *Penicillium oxalicum* GRS-1 [15], *Aspergillus fumigatus* BTCEB10 [16], and *Trichoderma longibrachiatum* [17] have been documented. However, the following set back was recorded; expensive cost of isolation, difficulties in maintaining aseptic conditions, culture media, and toxicity of some microorganism [18].

It is worth knowing that the phytosynthesis of AgNPs puffer solution to the limitations associated with both the chemical and microbial methods of synthesis because the reduction process and mechanism of phytosynthesis of AgNPs are based on the biomolecules found in the plant extract; therefore, they are said to be cheap, environmental friendly, easy, and cost-effective [19]. The following biomolecules: terpenoids, carbohydrates, tannins, fats, enzymes, flavonoids, and phenols have been reported proficient for the reduction of silver to nanoparticles [20].

## 2. Synthesis of AgNPs from Plants

In synthesis of AgNPs from plant encourage large-scale production of AgNPs, which is a remedy to the high demand of AgNPs, plant leaf is more preferable than the whole plant in the synthesis of extracellular AgNPs [21]. Plant extract possesses diverse active biomolecules such as phenolic acids, sugars, terpenoids, alkaloids, polyphenol, and proteins that play vital role in this biological reduction and stabilization of silver ions [22]. The structure of some active biomolecules that are capable of reducing and stabilizing silver ions are shown in Table 1. The size and shape of AgNPs depend on the following parameters: volume of plant extract used, concentration of silver, temperature, reaction time, and pH value of the reaction [23]. The procedure for the synthesis of AgNPs entails collection and identification of plants part (seeds, fruits, leaves, rhizomes, roots, barks, pulps, stem, pod, and latex), purification of plant parts by sorting and washing, drying of plants parts at room temperature to prevent evaporation of volatile biomolecules, pulverization of dried plant parts to aid rapid extraction, extraction with water or other solvent at minimum temperature if heat is required, preparation of silver salt usually in concentration of 1–5 mM, and combination of plants extract with prepared silver salt in ratio of 1 : 5. Application of minimal heat to the mixture with continuous stirring until a color change has been observed; finally, the solution will be filtered and incubated [24]. Report has shown that the biosynthesis of AgNPs could be completed in the silver salt solution within minutes at temperature of 25°C; however, the types of secondary metabolites present in plant extract have a great significance effect. Also, the concentration of the extract,

TABLE 1: Structures of some secondary metabolites used as stabilizing and reducing agents in AgNPs synthesis.

Structures of some secondary metabolites used as stabilizing and reducing agents in AgNPs synthesis		
Rutin	Genistein	Quercetin
Gallic acid	Daldzein	Papaverine

concentration of silver salt, temperature, pH, and contact time matter [25]. The chemical and physical methods are equally employed in the synthesis of AgNPs. The chemical synthesis entails the use of some hazardous chemicals and reagents which can cause some health and environment implications for the reduction of the silver ions and stabilization of formed nanoparticles, while the physical method makes use of electric current in generation of electron needed for AgNPs synthesis. Electrospraying, laser pyrolysis, laser ablation, and evaporation-condensation rampantly used physical methods of AgNPs synthesis [26–28]. The flow chart illustrating the synthesis of AgNPs is given in Figure 1.

## 3. Optimization Conditions for the Synthesis of AgNPs from Plants Extract

The roles of reaction parameters are very imperative in optimizing the size, stability, and yield of biosynthesized AgNPs. Alteration of concentration of the plant extract, pH, time of incubation, concentration of silver salt, and temperature has been reported as good optimizing condition for the synthesis of AgNPs [29]. Properties of AgNPs greatly depend on optimization conditions. Many researchers had reported pH values in the range of 2 to 14 for AgNPs synthesis [13]. Nevertheless, a pH value of 7 has been reported as an optimal condition for monitoring the complete reduction of  $\text{Ag}^+$  to  $\text{Ag}^0$  during the synthesis of AgNPs using *Pinus eldarica* bark extract [30]. Also maximum nanoparticles synthesis occurred between pH of 7 and 9 during the synthesis of AgNPs using *Fusarium oxysporum* [31]. The synthesis of AgNPs can be attained at different temperatures but 25°C (room temperature) has been documented as optimal for the synthesis of small size and spherical AgNPs [32]. Maximum yield of biosynthesized AgNPs was recorded at room temperature using aqueous *Aloe barbadensis* leaf extract [3]. Similar result was obtained from the synthesis of AgNPs using *Annona squamosa* peel extract [33]. Temperature has been found to be a good parameter in determining the nature of peaks of synthesized AgNPs, and low temperature corresponds to sharp peaks, while higher temperature is associated with broad peaks. The synthesis of AgNPs using the *Aspergillus fumigatus* revealed maximum yield and desired particle size of 322.8 nm with sharp peaks at 25°C. With an increase in temperature, AgNPs with increased size and broad peaks were produced [16]. Concentration of silver salt played vital role in estimating the level of agglomeration in the synthesis of AgNPs and concentration above 10 mM resulted in increase in the surface plasmon resonance (SPR) band, agglomeration buildup of silver, and blurred surfaces. A period of 10 minutes has been regarded as the optimal incubation time for the AgNPs [34].

