Review Article

Plant-mediated noble nanoparticle biosynthesis, characterization approaches, synthesis parameters, and antibacterial action: A review

Abstract

Metallic nanoparticles are receiving more attention as a result of their extensive uses in fields such as health, chemistry, agriculture, and biotechnology, which may be related to their matching small sizes. Because most plants are normally economically, readily accessible, eco-friendly, and harmless, the utilization of plant material for nanoparticle production has increased a lot of traction. The findings of this review are noteworthy because nanoparticle production is different in the properties, types, and physical as well as chemical processes of nanoparticle development for the green development of nanoparticles, their types, and their properties. We have studied in detail the biosynthesis of nanoparticles utilizing extracts from most common plants and their various sections, as well as the various kinds of characterization processes employed for their identification. Numerous current investigations have shown that plant extracts can be used as a non-hazardous precursor for the combining of nanomaterial. Various kinds of reducing and capping/balance factors are abundant in plant extracts. As a result, this approach has great scale-up potential and can generate nanoparticles with a variety of morphologies. Plant-derived NPs are not at most further stable with regards to forming a size and produce a better yield than conventional physical and chemical approaches. As a result, the effect of numerous experimental agents on the size as well as the rate of nanoparticle formation is also discussed. The antibacterial activity of plant-mediated biosynthesized nanoparticles is also discussed in this paper.

Keywords: antimicrobial, biosynthesis, capping/stabilizing agents, characterization, nanoparticles

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Introduction

Nanoscience, a new interdisciplinary discipline with potential applications in electronics, medicine, and a range of other fields, has grown as a main sector of current experiments in recent decades.[1,2] Researchers and the scientific community have become more interested in Nanotechnology which is a modern branch of nanotechnology. It blends natural concepts with organic and inorganic approaches to develop nanoparticles (NPs with sizes ranging from 1 to 100 nanometers) capable of performing specific tasks.[3] The characteristics of materials in this range may vary considerably from those envisaged when they have larger dimensions. NP has multifunctional qualities and noteworthy uses in a broad scope of disciplines, along with nutrition, power, as well as medicine,[4] and has provided substantial benefits in the pharmacy sector by curing a variety of viral and bacterial diseases.[5] Owing to highly enhanced properties of metallic nanoparticles (MNPs) as compared to their bulk counterparts[6] increasing attention is being paid for synthesis and optimization of MNPs for the reason that diverse function in many practices like as chemistry, medicine, biotechnology, as well as agriculture.[7]

Chemical methods are the most prevalent tool for producing MNPs, however, there are others.[8] However, most chemical methods are prohibitively expensive, and the depletion of metallic particle mixture requires the utilization of hazardous and toxic chemicals in combination with conventional capping and reducing factors like sodium dodecyl sulfate, sodium citrate, and sodium borohydride, which are associated with a variety of biological risks and health hazards.[9] This limits the applications of MNPs, and as a result, there has been a rising demand in recent years to discover alternatives to chemical techniques.[10]

Plant extract-based methods are said to be the best of all since they provide a superior choice for NP synthesis because the protocols incorporating plant sources are devoid of harmful compounds, and natural capping agents are easily available from the plants.[11] Organisms can also be used to produce NPs, however, the amount of synthesis is slower than that of plant-mediated synthesis. Plant extracts have become increasingly popular in recent years because they are generally inexpensive, readily available, nontoxic, and environmentally friendly. Due to their distinctive physiological activities, like enzymatic activity, optical dynamic, photoelectric process, magnetic properties, and antibacterial properties,[12-17] and various critical applications, the demand for MNPs like Silver (Ag), Gold (Au), Iron (Fe), Palladium (Pd), and others have increased. Plant extracts are used in most research on the development of Au-NPs and Ag. The bactericidal activity of bite-size and large external surface-to-intensity proportion of MNPs has been connected to their ability to combine around with microbial film instead of present in solution. Gold nanoparticles (Au-NPs) have received Platinum (PT), far more attention among MNPs have great scattering and absorption because of biocompatibility and broad range scale of utilization in medicine as well as biology[18,19] tunable surface plasmon resonance (SPR)[20] easy surface functionalization simple synthesis methods[21] and low toxicity.[22] AgNPs are common antimicrobial factors used in accurately inserted catheters to prevent allergy.[23] They are believed to have anti-permeability properties, anti-angiogenic, anti-inflammatory and antifungal. MNPs also have agriculture and plant sciences that cover a wide range of responsibilities. For example, the NP turns food wastes and agriculture into energy and beneficial results using bioprocessing technology. Nano Agriculture refers to the use of nanoparticles in agriculture, in which new technology is frequently used to increase crop productivity.[24]

Chemically synthesized CuNPs were found to be oxidized, aggregated, and settled down after 24 hours, CuNPs made with Magnolia leaf extract, on the other hand, Since some capping components surrounded the NPs' surface, they were demonstrated to remain stable for over 30 days, that is an additional benefit of employing plant extract over chemical techniques for NP synthesis.[25] The reduction of Cu ions and the stability of synthesized CuNPs appear to be mediated by biomolecules with functional groups of alcohols, ketones, amines, aldehydes and carboxylic acids, like reducing sugars and terpenoids. PtNPs have been used in biomedical applications as alloys, core-shell nanoclusters, and bimetallic nanoclusters in combination with other metal nanoparticles.[26] Zinc oxide (ZnO) is a metal oxide nanoparticle that has recently received a lot of interest (MONPs). Because of their unique features and a vast range of uses, ZnO nanostructures are at the forefront of research.[27]

This review presents highlights of biosynthesis of M/MO-NPs using plant-extract; critically analyze characterization techniques and their antibacterial properties.

