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BIOSYNTHESIS OF METALLIC NANOPARTICLES FROM PLANTS: INDUSTRIAL APPLICATIONS

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Abstract
The biosynthesis of metallic nanoparticles from plants is a very wide field, which has attracted increasing interest lately due to their unique properties. Nanoparticle production volumes around the world are increasing due to their widespread application, especially in technology and science. The chemical and physical methods used to make the nanoparticles are often expensive and potentially dangerous to the environment. Biosynthesis is an alternative, inexpensive, efficient and environmentally friendly method of obtaining nanoparticles with the desired properties. This approach is carried out by various macro- and microscopic organisms, such as plants, fungi, bacteria, algae and microalgae. A major factor is the natural plant compounds involved in the bioreducing of metal salts during the synthesis of nanoparticles. Plants contain natural compounds such as alkaloids, flavonoids, saponins, steroids, tannins, and other nutrients. They have been used in the synthesis of various nanoparticles such as silver, gold, copper, cobalt, zinc oxide, palladium, platinum, and others. The main advantages of this approach are the low cost, the short preparation time of the final product and the biological safety.

Keywords: Biosynthesis, plants, metallic nanoparticles, nanotechnology

1 Background

Green chemistry methods for creating nanoparticles (NPs) are one-step, quick, easy, and inexpensive. They also avoid using harmful compounds and instead employ non-toxic solvents like water [1].

In the past ten years, there has been a great deal of interest in the production of nanostructured materials, particularly metallic nanoparticles, due to their distinctive features that make them useful in numerous scientific and technological domains. The lack of an efficient synthesis technique that will create uniform size and shape nanoparticles as well as particles with minor or no toxicity effect to human health and the environment places, they assessed a limit on the utilization of these nanoparticles. The biological approach to NPs creation is superior to the traditional chemical method of creating them since it is more straightforward, affordable, and ecologically benign. One of these biological methods is the biomineralization of NPs in protein cages [2].

Different macro or microscopic species, including plants, bacteria, fungi, seaweeds, and microalgae, are responsible for the biological creation of nanoparticles. The diverse endemic diseases have been successfully controlled by biosynthesized nanomaterials with few side effects. Alkaloids, flavonoids, saponins, steroids, tannins, and other natural chemicals with nutritional value are numerous in plants. These organic items are made from a variety of plant parts, including seeds, leaves, stems, roots, shoots, flowers, and bark [3].

Recent research has shown that plant extracts can operate as a safe precursor for the creation of nanomaterials [4].

The biological synthesis of metal nanoparticles (especially, gold and silver NPs) using plants (inactivated plant tissue, plant extracts and living plant) has received more attention as a suitable alternative to chemical procedures and physical methods. Synthesis of metal NPs from plant extracts is very cost-effective, and therefore can be used as an economic and valuable alternative for the large-scale production of metal nanoparticles. Extracts from plants may act both as reducing and capping agents during the NPs synthesis.

Different biochemicals found in plants have therapeutic characteristics, including those that are antibacterial, germicidal, antifungal, antioxidant, anticancer, and disinfecting [5]. Therefore, the phytochemicals from plants that adhere to the surface of plant-mediated nanoparticles can have synergistic effects and increase the antibacterial and anticancer properties of nanoparticles [6], [7].

The plant extract functions as a reducing and stabilizing agent for the bioreduction reaction to create unique metallic nanoparticles since it contains a variety of secondary metabolites. Additionally, the biological synthesis of metallic NPs is a simple, low-cost, and environmentally benign process. Many greener nanoparticles, including cobalt, copper, silver, gold, palladium, platinum, zinc oxide, and magnetite, are effectively synthesized using plants [3].

However, the important and critical roles of plants in bio-based protocols for metal nanoparticles production, and the green synthesis of metal NPs using plants have been discussed in this review.

2 Synthesis of nanoparticles from plant extracts

Recently, researchers have widely investigated the metal nanoparticles obtained from plants extract and their potential applications [8-12].

A cost-effective, low-toxic, straightforward, and potentially industrial ecological strategy has been developed using research on the production of barium carbonate nanoparticles. Deionized water was used to clean the healthy, young leaves of the natural sweetener (*Stevia rebaudiana Bertoni*) before they were dried at 25ºC for 72 hours and pulverized. The biosynthesized nanoparticles were separated, cleaned with deionized water, centrifuged, and separated using filter paper before being stored at 4ºC in the dark [13].