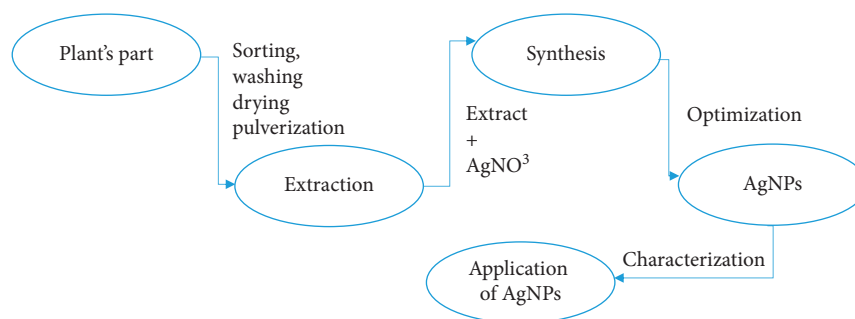


FIGURE 1: Flow chart illustrating the synthesis of AgNPs.

#### 4. Mechanism of AgNPs Synthesis

The biosynthesis of AgNPs is a simple and facile method achieved by mixing silver nitrate ( $\text{AgNO}_3$ ) with biological substances usually microorganism (fungi, bacterial and algae) or extract from plant's part serving as the capping and stabilizing agents [35]. The reduction and stabilization of silver ions from  $\text{Ag}^+$  to  $\text{Ag}^0$  has been traced to the presence of OH functional groups in plants biomolecules such as proteins, amino acids, enzymes, steroids, alkaloids, polyphenols, quinones, tannins, saponins, carbohydrates, flavonoids, and vitamins in plants extracts or microorganism [35, 36], though the right mechanism involved in the reduction and stabilization of silver ions has not been clearly understood because biomolecules varies from plant to plants, hence, the complexity of the mechanism because 4000 phytochemicals had been known in plants [36]. Therefore, the synthesis of AgNPs from plants needs more detailed research as to divulge the appropriate biomolecules serving as the capping and stabilizing agent. Nevertheless, numerous plants are described to support the synthesis AgNPs. Some of such plants are documented in Table 2.

The illustration of the possible mechanism involved in the synthesis of AgNPs from plant extract is given in Figure 2. The conversion of the hydroxyl groups from a secondary metabolite quercetin (2-(3,4-dihydroxyphenyl)-3,5,7-trihydroxy-4H-chromen-4-one) usually found in plant extract to the 3,5,7-trihydroxy-2-(4-hydroxy-3-oxocyclohexa-1,5-dien-1-yl)-4H-chromen-4-one generates reducing equivalents that are used for the conversion of silver metal ions ( $\text{Ag}^+$ ) into elemental ( $\text{Ag}^0$ ) nanostructures [36]. This usually accomplished a color change during nanoparticles synthesis.

#### 5. Characterization of AgNPs Synthesized from Plants

Characterization is required for determination of the structural and morphological properties of AgNPs. The major techniques used for the characterization of AgNPs are X-ray diffraction (XRD) for identification of the crystalline or amorphous natures of AgNPs, scanning, and transmission electron microscopy (SEM) for evaluation of size and morphology of synthesized AgNPs; Fourier transform infrared (FTIR) is used for identification of functional groups used in reduction of silver salt. For each of the characterization techniques, a different method of sample preparation is required [64].

#### 6. XRD Analysis

XRD analysis determines the crystallite size of AgNPs. This is achieved with Philips diffractometer of 'X' pert company and a nanochromatic Cu K  $\alpha$  radiation of ( $\lambda = 1.54060 \text{ \AA}$ ) radiation. The width of XRD peaks is used for the size determination following Scherrer's formula,  $D = 0.86\lambda/\beta \cos \theta$ . The three diffraction peaks of (111), (200), and (220) represent the face-centered cubic silver. The sharpness of these peaks illustrates formation of particles the nanosize [64]. Another study also reported the indexing peak of AgNPs displayed strong Bragg's reflection which correspond to the reflections of face centered cubic of silver as shown in Figure 3.