Classification

Based on the type of material used, organic, inorganic, and carbon-based NPs are the most common types. Table 1, lists a few of the most typically synthesized NPs for use in an extensive range of functions:

Synthesis

In common, the two major techniques of NP production are the bottom-up approach and the top-up approach. The major methods of NPs synthesis, including the bottom-up and top-down approaches, are summarized in Figure 2. In the bottom-up approach, a convenient bulk material is reduced to nanometric scale particles using various lithographic methods like grinding, milling, thermal/laser ablation sputtering, etc. whereas in the top-down technique, a convenient bulk substance is lesser to nanometric scale particles using various lithographic techniques such as milling, grinding, thermal/laser ablation sputtering, and so on.[28]

The formation of substances from atoms to groups to NPs is called the bottom-up approach. Among the approaches previously covered, this is arguably the most flexible and straightforward method for creating impurity-free NPs. Chemical reduction is a popular technique for synthesizing AgNPs in the bottom to top strategy.[29,30] To decrease silver ions (Ag+) in non-aqueous and aqueous mixtures, inorganic and organic reducing factors such as sodium citrate, sodium, ascorbate, borohydride (NaBH4), tollen's reagent, elemental hydrogen, N,N-dimethylformamide (DMF), and poly (ethylene glycol) organic linkers are utilized.

Industrially, the physical method of synthesis is considered to be the most promising since it is cheap, easy and gives very high production yields. It entails first creating large-scale designs and then reducing them to the nanoscale. Because it is an expensive and time taking process, this process can't be used for board-scope NP formation. Typically, the "top-down" approach necessitates the deployment of a compound and difficult apparatus.[30] Metallurgy, sputtering, nanolithography, mechanical milling, laser ablation and thermal breakdown are some of the largely utilized NPs formation procedures.

Bottom-up method is the build-up of material from atoms to clusters to NPs. This is perhaps the most flexible and simple method of producing impurity free NPs amongst the methods previously discussed. Chemical reduction is the most popular technique for synthesizing AgNPs in the bottom to top approach.[31,32] Silver ions (Ag+) are reduced unsaturated and saturated mixture using a variety of chemical and physical reducing factors like sodium borohydride (NaBH4), sodium citrate, ascorbate, elemental hydrogen, Tollen's reagent, poly (ethylene glycol) block copolymers and N,N-dimethyl formamide (DMF).[33] Capping agents are also utilized to keep the size of the NPs stable. One of the most significant advantages of this technology is the ability to synthesize a high number of NPs in less duration of time. The chemicals utilized in these types of production are hazardous, resulting in non-eco-friendly by-products.

Chemical bottom-up methods involve hydrothermal process, solvothermal process, sol-gel method, Spinning, microemulsion technique, microwave technique, pyrolysis, Chemical Vapour Deposition (CVD) etc. All these techniques are, although simple and cost-effective, the use of chemicals in these methods may be avoided by considering biosynthesis. At this point, some people experiment with temperature, pH, extract concentration, and duration to see what works best. The mixture turns yellow after the incubation period, which is visual evidence of the synthesized NPs.[34,35] Biological bottom-up strategies for the biosynthesis of nontoxic and biodegradable NPs are a green and environmentally beneficial process.[36] For bio-reduction and capping reasons, biosynthesis uses bacteria, plant extracts, fungus, algae, yeast, actinomycetes, and other precursors to generate NP instead of conventional chemicals.[37] The synthesized NP possesses distinctive and broadening characteristics that make their way into biomedical applications. Three key criteria in the biogenesis of MNPs utilizing plant extract are mineral salt, a reducing agent, and a stabilizing or capping factor for dimensions of NPs and avoiding their accumulation.[38] Because contamination makes maintaining and storing a microbial culture difficult, plants may be employed to circumvent the time taking process of sustaining and containing nutrients.[39] Plant-moderate synthesis is an easy and effective way for producing NPs on a large scale without contamination.[40]

Because of their quick, eco-polluting, non-infective, inexpensive process and providing a one-pace approach for the formation of biomolecule procedure, the plants use in the construction formation of AgNPs have sparked the interest of all scientific researchers to focus on their synthesis. Silver ions are reduced and stabilized by a mixture of molecules that are so far present in medicinal plant extracts and are chemically complex structures, such as amino acids, proteins, enzymes, alkaloids, polysaccharides, tannins, saponins, phenolic, vitamins and, terpenoids.[41] Plants that contribute to the formation of NPs have been discovered in great numbers (Table 2), and they are briefly described in this study.

