MINI REVIEW

Green-synthesis, Characterization, and Applications of Nanoparticles (NPs): A Mini Review

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Abstract

Nanobiotechnology is an encouraging and noticeable field of nanotechnology. In recent years, the demands for the synthesis of biocompatible nanoparticles (NPs) are increasing for various applications in different areas such as health, medicine, environmental pollution, and agriculture, etc. A green synthesis of various NPs from different metal/ metal ions using different plant extracts has been extensively studied. Green synthesis of NPs is an alternative way of chemical and physical methods of NPs synthesis and is considered an eco-friendly approach in nanotechnology. Green synthesis of NPs is affected by various factors such as pH, temperature, and incubation time which must be considered to obtain an optimal result. NPs synthesized via green methodology have many potential applications in environment and climate change, biomedicals and agriculture. This mini-review provides brief information about different approaches and methods in synthesizing NPs, their characterization by various instrumental applications, and their applications in many areas that are important for humans, animals, and plants.

Keywords: AFM, EDX, Green synthesis, Nanoparticles, TEM, XRD.

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Introduction

According to the US Environmental Protection Agency (USEPA), nanoparticles (NPs)are usually defined as a particle of matter that is between 1 and 100 nanometres (nm) in diameter. NPs have various physicochemical properties (optical, electrical, magnetic, etc.), such as large surface area, high surface energy, and quantum confinement. Due to these exclusive properties, NPs find countless applications in the electronics, cosmetics, medicine, food, and chemical industry (Pal *et al.*, 2019). Natural NPs are generated in different environmental compartments by physical, chemical, and biological processes, such as photo-oxidation, redox (bio)chemical weathering of minerals, and (bio) mineralization, precipitation reactions, physical fragmentation, gas-solid nucleation in the atmosphere, etc. (Sharma *et al.* 2015). Anthropogenic nanoparticles (ANPs) generation result from human-related activity (e.g., combustion), due to the life cycle of products containing NPs or accidental releases; for example, generation of dust by different activities; tillage, mining, and mining construction/demolition. Atmospheric transportation of NPs also done by various processes such as atmospheric release and nucleation release of treated and untreated wastewater and storage in an insufficiently confined area or spreading of sludge from sewage treatment plants (Jun *et al.* 2016). Metallic NPs are generated through different routes comprised of physical, chemical, and biological pathways by two distinct processes a top-down approach and a bottom-up approach (Iravani *et al.*, 2014). NPs are synthesized via size reduction in the top-down approach, whereas in the bottom-up approach, NPs are generated from small entities such as atoms and molecules (Sepeur S., 2008).

In the green synthesis of NPs, plant or plant parts are used for the bioreduction of metal ions into their elemental nano form (1–100 nm) (Hussain *et al.*, 2016). The process of green synthesis is more efficient, effortless, economical, and can easily be implied to carry out at a large scale (Iravani *et al.* 2014). For the green synthesis of NPs, there is no need to maintain the large culture and it does not create poisonous products (Saravanan *et al.* 2020). Different NPs such as gold, silver, palladium, iron, and zinc oxide (Pal *et al.* 2019) have easily been synthesized through green synthesis. The plants and plant parts contain large amounts of phyto-compounds which are responsible for bioreduction of metallic ions into metal NPs (Saravanan *et al.* 2020).

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Approaches for Nanoparticles Synthesis

Chemical, physical and biological methods of NPs generation follow either top-down or bottom-up approaches. In the top-down approach, the relevant bulk material breaks down to fine particles by using suitable mechanic techniques such as sputtering, grinding, and milling. Most of the physical methods come in this approach (Meyers *et al.* 2006). Bottom-up involves NPs generation through the self-assembly of atoms into new nuclei, which further grow into a particle possessing nanoscopic dimensions and employing various chemical and biological methods (Jamkhande *et al.*, 2019).

Biological Method

The biological methods are the synthesis of NPs using bacteria, fungi, algae, or plants. The primary requirements of green synthesis of metal NPs are a metal salt solution and a reducing biological agent. Biological systems (cells) contain reducing agents or other constituents which work as the stabilizing and capping agents, and therefore, no need to add stabilizing and capping agents are required from outside.

Green Synthesis of NPs

As discussed earlier, Green synthesis of NPs means using plants or plant parts to synthesize NPs from their metal compound or salt. Generating NPs through chemical and physical pathways has more chances of toxicity and environmental issues. The chemical method of NPs synthesis is its use of toxic chemicals and solvents, which could harm the environment. The physical pathway demands a bigger space and generates a large amount of heat, increasing the earth surrounding temperature of the source material. Due to these physical and chemical methods, the green synthesis of NPs has got more recognition as an alternative to chemical and physical methods. Green nanotechnology is easy, cost-effective, and eco-friendly and has gained much importance in the recent past. A large number of NPs synthesized via green synthesis approach using microbes, plants, and their size description are presented in Table 1(Pal *et al.*, 2019).