#### 7. Scanning Electron Microscope (SEM)

This technique is used to study the size and shape of the nanoparticles. In SEM technique, electrons are used for the formation of an output image instead of light [66]. The synthesized AgNPs is placed on a stub made for SEM analysis. The stub is usually made up of small cylinder copper of 1 mm diameter. One layer of the stub contains carbon. When the synthesized AgNPs is placed on the carbon material, the stub is attached to a holder. The holder can take up to seven samples [63]. A spherical, hexagonal, round, oval, cuboidal, and triangular shape of AgNPs has been detected using the SEM techniques as shown in Table 2. An example of SEM microgram of synthesized AgNPs is shown in Figure 4. Aside from the morphological assessment of AgNPs, SEM analysis can also be useful for the estimation of stability of AgNPs; SEM analysis of AgNPs synthesized from *Carica papaya* leaf extract showed that increase in concentration of plant extract led to agglomeration and destabilization of AgNPs [67].

#### 8. Fourier-Transform Infrared (FTIR) Spectroscopic Technique

FTIR technique is useful for the determination of the functional groups in the plants biomolecules that are responsible for the reduction and stabilization of the silver ion. For FTIR analysis, synthesized AgNPs and plant extract could be in the solid or liquid state. The dry method of analysis synthesized AgNPs and plant extract was carried out by mixing 1% (w/w) AgNPs and plant extract with 100 mg of potassium bromide powder separately. The mixture was properly pressed into a sheer slice and was scanned by on

TABLE 2: Characterization of AgNPs synthesized from plants extracts.

S/ N	Scientific names	Plants extract	Wavelength (nm)	Techniques used	Shape	Size (nm)	Ref
1	<i>Artemisia vulgaris</i> L.	Leaf	420	UV, FTIR, AFM, SEM and TEM	Round	25	[37]
2	<i>Mentha spicata</i>	Leaf	460	UV, FTIR, SEM and XRD	Spherical	44.98	[38]
3	<i>Oryza sativa</i>	Husk	425	UV, FTIR and SEM	Spherical	47.90	[39]
4	<i>Carica papaya</i>	Peel	435	UV, FTIR, XRD, SEM and TEM	Spherical	20.10	[40]
5	<i>Coriandrum sativum</i>	Leaf	316	UV, FTIR, XRD, SEM	Spherical	6.45	[41]
6	<i>Eriobotrya japonica</i>	Leaf	469	TEM, FESEM, and SAED	Spherical	3–30	[42]
7	<i>Ocimum tenuiflorum</i>	Leaf	420	UV, FTIR, AFM, SEM, and XRD	Spherical	28	[43]
8	<i>Solanum trilobatum</i>	Leaf	423	UV, FTIR, AFM, SEM, and XRD	Spherical	26.5	[43]
9	<i>Syzygium cumini</i>	Leaf	422	UV, FTIR, AFM, SEM, and XRD	Spherical	65	[43]
10	<i>Centella asiatica</i>	Leaf	421	UV, FTIR, AFM, SEM, and XRD	Spherical	22.3	[43]
11	<i>Citrus sinensis</i>	Peel	420	UV, FTIR, AFM, SEM, and XRD	Spherical	28.4	[43]
12	<i>Salvia spinosa</i>	Seed	450	UV, FTIR, XRD and FESEM	Oval	19–25	[27]
13	<i>Morus nigra</i>	Leaf	430	UV, FTIR, XRD and TEM	Spherical	15–20	[44]
14	<i>Silybum marianum</i>	Fruit	425	UV, FTIR, XRD and TEM	Spherical	25	[45]
15	<i>Berberis vulgaris</i>	Leaf	450	UV, FTIR, XRD, DLS and TEM	Spherical	30–70	[46]
16	<i>Quercus brantii</i>	Leaf	435	UV, FTIR and TEM	Spherical	6	[47]
17	<i>Prunus japonica</i>	Leaf	425	UV, FTIR and SEM	Hexagonal	26	[48]
18	<i>Pistacia atlantica</i>	Seed	438	UV, FTIR, XRD, and TEM	Spherical	10–50	[49]
19	<i>Catharanthus roseus</i>	Root	429	UV, FTIR, XRD and TEM	Spherical	35–55	[50]
20	<i>Rumex hymenosepalus</i>	Root	456	UV, FTIR, XRD and TEM	Hexagonal	2–40	[51]
21	<i>Aloe vera</i>	Leaf	430	UV, FTIR, XRD and TEM	Triangular	70	[52]
22	<i>Calotropis procera</i>	Latex	454	UV, FTIR and SEM	Spherical	12.33	[53]
23	<i>Acorus calamus</i>	Rhizome	437	UV-Vis, DLS, SEM, XRD, FTIR	Cuboidal	59	[54]
24	<i>Erythrina indica</i>	Root	460	UV-Vis, DLS, EDX, SEM, XRD, FTIR	Spherical	20–118	[55]
25	<i>Cymodocea serrulata</i>	Leaf	454	UV-Vis, DLS, TEM, SEM, XRD, FTIR	Spherical	29.28	[56]
26	<i>Dimocarpus longan</i>	Peel	432	TEM, SEM	Spherical	8–22	[57]
27	<i>Cymodocea serrulata</i>	Whole plant	441	UV-Vis, DLS, EDX, SEM, XRD, FTIR	Spherical	17–29	[58]
28	<i>Quercus acuta</i>	Fruit	421	UV-Vis, SEM, TEM, XRD, FTIR, DLS	Spherical	40	[59]
29	<i>Rubus glaucus Benth</i>	Leaf	422	UV-Vis, TEM, SEM, FTIR, XRD	Quasi spherical	12–50	[60]
30	<i>Plumeria alba</i>	Flower	436	UV-Vis, DLS, SEM,	Spherical	36.19	[61]
31	<i>Rosa damascena</i>	Petal	429	UV-Vis, TEM, SEM, FTIR, XRD, EDX	Spherical	15–27	[62]
32	<i>Rosa indica</i>	Petal	415	UV-Vis, TEM, SEM, FTIR, XRD, EDX	Spherical	23.52–60.83	[63]