Regular observations of the solution's UV–visible spectra can reveal the presence of a metal salt solution.[42] Plant extracts of biosynthesized NPs are depicted schematically in Figure 3.

Characterization of biosynthesized nanoparticles

Nanometric materials are being developed for a variety of purposes. The effects of these NPs are crucial for the industrial revolution, which primarily focused on synthesis procedures for future appliances like antifungal and bactericidal effects.[43] A number of experimental methods are used to investigate the production and characterization of metallic NPs. The following procedures are used to characterize the NPs that have been synthesized: Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), Field Emission Scanning Electron Microscopy (FE- SEM), Photoluminescence Analysis (PL), Inductively Coupled Plasma spectrometry (ICP), Thermal-gravimetric Differential

Thermal Analysis (TG-DTA), Energy-Dispersive X-ray Spectroscopy (EDS), Atomic Force Microscopy and High-Resolution Transmission Electron Microscopy (HR-TEM), Energy-Dispersive X-ray Spectroscopy (EDS), Atomic Force Microscopy (AFM), and Dynamic Light Scattering (DLS), Raman Spectroscopy, UV-Visible Diffuse Reflectance Spectroscopy (UV-DRS), Attenuated Total Reflectance (ATR), and Dynamic Light Scattering.[44-46] Plant-made nanoparticles are more stable and come in a greater variety of forms and sizes than those manufactured by other creatures.[47] The next sections go through some of the most essential techniques for characterization. Raman Spectroscopy, X-ray Photoelectron Microscopy (XPS) and UV-Visitive Spectroscopy.

Spectroscopy methods like UV-vis, XRD, FT-IR, DLS, EDS, and Raman can also be used to know crystal size, plane, structure, phase, and composition. The production of NPs is confirmed by UV-Vis spectrophotometry. The rate of synthesis rose as the temperature climbed from 0 to 100 degrees Celsius, according to UV-Vis-NIR spectroscopic observations.[48] Surface residues and functional groups present in plant extracts like alkaloids, flavonoids, tannins, terpenes and quinones, phenol, hydroxyls, and others that adhere to the surface of NPs at the time of their production and are thus responsible for efficient metal ion reduction and capping of NPs, resulting in their remarkable stability, are revealed by Fourier Transform Infrared Spectroscopy (FTIR).[49-52] FTIR spectroscopy can be used to describe natural activities of nanoparticles and their functions.[53] Chemical binding in functional and surface atoms on the surface of NPs is evaluated using this method. Minor band shifts are sometimes seen in FTIR analysis of plant physiochemicals in preform or bound to NPs, which are seized as an indication for metal deduction and NP production. Flavonoids, Alkaloids, tannins, terpenes, and quinones are some of the factors found in plants, are the most essential phytochemical elements that enable metal ion reduction and NP capping.[54] Obviously, distinct reducing and capping agents exist inside a plant extract. Table 3 lists the phytochemical elements of the plants studied. The identification of these biomolecules is critical for creating novel ways for NPs synthesis as well as investigating how NP surface chemistry influences their properties and uses. FTIR test revealed the plant extract's dual action as a reducing and capping agent, as well as the existence of a specific functional bond. While phenolics, terpenoids, and amines act as capping factors, flavonoids have been shown to aid in the reduction of silver ions in the production of NPs.[55] Some of the bioorganic components in the *A. indica* extract created a robust coating/capping on the NPs, according to the FTIR data.[56] According to FTIR study, proteins as well as biomolecules like terpenoids containing amines, alcohols, ketones, carboxylic acids and aldehydes, as functional groups surround AuNPs generated using the *Magnolia kobus* extract.[57]

X-ray photoelectron spectroscopy (XPS) is a procedure for determining element speciation and elemental analysis on a surface. This approach irradiates the extract with X-ray light although calculating the kinetic intensity and amount of electrons that depart from the material's area. Because each element forms a different collection of XPS points at distinct adhesive intensity, precisely analyze every element that occurs in the area of the material being investigated.[58] The indicated approach is especially meaningful for identifying amorphous MNPs that are difficult to identify using XRD. The formation of non-crystalline FeNPs in the green biosynthesis of zero-valent FeNPs using green tea samples was confirmed using this approach.[59] XPS can also be used to discover MNPs with low plasmon resonance absorption, such as platinum and palladium. The chemical or elemental makeup of NPs indicates their performance and purity. The unwanted components in higher concentrations in the NP can lessen its productivity as well as trigger secondary reactions and contagion. Composition is typically determined using X-ray photoelectron spectroscopy (XPS).[60]

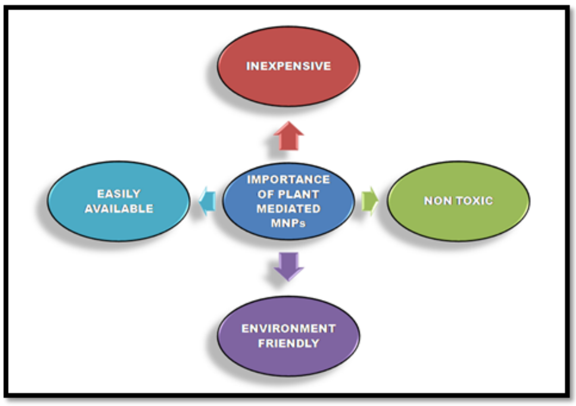

Figure 1 L Importance of biosynthesized NPs.