The General Procedure for Green Synthesis of NPs

Plants contain primary metabolites (amino acids, enzymes, vitamins, proteins, carbohydrates, etc.) and secondary metabolites (alkaloids, terpenoids, phenolics, flavonoids, tannins, etc.). The secondary metabolites play an important role in oxidation/reduction reaction in metal/metal ion suspension, which results in the metal NPs. Nowadays, the green synthesis of AgNPs has gained attention because it is a rapid, non-toxic, eco-friendly, and economical method. During the process of NPs synthesis, the biomolecules (proteins, amino acids, polysaccharides, alkaloids, phenolics, terpenes, saponins, and vitamins) present in plant's extract work as reducing as well as stabilizing agents (Roy *et al.,* 2015). Figure 1 presents the major steps involved in the green synthesis of NPs using various metal/metal salts.

Conditions Influencing the Green Synthesis of NPs

Conditions such as pH, temperature, and reaction time have a major influence on the synthesis and stabilization of NPs using biological sources. The description of each factor is given below.

pH

The pH of the reaction medium plays an important role in the synthesis of NPs (Gericke *et al.,* 2006). The size and shape of the NPs vary due to the different concentrations of hydrogen ions. The larger particles are synthesized at lower pH values than higher pH values (Sathishkumar *et al.*, 2010). For instance, the maximum number of AuNPs (25–85 nm) were synthesized from *Avena sativa* at pH 2, whereas relatively smaller NPs (5–20 nm) were synthesized at pH 3 and 4 (Armendariz *et al.* 2004). The larger size AgNPs were synthesized at lower pH, whereas dispersed and smaller AgNPs were synthesized at higher pH using *Cinnamon zeylanicum* bark extract (Sathishkumar *et al.* 2009).

Table 1: A list of green synthesized NPs and their size using bacteria, fungi, and plants sources (Pal *et al.*, 2019)

SN.	*NPs*	*Sources*	*Size*
1.	Silver	Rhodococcus NCIM 2891	10 nm
2.	Selenium	Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus and S. Aureus	90-150 nm
3.	Selenium	Vibrio natriegensas	136 ±31 nm
4.	Gold	Cladosporium cladosporioides fungus isolated from seaweed	>100 nm
5.	Gold	Trichosporon montevideense	53-12 nm
6.	Lead	Aspergillus	5-20 nm
7.	Zinc oxide	Seaweeds	36 nm
8.	Silver	Reetha and Shikakai leaf extract	~30 nm
9.	Silver	Pongamia pinnata leaf extract	5-15 nm (small) and 22-55 nm(large)
10.	Silver	Azadirachta indica leaf extract, Chenopodium murale leaf extract	15-35 nm, 30-50 nm
11.	Silver	Chenopodium murale leaf extract	30-50 nm
12.	Gold	Hibiscus leaf extract	16-30 nm
13.	Gold	Trigonellafoenum-graecum leaf extract	15-25 nm
14.	Copper	Coccinia grandis fruit extract	40-50 nm
15.	SnO2-NP-AC catalyst	Phaseolus lunatus leaf extract	18 nm
16.	Zinc oxide	Rosa canina leaf extract	>50 nm
17.	Zinc oxide	Limonia acidissima leaf extract	12-53 nm
18.	Zinc oxide	Moringa oleifera leaf extract	16-20 nm
19.	Zinc oxide	Azadirachta indica leaf extract	9.6-25.5 nm
20.	Zinc oxide	Ocimum basilicum leaf extract	50 nm
21.	Zinc oxide	Calotropis gigantea leaf extract	30-35 nm