[AFM = atomic force microscopy, FESEM = field emission scanning electron microscopy, SEAD = selected area electron diffraction, DLS = dynamic light scattering, and UV-Vis = ultraviolet-visible].

FTIR spectrometer (FTIR Nicolet 5700, Thermo Corp. USA) at a resolution of  $2\text{ cm}^{-1}$  [65]. The FTIR analysis of synthesized AgNPs and plant extract had revealed that functional groups such amides and amino carboxyl are responsible for the stabilization of synthesized AgNPs [68–71]. The FTIR spectrum illustrating that plant extract contained some biomolecules is shown in Figure 5.

## 9. Transmission Electron Spectroscopy (TEM)

Determination of size distribution of AgNPs is very vital because they possess different physical and chemical features depending on their shape and size [73]. In the preparation of AgNPs for TEM analysis, small amount of AgNPs is placed on carbon coated copper grids. A ray of photons is transmitted through an ultrathin dried grid containing the AgNPs and interacting with it as it passes through [22]. The electrons are transmitted through the AgNPs to produce an interaction that results in the formation of an image. The

image is magnified and recorded by an imaging device [74]. The use of medicinal plants for the synthesis of AgNPs is not only for the enhancement of their antimicrobial properties but also to regulate the size and shape of AgNPs [37]. Numerous plant extracts have been used for the synthesis of AgNPs and different morphologies have been obtained in Table 2. SEM microgram showing a spherical shape synthesized nanoparticles is shown in Figure 6.

## 10. UV-Vis Spectroscopy

The UV-Vis spectroscopy is used to measure the plasmon absorbance responsible for characteristic colors observed during the synthesis of AgNPs. The absorption of the electrons on the surface of AgNPs and electromagnetic radiation by incident light produces oscillations. The absorption maximum for AgNPs has been reported to be in the range 0.5 and 0.7. The plasmon resonance produces a peak near 400 nm which confirmed the synthesis of AgNPs [71].

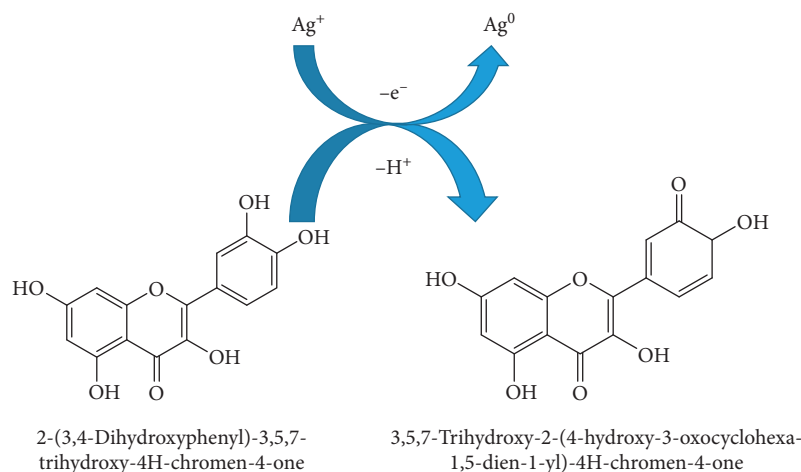


FIGURE 2: The proposed mechanism for the synthesis of AgNPs.