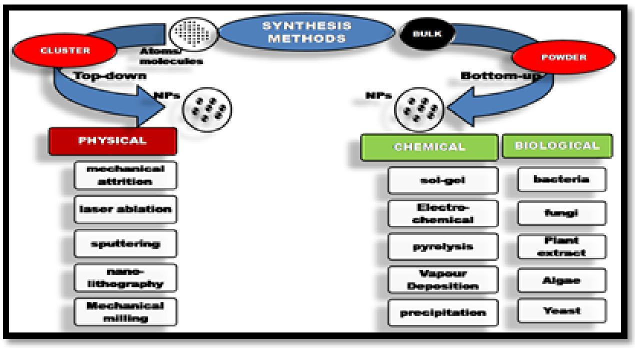

Figure 2 An overview of NPs synthesis methods.

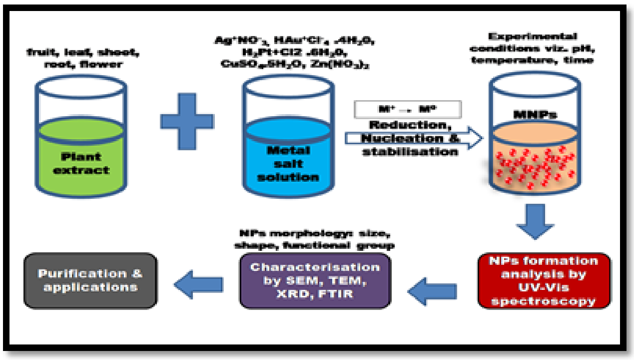

Figure 3 Plant extracts biosynthesized NPs.

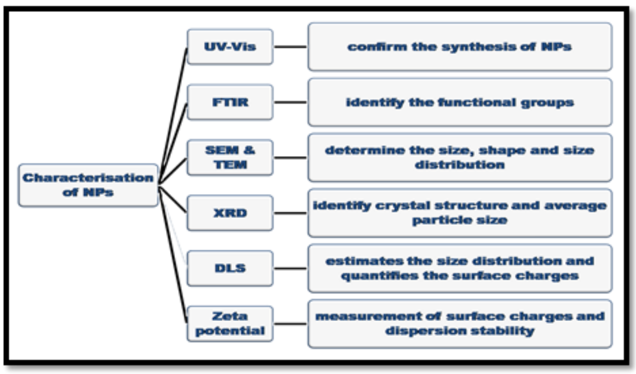

Figure 4 Representation of commonly used characterization techniques of plant extracted biosynthesized NPs.

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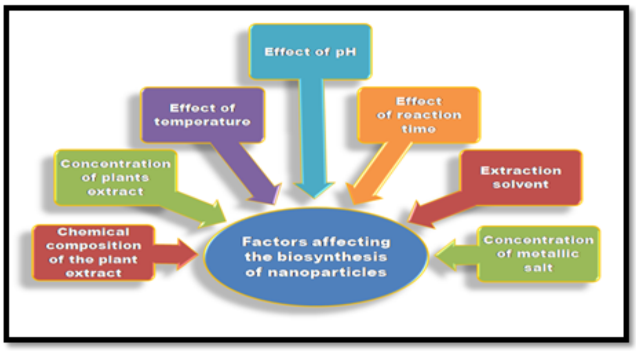

Figure 5 Factors affecting biosynthesis of NPs.

When it comes to utilizing the properties of NPs, their shapes and surface structures are crucial. Some of the pattern consists of flat, spherical, tubular, cylindrical conical, and irregular shapes having crystalline or amorphous surfaces with uniform or imperfections. To determine the surface, electron microscopy imaging techniques such as SEM and TEM are often utilized.[61] The most commonly used procedure for analyzing particle size and dispersion is electron microscopy. Nanoparticles and molecules are measured using Scanning Electron Microscope and Transmission Electron Microscope pictures, whereas substances in the solid phase are analyzed using laser diffraction techniques.[62] A combination of morphologies structures were generated at lower leaf broth concentrations and high pH, whereas minor rounded shapes were collected at heavy concentrations and low pH.

When using olive leaf extracts as reducing agents, the synthesized AuNPs were mostly nanotriangle in shape at low extract concentrations (0.5 ml), but when using greater extract concentrations, The tiny triangular and hexagonal formations vanish, and almost spherical AuNPs take their place.[63,64] This shows that when a large volume of the extract is used to lower aqueous $HAuCl_4$, the biomolecules function as capping agents, resulting in structured rounded nanoparticles in place of nano triangular or hexagonal structures.