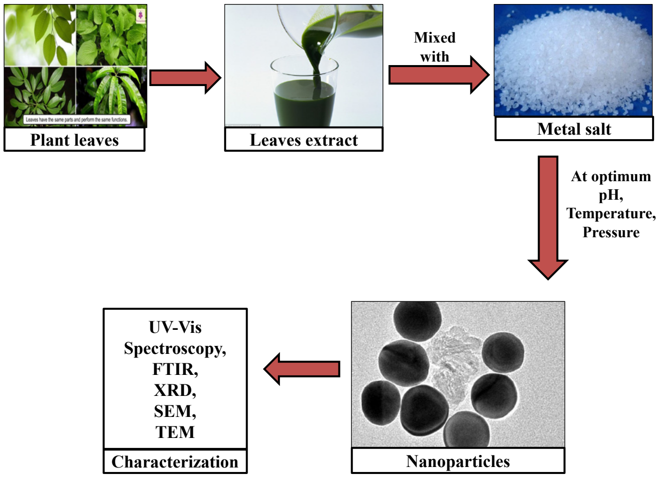

Fig. 1: Schematic diagram showing steps involved in green synthesis of NPs and their characterization using the various instrumental application such as UV-Vis Spectroscopy, Fourier Transform Infrared Spectrometry (FTIR), X-Rays Diffraction (XRD), Scanning Electron Microscopy (SEM), and Transmission Electron Microscopy (TEM) (*Source: Images are taken from google image*) **https:**//www.google.com/search?q=plant+leaves, https://www.google.com/search?q=leaves+extract, https://www.google.com/search?q=metal+salt, https://www.google.com/search?q=TEM+images+of+nanoparticles

Temperature

Temperature is a stimulating factor in the synthesis of metallic NPs, affecting the shapes and sizes of the synthesized NPs. When Au NPs were formed using *Cymbopogon flexuosus* leaf extract, at lower reaction temperatures (25 to 100°C) nano triangles were formed, whereas spherical NPs along with the nano triangles were synthesized at higher reaction (100° C) temperatures (Raju *et al.,* 2011).

Pressure

The pressure is also an important factor that influences the synthesis of NPs. Pressure affects the shape and size of the NPs synthesis (Abhilash *et al.,* 2012). It has been reported that ambient pressure (1–3 megapascle) reduces the time required to reduce metal ions through a phytochemical agent (Tran *et al.,* 2013).

Incubation Time

The incubation time affects the quality, shape, and size of the NPs (Darroudi *et al.,* 2011). It has been reported that a long incubation time could have resulted in shrinkage or aggregation of NPs, which can cause a limitation in the NPs' potential (Baer 2011).

Characterization of NPs by Various Instrumental Applications

The characterization of NPs provides the knowledge of NPs morphology, composition, and coating. The various instruments