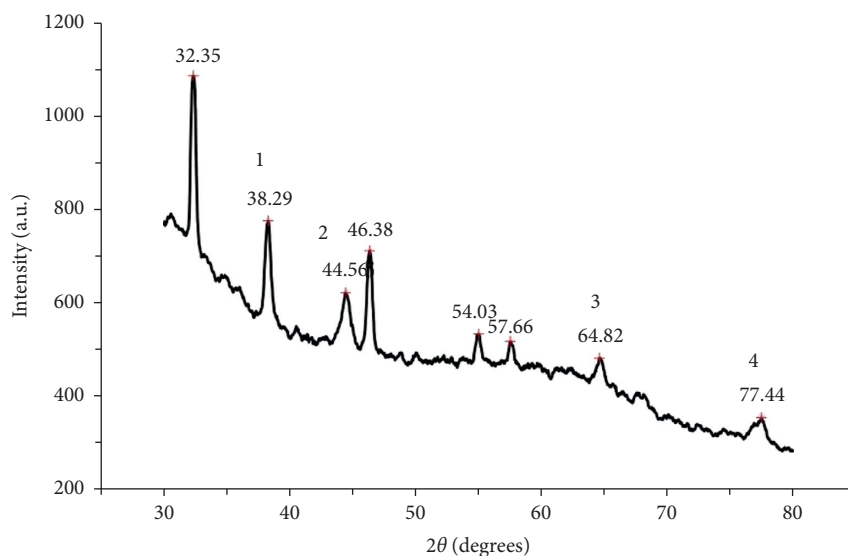


FIGURE 3: XRD micrograph of the synthesized silver nanoparticles Adapted from [65].

The UV-Vis spectroscopic analysis of AgNPs synthesized from plant and their corresponding plasmon resonance peaks are shown in Figure 7 and Table 1.

### 11. Energy-Dispersive X-Ray Spectroscopy

The elemental composition of synthesized AgNPs is determined with the energy-dispersive X-ray technique [76]. The working principle of an energy-dispersive X-ray is based on the collision of electrons with the nanoparticles to produce X-rays, the uniqueness of the atomic structure of each element in making a distinct set of peaks on its X-ray spectrum results to the characterization of the elements. The distinct

peak at 2.8–3.2 keV on the EDX is associated with the presence of silver [77]. EDX analysis of AgNPs shown in Figure 8 revealed an optical absorption peak at 3 keV [75].

### 12. Antibacterial Activity of Silver Nanoparticles

Recently, the increase in antibiotic-resistant microbes is becoming alarming and worrisome, and certain pathogens associated with some infections which increase the mortality rate in human and method of treatment with available antibiotic are proving abortive cost. Therefore, the need to

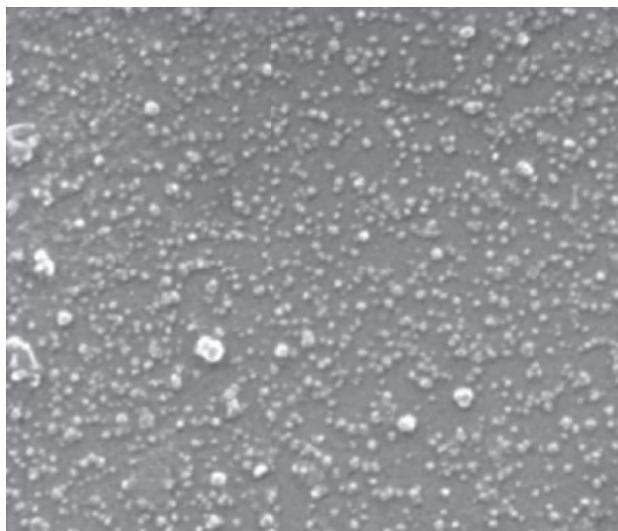


FIGURE 4: SEM micrograph of the synthesized silver nanoparticles adapted from [28].