The surface charges are quantified and the size distribution of NPs is determined using DLS analysis. The DLS technique, also known as photon correlation spectroscopy, calculates the hydrodynamic particle size of NPs and their dispersion using the light scattering process. Due to the Doppler effect, Brownian motions of the nanoparticles inside the samples cause time-dependent changes in reflecting intensities.[65] These variations are detected by the DLS instrument as related to the hydrodynamic diameter. Regarding size measurement, the method is both faster and less expensive than electron microscopy.

Zeta potential measurements offer details about the surface charge and can be used to forecast the long-term stability of manufactured MNP dispersion.[66] Higher zeta-potential values are a significant parameter for maintaining suspension stability by electrostatic repulsion between particles, resulting in high suspension stability.[67] The zeta potential, which is also the ratio in potential between both the dispersed phase as well as the stationary layer of fluids attaching to the scattered nanoparticle, provides data about the subatomic particle charge density.[68]

Factors affecting biosynthesis of nanoparticles

The results of numerous frameworks on the production of plant-mediated NPs, as well as their description and biological actions, are also defined and analyzed. The green biosynthesis of NPs is influenced by a figure of variables, including substrate concentration, temperature, reaction duration, and pH. The size, shape, and dispersion of M/MO nanofabrication are influenced by these reaction parameters. The most critical factors are identified and explored in the following sections. When the content of *Magnolia kobus* and *Diopyros kaki* leaf broth was increased, the particle size of AuNP decreased.[69,70] When a little amount of plant extract was utilized to react with HAuCl4, hexagonal or triangular AuNPs were generated; however, once the plant extract absorption was raised, the shape of the AuNPs changed.

Chemical composition and concentration of plants extract of the plant extract

Chemically created CuNPs oxidized and settled down after 24 hours due to some capping components covering the surface of the NPs, but CuNPs synthesis using plant extract was firm for more than 30 days, suggesting a benefit of using plant extract for NPs biosynthesis with more organic approach.[71,72] As the amount of plant extract in the solution interchanges, the number and size of NPs in the mixture change as well. The size of synthesized NPs reduces as the intensity of a plant extract increases due to the high nucleation rate. The availability of more lowering agents increased with a narrow size distribution, the number of particles increased.[73,74] Similar findings are obtained when AgNPs are synthesized using tansy plant fruit extract.[75] Raisins contain sugars (60 percent), flavonoids, phenolic compounds, minerals, iron, vitamins, potassium, calcium, and other components that may help to produce SeNPs.[76,77] According to a study, phyto-constituents such as tannins, terpenoids, flavonoids, ketones, aldehydes, amides, and carboxylic acids are responsible for the reduction of silver ions.[78] In the reduction of Ag^+ ions to Ag, several constituents can donate electrons.[79] Tannins have been discovered to play an important function in the reduction and capping of silver nanoparticles.[80] As the amount of *Origanum vulgare* L. plant extract was increased, the size of AgNPs was found to decrease.[81]

A wide peak at a notable wavelength suggests a bigger particle size, while a thin edge at a lower wavelength indicates a smaller particle size. Furthermore, multiple studies have demonstrated that increasing the quantity of plant extract has a significant impact on the size and width of NPs.[82] At 439 nm, the absorption band becomes bigger and moves back into the red area. This is owing to the large amount of reaction medium present, which causes the Ag ions to rapidly deplete. The average particle size of CuNPs dropped while the Magnolia kobus leaf broth content increased percentage of leaves broth equal to 15%, subsequently raised to 20% percentage of leaves broth.[83] At such a higher leaves broth content of 20%, it is thought that many capping components from the plant leaves broth caused a significant aggregate of copper particles, more probably caused by the interaction among NPs, that is surrounded by proteins and compounds including such terpenoids and fructose.[84,85]

Effect of temperature

The rate of reaction increases as the temperature increases, and so does the total conversion of protons into NPs in suspension. Because ion to nucleus conversion is faster at higher temperatures, particle size reduces; preventing secondary reduction. Operating at room temperature is clearly necessary for the stability of plant metabolites.

As the reaction temperature climbed (from 25, 60, to 90°C), Around 95°C, the average diameter dropped between 110 nm at 25°C to 45 nm.[71] In *Magnolia kobus* and *Diopyros kaki* methanolic extracts, the efficiency of AuNPs production rose as the process temperature rose. As the reaction process was elevated, the rate of PtNPs synthesis increased.[57] The size of AgNPs is initially NP clustering decreased, but increased temperature above a specific threshold (75°C) helps the crystalline around the nucleus expand, resulting in reduced absorbance.[75]