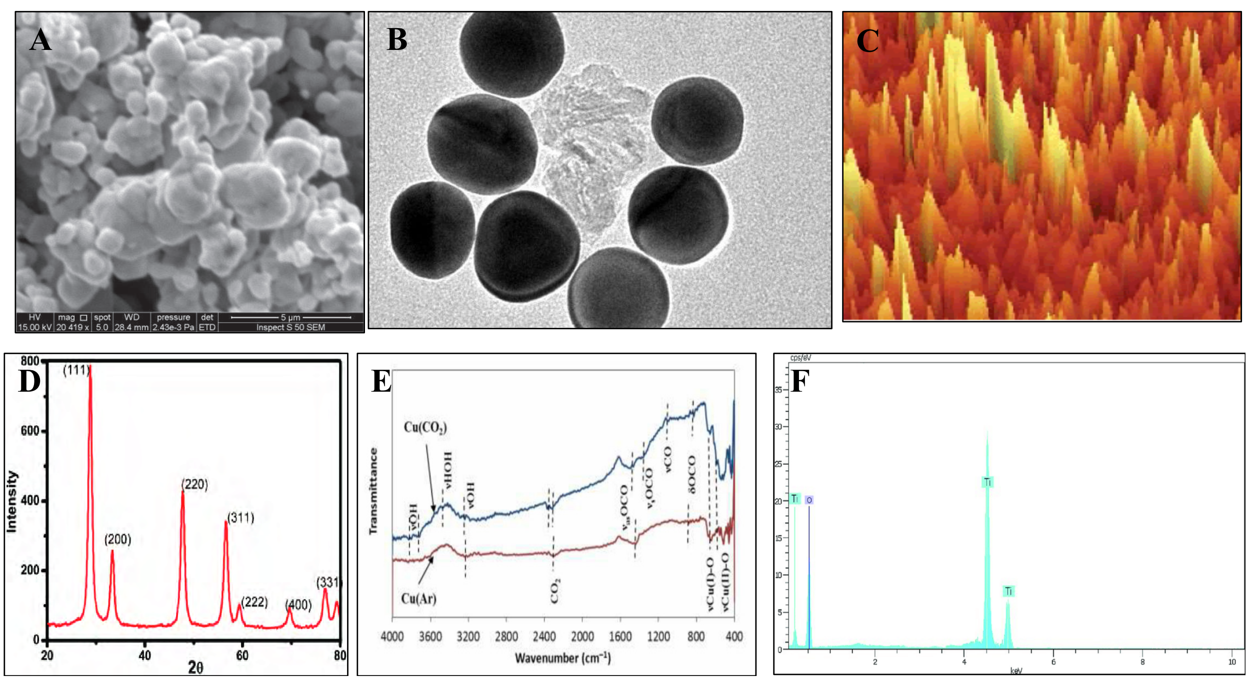

Fig. 2: Diagrammatic presentation of different techniques used in NPs characterization (**2A** shows Scanning Electron Microscopic (SEM) image, **2B** shows Transmission Electron Microscopic (TEM) image, **2C** shows Atomic Force Microscopic (AFM) image, **2D** shows the X-Rays Diffraction (XRD) spectra, **2E** shows Fourier Transform Infrared Spectrometry (FTIR)spectra and **2F** shows the Energy dispersive spectroscopy X-Ray (EDX) spectra).
Source: Images are taken from Google image
2A:https://www.google.com/search?q=SEM+images+of+nanoparticles,
2B: https://www.google.com/search?q=TEM+images+of+nanoparticles,
2C: https://www.google.com/search?q=AFM+images+of+nanoparticles,
2D: https://www.google.com/search?q=XRD+spectra+of+nanoparticles,
2E: https://www.google.com/search?q=FTIR+spectra+of+nanoparticles,
2F: https://www.google.com/search?q=EDS+spectra+of+nanoparticles

used for NPs' characterization are UV-vis spectroscopy, X-ray diffraction, Fourier transforms infrared spectroscopy, Energy dispersive spectroscopy X-ray, Scanning electron microscopy, Transmission electron microscopy, and Atomic force microscopy (Fig. 2) (Fabrega *et al.* 2011). A brief description of each instrument is given below:

Spectrometric Techniques

Spectroscopic techniques give information about the optical properties, state and nature, constitution, and functional groups present on NPs. UV-vis spectroscopy is the primary technique used for the characterization of NPs, and it gives an idea about the particle's aggregation and the optical properties of NPs (Rajsekharreddy *et al.,* 2010). X-ray diffraction (XRD) gives information about the different phases of a crystalline material and provides NPs dimensions (Hassellov *et al.* 2008). Fourier-transform infrared spectroscopy (FTIR) spectra divulge the functional groups present on the NPs surface during its synthesis (Sankar *et al.,* 2014).

Microscopic Techniques

It is one of the most commonly used techniques generally used to analyze size, shape, and particle aggregation of NPs (Fabrega *et al.* 2011). This technique requires no standard as in other techniques above. The Scanning Electron Microscopy (SEM) gives the images to identify the size and shape of metal NPs. Transmission Electron Microscopy (TEM) is the most efficient and widely used for the characterization of NPs (Sharma *et al.* 2019). TEM images give an idea about the size and aggregation of NPs and the single NPs can be studied by TEM (Sang *et al.* 2014) while SEM cannot access it. Atomic Force Microscopy (AFM) is a high-resolution technique that can be applied for the study of either single NP or aggregated NPs and that are visualized in three (3D) dimensions (Fabrega *et al.* 2011).

Applications of NPs in Various Fields

The demands of NPs are increasing in various fields such as biomedical, cosmetic industries, agriculture, electronics, environment, energy, etc. NPs are of great interest for biomedical sciences, such as silver and gold NPs, the most preferred and frequently used NPs in this field. Gold NPs have been reported for cancer cell detection, protein assay, capillary electrophoresis, and biomarker in a biological screening test; AuNPs also induce apoptosis in B cell- chronic lymphocytic leukemia (Jadoun *et al.* 2020). Engineered NPs are using as growth stimulators that directly or indirectly improve crop production. Nano-fertilizers, nano-pesticides, and sensors have been developed to observe the different agriculture parameters (Usman *et al.* 2020). NPs have been reported for developing specific sensors and detectors to detect pollutants in an open environment, which can remove harmful particles from the air, water, and soil (Aguilar-Pérez *et al.* 2020).

Conclusion

In recent years, nano-biotechnology has emerged as a major tool for synthesizing NPs that are eco-friendly, nonpoisonous, and cost-effective. Various types of NPs from different metals can be synthesized using plant sources, and these NPs have several important applications. The NPs synthesis using greener methods is dependent on different factors such as pH, temperature, and incubation time of the reaction. However, more studies are still needed to explore how to synthesize the monodispersed NPs of specific shape and size to maximize the functional characteristics of NPs for different applications in various fields.

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