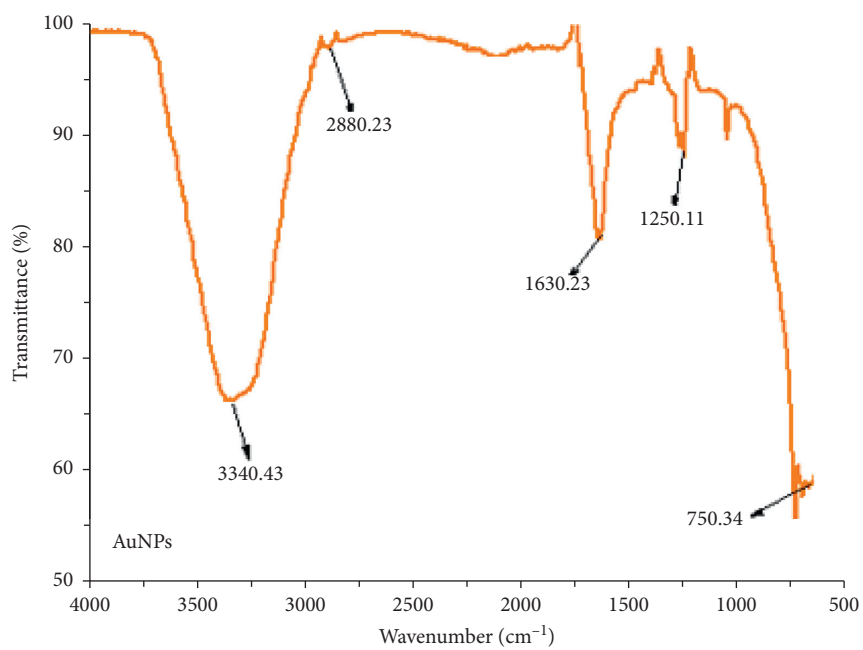


FIGURE 5: FTIR spectrum of synthesized silver nanoparticles adapted from [72].

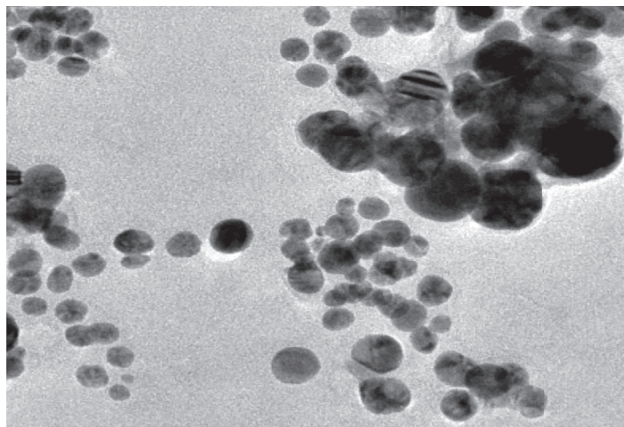


FIGURE 6: TEM micrograph of the synthesized silver nanoparticles adapted from [72].