Effect of pH

The pH of the colloidal solution has been discovered to have a significant impact on NP size distribution management. The reaction process is slower at acidic pH than at normal pH, according to various studies. At normal pH, the accessibility of a variety of functional groups aids in the depletion process and increases particle stability in mixture. Higher pH values allow for higher monodispersity in microscopic particles by preventing them from aggregating for longer periods of time.[66,73,86] pH has a variety of effects on NP production, including modifying the accessibility of functional bonds, which influences the redox reaction and the interaction between metal and phytochemical capping factors. As a result, the reaction medium's acidity and basicity have an impact on the shape and size of the NPs. Furthermore, medium pH has an impact on NP stability.[87]

Effect of reaction time

Initially, increasing reaction time increases the number of NPs, but after a given length of time, the particles agglomerate into larger sizes with random shapes.[66,72,74] Plant-mediated AgNP synthesis provides a number of distinct advantages, including shorter processing times and less toxic methods. The reaction is typically carried out. It takes a lot of time to accomplish at ambient temperature, but this can be sped up by raising the temperature of the precursor solution. Increased reaction temperature caused a drastic drop in the rate of Ag+ ions, followed by homogeneous nucleation of silver nuclei, allowing individual AgNPs to shape. It has been discovered that the efficiency of NP synthesis increases as temperature of the reaction medium rises.[75]

Metal ion concentration

NPs grow in size when the concentration of metal ions rises, and they are made from a variety of plant leaves.[71,73,74,77] Whenever latex from a variety of species was employed, similar results were found.[88,89] The introduction of a higher ion concentration is intended to hasten nanoparticle formation. This really is especially relevant if the plant extract's content of lowering phytonutrients is really not sufficiently strong. The use of a high concentration of metal ions is expected to speed up the development of nanoparticles. This is especially important if the level of reducing phytochemicals in the plant extract isn't high enough.

Applications as an antimicrobial

MNPs have been extensively studied for their therapeutic value in coming times due to their sizes being identical to molecules and very elevated specific ratio, which allows them to readily interact with harmful bacteria and so perform useful roles in delivery of drugs.[90] For its outstanding and extensive antibacterial efficacy against viral, bacterial, and fungal infection, AgNP is well-known as a crucial nanomaterial. As a result, it's widely used to wrap food, perform therapeutic activities, and bandage wounds.[91] Selenium is also an antibacterial and anti-carcinogenic agent that can be used to treat a variety of tumors.[92] MNPs' antibacterial activity has been demonstrated by a considerable zone of inhibition in various tests, it was found to be effective against both gram-positive and gram-negative bacteria. Table 1 presents the antibacterial effect of plant-mediated produced NPs. The antimicrobial property of CuNPs produced by *Magnolia kobus* was examined towards gram-negative *E. coli*, and it was discovered that when the production temperature and leaf broth concentration was increased, the mean NPs size dropped, and therefore the antibacterial activity increased. Antimicrobial effect of Ag-NPs made from *Azadirachta indica* (neem) leaf extract was discovered against *Escherichia coli* and *Staphylococcus aureus*.[93] The bacteria tested had no reaction to the plant extract. AgNPs adhere to and infiltrate the cell membrane of microorganisms due to their tiny size. Following that, Ag+ ions from AgNPs showed a strong affinity for protein binding, resulting in DNA damage, bacterial growth inhibition, and eventually bacterial death. Bacterial DNA is damaged as a result of this binding, which prevents bacterial reproduction and, as a result, bacterial death.

Table 1 Classification of NPs based on the type of material used

Type		Example	Properties	Reference
Organic nanoparticle		Dendrimers, micelles, liposomes and ferritin.	Biodegradable, harmless, susceptible to heat and electromagnetic radiation.	11
Inorganic nanoparticle	Metal based	Zinc (Zn), gold (Au), lead (Pb), silver (Ag), cadmium (Cd), cobalt (Co), copper (Cu), Aluminum (Al), iron (Fe).	Large external surface to intensity proportion, Pore shape, mass, space charge, amorphous and crystalline arrangement, pigment color, receptivity, susceptibility to biological agents air, thermal sunshine, and moisture, so on Antibacterial, anti-corrosive and anti-fungal.	6, 34
	Metal oxide based	Cerium oxide (CeO_2), Aluminum oxide (Al_2O_3), Magnetite (Fe_3O_4), Silicon dioxide (SiO_2), Iron oxide (Fe_2O_3) Titanium oxide (TiO_2), and Zinc oxide (ZnO).	Have notable activities when analyzed to their metal equivalent like highly reactive, susceptible to sunlight, moisture and heat, Antibacterial, antifungal, anti-corrosive, Large external surface, High surface area, prohibit bacterial development.	93, 89
Carbon based		Graphene, carbon nanotubes (CNT), fullerenes, carbon black and carbon nanofibers.	Unique structural dimension, excellent mechanical, electrical and thermal conductivity.	70