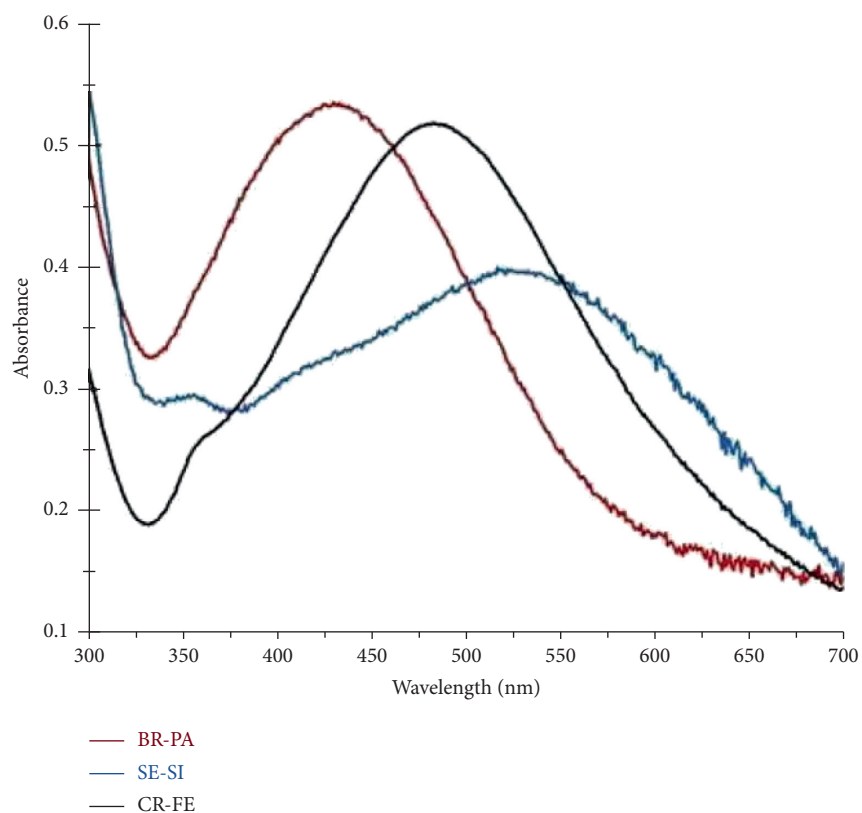


FIGURE 7: UV spectrum of the synthesized silver nanoparticles adapted from [75].

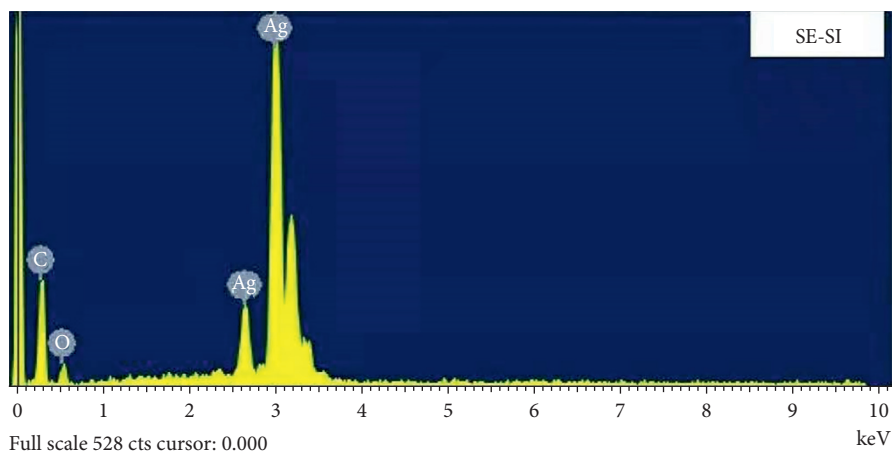


FIGURE 8: EDX micrograph of the synthesized silver nanoparticles adapted from [75].

develop novel antibacterial agents with good potency against MDR strains is of great importance [78]. AgNPs possess some features that can inhibit the growth of the MDR organism. The concentration, shape, colloidal state, and size are the major parameter that determine the antibacterial efficacy of AgNPs [79]. It has been established by researchers that the lower the size of AgNPs, the higher its stability and biocompatibility. The effectiveness of AgNPs against bacteria, fungi, and viruses has been established. The antibacterial activity of AgNPs has been recorded to be greater than that of silver nitrate [80]. AgNPs with smaller particle size

are found more lethal because of their larger surface area and easy adsorption. Hence, AgNPs toxicity depends largely on size [80, 81]. The ability of AgNPs to form an attachment on the bacterial cell wall and membrane, its capability in destruction of the structures within the cell, production of reactive oxygen species, and free radicals that stimulate cellular toxicity and oxidative stress and regulation of the signal transduction pathway are the distinct antibacterial actions of AgNPs [82]. When microorganisms are treated with AgNPs, AgNPs binds on the cell wall of the pathogen and causes the shrinkage of the cytoplasm and busting of the

TABLE 3: The antibacterial activities of AgNPs synthesized from some plants extracts.

S/ N	Plant extract	Plant parts	Zones of inhibition (mm)	Bacterial strains	Ref.
1	<i>Althaea officinalis</i>	Flower	15–18	<i>Escherichia coli</i> and <i>Staphylococcus aureus</i>	[86]
2	<i>Thymus vulgaris</i>	Leaf	16–18	<i>E. coli</i> and <i>S. aureus</i>	[86]
3	<i>Mentha pulegium</i>	Leaf	16–18	<i>E. coli</i> and <i>S. aureus</i>	[86]
4	<i>Gleichenia pectinata</i>	Whole plant	5–15	<i>Pseudomonas aeruginosa</i> , <i>Klebsiella pneumonia</i> , and <i>Candida albicans</i>	[87]
5	<i>Berberis vulgaris</i>	Root	3–5	<i>E. coli</i> and <i>S. aureus</i>	[46]
6	<i>Saraca asoca</i>	Leaf	10	<i>Staphylococcus aureus</i> , <i>Streptococci pyogens</i> , and <i>Salmonella typhi</i>	[88]
7	<i>Glycosmis mauritiana</i>	Leaf	7–19	<i>Bacillus cereus</i> , <i>B. subtilis</i> , <i>Enterococcus faecalis</i> , <i>E. coli</i> , and <i>K. pneumonia</i>	[89]
8	<i>Moringa oleifera</i>	Leaf	12–25	<i>S. aureus</i> , <i>E. faecalis</i> , <i>E. coli</i> , <i>P. aeruginosa</i> , and <i>K. pneumoniae</i>	[90]
9	<i>Olive europaea</i>	Leaf	18–21	<i>Staphylococcus aureus</i> , <i>Escherichia coli</i> , and <i>Salmonella enterica</i>	[91]
10	<i>Salvia rosmarinus</i>	Leaf	9–13	<i>Staphylococcus aureus</i> , <i>Escherichia coli</i> , and <i>Salmonella enterica</i>	[91]
11	<i>Amaranthus tricolor</i>	Leaf	7.8–11.8	<i>Escherichia coli</i>	[92]
12	<i>Musa balbisiana</i>	Leaf	6–16	<i>Bacillus subtilis</i> and <i>E. coli</i> cultures	[93]
13	<i>Azadirachta indica</i>	Leaf	8–14	<i>Bacillus subtilis</i>	[27]
14	<i>Ocimum tenuiflorum</i>	Leaf	8–14	<i>E. coli</i> cultures	[27]
15	<i>Salvia spinosa</i>	Seed	12–16	<i>Bacillus subtilis</i> , <i>Bacillus vallismortis</i> , and <i>Escherichia coli</i>	[27]
16	<i>Malachra capitata</i>	Leaf	14–21	<i>Bacillus subtilis</i> , <i>Micrococcus luteus</i> , <i>Staphylococcus aureus</i> , and <i>Pseudomonas aeruginosa</i>	[94]
17	<i>Tectona grand</i>	Seed	12–20	<i>B. cereus</i> , <i>S. aureus</i> , and <i>E. coli</i>	[25]
18	<i>Garcinia mangostana</i>	Fruit	12–18	<i>Staphylococcus</i> sp., <i>Bacillus</i> sp., <i>Klebsiella</i> sp., and <i>Pseudomonas</i> sp.	[95]
19	<i>Zanthoxylum chalybeum</i>	Root	0.83–2.67	<i>B. subtilis</i> , <i>E. coli</i> , and <i>P. aeruginosa</i>	[96]
20	<i>Azadirachta indica</i>	Leaf	11–13	<i>E. coli</i> , <i>K. pneumonia</i> , <i>P. aeruginosa</i> , and <i>S. aureus</i>	[97]
21	<i>Camellia sinensis</i>	Leaf	11–18	<i>Escherichia coli</i>	[97]
22	<i>Mangifera indica</i>	Peel	12–19	<i>Klebsiella pneumonia</i>	[97]
23	<i>Syzygium cumini</i>	Bark	10–12	<i>Escherichia coli</i> and <i>Bacillus subtilis</i> .	[98]
24	<i>Plectranthus amboinicus</i>	Leaf	0–31	<i>P. vulgaris</i> , <i>P. aeruginosa</i> , <i>B. subtilis</i> , and <i>S. aureus</i>	[99]

mm, millimeter.

cell wall [83]. The interaction of AgNPs with sulfur-containing enzyme such as O-acetylserine sulfhydrylase (CysK) changes destroys the cell wall morphology of the pathogen [84]. AgNPs has been recommended for the treatment of infections caused by Gram-negative bacteria because AgNPs display higher toxicity against the Gram-negative bacteria than Gram-positive bacteria because of the thinner cell wall and small amount of peptidoglycan they have [85]. The antibacterial activities of AgNPs synthesized from some plants extracts are shown in Table 3.

### 13. Conclusion

Over the years, many efforts have been invested into the development of safer method of synthesizing AgNPs. The morphological evaluation of AgNPs synthesized from plants using various characterization techniques revealed variations in size, crystallinity, and shape distribution which is a huge challenge and a major limitation. This suggests that the regulation of silver salt concentration, volume of plant extract, pH value of the solution, reaction temperature, and time have crucial roles in procurement of Ag NPs with uniform size and shape distribution. All the same, the production of AgNPs with uniform morphological properties is of importance. Furthermore, the identification of the exact functional group in the biomolecules of plant

accountable for the reduction and stabilization of silver ion required more investigation. Aside from the investigation of the antibacterial potency of AgNPs, the *in vivo* examination should also be investigated to assess their biocompatibility and toxicity level so that novel and potential therapeutic agent for bacterial can be produced.

### Conflicts of Interest

The authors declare that they have no conflicts of interest.

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