Table 2 Few plant-mediated biosynthesized NPs and their characterization

Plant Name (Plant Part)	Characterization techniques	Product NPs, absorbance peak, Stability	Size (nm), Shape & zeta potential	Reaction Time, Temp (°C), pH	Reference
Magnolia kobus (leaf)	UV-Vis, SEM, HR-TEM; EDS, XPS	**Cu,** 560 nm, 30 days	45 – 110, spherical	24 hrs, 25 - 95⁰C	71
Andrographis paniculata (stem)	UV-Vis, FTIR, DLS, SEM,	**Ag,** 425 nm	70 - 95 nm , spherical, − 21.4 mV	-	60
Phyllanthus niruri (leaf)	UV-Vis, FTIR, DLS, SEM	**Ag,** 424 nm	70 - 120 nm, spherical − 20 mV	-	60
Tinospora cordifolia (leaf)	UV-Vis, FTIR, DLS, SEM	**Ag,** 452 nm	50 - 70 nm, spherical − 17.0 mV	-	60
Azadirachta indica (leaf)	UV-Vis, FTIR, DLS, TEM,	**Ag,** 445 nm	34 nm. Spherical & irregular	15 min	56
Origanum vulgare L.	TEM), UV–Vis, FTIR	**Ag,** 430 nm	12 nm, Spherical (fcc), 3 keV	120 min, 90°C	81
Magnolia kobus (leaf)	UV–vis, EDS, XPS, ICP, HR-TEM	**Cu,** 560 nm, 30 days	37 - 110 nm, spherical	24 hrs, 25–95 ◦C	25
Magnolia kobus (leaf) & *Diopyros kaki* (leaf)	ICP, EDS, SEM, TEM, AFM, XPS, FTIR	**Au,** 540 nm	40 - 110 nm, spherical	3 to 11 min, 95°C	57
Alternanthera sessilis (leaf)	UV-vis, SEM, XRD, FTIR.	**Ag,** 420 nm	30–50 nm**,** spherical **(**fcc)	6 h,	91
Myrmecodia pendans (leaf)	UV–vis, XRD, FTIR, SEM, TEM	**Ag,** 448 nm	10 - 20 nm. spherical **(**fcc)	90 min, pH 4.3 to 6.8	37
Ixora coccinea (leaf)	UV-Vis, XRD, FTIR, DLS, SEM, EDX	**ZnO,** 340 nm	78 - 145 nm, spherical	pH 12, 60˚C	37
Calotropis gigantean (leaf)	UV–Vis , DLS, XRD, FTIR, SEM, EDX, AFM	**ZnO,** 350 nm, 3 months	8–12 nm, spherical	pH 6.58	17
Artocarpus elasticus (stem, bark)	UV–vis, TEM, SEM, FTIR, TEM, XRD	**Ag,** 460 nm	6 - 29 nm, Spherical (fcc)	24 h	64
Diospyros Montana (stem bark)	UV–Vis, FTIR, XRD, SEM, TEM, EDX, DLS	**Ag,** 432 nm	5 - 40 nm, spherical (fcc)	-	6
Ceropegia thwaitesii (leaf)	UV–vis, SEM, EDX, XRD, FTIR	**Ag,** 430 nm	100 nm, Spherical (fcc)	-	47

Table 3 FTIR absorption bands & Potential Functional Group plant mediated synthesized NPs

Plant Name (Plant Part)	FTIR absorption bands (cm^{-1})	Potential Functional Group	References
Androgra phispaniculata (stem)	3240 cm^{-1} 2929 cm^{-1} 1391 cm^{-1} 1575 cm^{-1} 1032 & 1075 cm^{-1}	-O-H- or -N-H- -C-H- -C-N- -NH- -C-N-	60
Phyllanthus niruri(leaf)	3268 cm^{-1} 2920 cm^{-1} 1513 cm^{-1} 1633 cm^{-1} 1000 and 1149 cm^{-1}	-O-H- or -N-H- -C-H- -N-H- -C=O -CN-	60
Tinospora cordifolia (leaf)	3319 cm^{-1} 2831 & 2943 cm^{-1} 1418 & 1449 cm^{-1} 1021 cm^{-1}	-O-H- or -N-H- -C-H- -CH- -C-N-	60
Azadirachta indica (leaf)	3454 cm^{-1} 1636 cm^{-1} 2083 cm^{-1} 1113 cm^{-1}	-N-H- C=O Alkyne group -C-O-	28
Vitisvinifera (raisin fruit)	3420 cm^{-1} 1620 cm^{-1} 2840 & 2930 cm^{-1}	O-H, C-H, ether-methoxy-OCH3 groups	76
Trifolium pretense (flower)	3245 cm^{-1} & 1599 cm^{-1} 1383 cm^{-1} & 1076 cm^{-1} 2168 cm^{-1}	Hydroxyl group (O–H) –C–O and –C–O–C, C=C	90
Zingiber officinale (root)	2172 cm^{-1} 3417 cm^{-1} 1414 cm^{-1}	C=C O-H C-H	80

Table 3 Continued...

Plant Name (Plant Part)	FTIR absorption bands (cm^{-1})	Potential Functional Group	References
Olive taoenade (leaf)	3409 cm^{-1} 1733 cm^{-1} 1077 cm^{-1} 1624 cm^{-1}	O-H C=O C-OH, amide I	77
Tilia cordata (leaf)	3419 cm^{-1} 2952 cm^{-1} 1760 cm^{-1} 1688 cm^{-1} 1141 cm^{-1}	O-H (alcoholic or phenolic) C=H C=O C=C C-OH	81
Capparis spinosa L. (leaf)	1635 cm^{-1} 1080 cm^{-1} 1050 cm^{-1} 1635 cm^{-1} 1405 cm^{-1} 1381 cm^{-1} 1577 cm^{-1}	Carbonyl –C-O-C C-OH C-O C-O C-N N-H	79
Garcinia mangostana (leaf)	1619 cm^{-1} 1522 cm^{-1} 1340 cm^{-1} 1160 cm^{-1}	,–C–C– (in-ring) aromatic C–O–C (ethers) C–O (–C–OH) C–O of aromatic-OH	65
Ocimum sanctum (leaf)	1635 cm^{-1} 3430 cm^{-1}	amide I bond of proteins, OH of alcohols and phenols	76
Olea europaea (leaf)	3367 cm^{-1} 2936 cm^{-1} 1735 cm^{-1} 1654 cm^{-1} 1531 cm^{-1} 1083 cm^{-1}	N–H –CH, –CH3 and –CH2 C=O CO, C–O and O–H amide II C-N	77
Alternanthera sessilis (leaf)	3253 cm^{-1} 1634 cm^{-1} 2190 & 2040 cm^{-1}	−NH or −OH carbonyl CC or CN triple bond	91
Ixora coccinea (leaf)	3398.56 cm^{-1} 2912.09 cm^{-1} 2845.74 cm^{-1} 1561.06 cm^{-1} 1461.45 cm^{-1} 1018.12 cm^{-1}	OH C-H O-H C=C and C=O C-N C-O	33
Calotropis gigantean (leaf)	3390 cm^{-1} 2825 cm^{-1}	–OH –CH	17
Artocarpus elasticus (stem bark)	3222 cm^{-1} 2926, 2924 & 2928 cm^{-1}	O–H C-H	65

Conclusion

Nanotechnology is strengthening the performance and efficiency of common products, and it has gotten a lot of interest around the world. It's being tested for a variety of different applications in order to improve the object's efficiency and performance while also lowering the cost so that it's affordable to everyone. Metal nanoparticle biosynthesis utilizing plant derivatives has received a lot of attention in recent decades. Plant extracts are an easy, efficient, and ineffective technique to manufacture nanoparticles that can be readily scaled, use less power, are ecologically friendly, and eliminate the use of toxic chemicals while improving efficiency levels. Plant-mediated nanoparticles could be used in a wide range of sectors, including biomedicals, medicines, treatments, sustainable renewable energy, and other commercial products.

The significance of numerous plant organs in the ecologically friendly creation of nanoparticles has been discovered in the current work. To gain a feel of the most current advancements and achievements in this field, we looked at some of the most recent articles and reports published in various periodicals. Plants and their parts from a wide range of biological groupings have been shown to have an important role in non-toxic nanoparticle production. Nanoparticles come in a wide range of sizes, shapes, and stability due to the various variables involved in the synthesis method. Several microorganisms have been poisoned by the nanoparticles that have been created.

Plant extracts contain peptides, sugars, alkaloids, polyphenols, quinones, lipids, and terpenoids, and also reduction and capping agents for MNP production. Modifying reaction factors like temperature, acidity, and the quantity of plant material utilized can alter the shape, spatial, and diameter of MNPs, implying that extract can be employed as a reducing and binding agent for MNP synthesis. It will be feasible to improve the production procedure to produce a significant quantity of durable, tiny MNPs by doing further detailed investigations on reactivity factors such as pH, temperature, ratio, and quantity of plant extract to metal salt. The findings show that organically synthesized metallic nanoparticles plants containing extract outperform artificial nanoparticles in terms of antibacterial effectiveness. Metallic nanoparticles are created through synthetic chemistry. Expanding experimental research to an industrial level, using analytics to elucidate phytonutrients included in nanoparticle synthesis, and determining the particular molecular mechanism in pathogenic bacteria suppression are all potential goals for plant-mediated nanoparticle production.

Precursor solution of MNPs is believed to be much safer and much more ecologically friendly than physical and chemical synthesis. The utilization of chemical synthesis and green approaches for the manufacture of metal nanoparticles has inspired a drive to discover environmentally acceptable technologies. As an outcome, in the coming decades, the use of plant extract in synthesis may have a substantial impact. The fundamental disadvantage of employing plant extracts as reducing agents in nanoparticle synthesis is that the chemical constituents of plant extracts gathered from different parts of the world vary greatly, leading to contradictory results in different laboratories. There is a need to investigate and discover the molecules present in plants that have a function in the formation of nanoparticles that mediate the interaction. There is a need to research and uncover the biomolecules found in plants that have a role in mediating communication nanoparticle creation in order to breathe new life into green nanoparticle synthesis.

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Conflicts of interest

There are no conflicts of interest relevant to this article, declared by the authors.

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