Green iron particles were produced utilizing green tea leaf extract and the sodium borohydride method of producing iron particles. *Vitis vinifera* (black grape) leaves were gathered, cleaned with deionized water, dried in the shade for 15 to 20 days, and crushed. Its development was confirmed by strong black precipitation. It was vacuum-filtered, dried, and kept in a desiccator for future use [14].

The production of silver nanoparticles has been carried out using the leaf extract of the aquatic medicinal plant *Nelumbo nucifera*. Silver NPs produced through biosynthesis varied in form and size, averaging 45 nm [15]. The green production of silver nanoparticles with particle sizes ranging from 6 to 20 nm was also investigated. The plant extract served as a stabilizing and a reducing agent in Kumar's study [16]. For the first time, cubic silver NPs with an average particle size of 15 nm were created utilizing a plant extract from the root of *Trianthema decandra*. Within 15 minutes, the stable silver nanoparticles were bio-synthesised from *Sorbus aucuparia* leaf extract [17], [18]. An approach to biological synthesis that is simple, effective, affordable, and environmentally benign can be used to produce green-synthesized NPs [19].

Also, various studies have described the synthesis of ZnO nanoparticles using plant extracts [20], [21]. Iqbal *et al.* synthesized ZnO NPs through green plant extract of *Rhamnus virgate* [22].

SnO_2 nanoparticles also have many applications such as their antifungal, antibacterial, photocatalysis, antioxidant activities, and are also used in the development of sensors. The plant parts are mostly utilized for SnO_2 nanoparticles' production as buds, leaves, flowers, fruits, bark, and seeds [23].

Titanium oxide nanoparticles are of great interest as these exhibit exclusive morphologies and surface chemistry. TiO_2 nanoparticles are very useful in the preparation of textiles, plastics, papers, tints, cosmetics, foodstuffs etc. These nanoparticles are reported in light green to dark green color. TiO_2 nanoparticles in spherical shape were synthesized by the reaction of leaf extract of *Annona squamosa* and an aqueous solution of TiO_2 salt at room temperature [24].

Also, copper nanoparticles are synthesized by various plant extracts such as *Aloe vera* flower extract via the reduction of aqueous copper ions. The formation of an average size of 40 nm, Cu nanoparticles was confirmed by 578-nm peak at UV–Visible spectrometer [25].

Figure 1 illustrates how cell- or cell-free extracts of various biological resources can be used to create metallic nanoparticles. The selection of a solvent medium, an eco-friendly reducing agent, and a non-toxic substance for NPs stabilization are just a few of the important factors that should be taken into account when creating the nanoparticles [26].

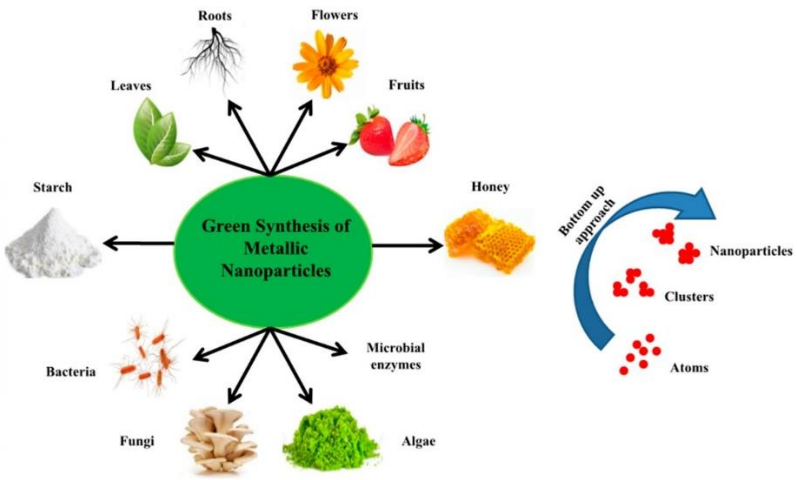

Figure 1. Green synthesis of metallic nanoparticles [28].

Additionally, it was discovered that substances from coffee and tea extracts, such as peptides, polyphenolics, sugars, vitamins, and water are suitable for the creation of nanoparticles [27]. Plant-based NPs are more stable and monodispersed than microbial NPs, and plant extract reduces metal ions more quickly. One method for making nanomaterials is by microbial synthesis [28].

In order to produce NPs, typically plant biomass or extract is mixed with a metal salt solution at the proper temperature and pH. By watching the color change in the solution, the primary verification of NPs formation may be confirmed. The experimental procedure for producing NPs from plant biomass is depicted in Figure 2 [29].

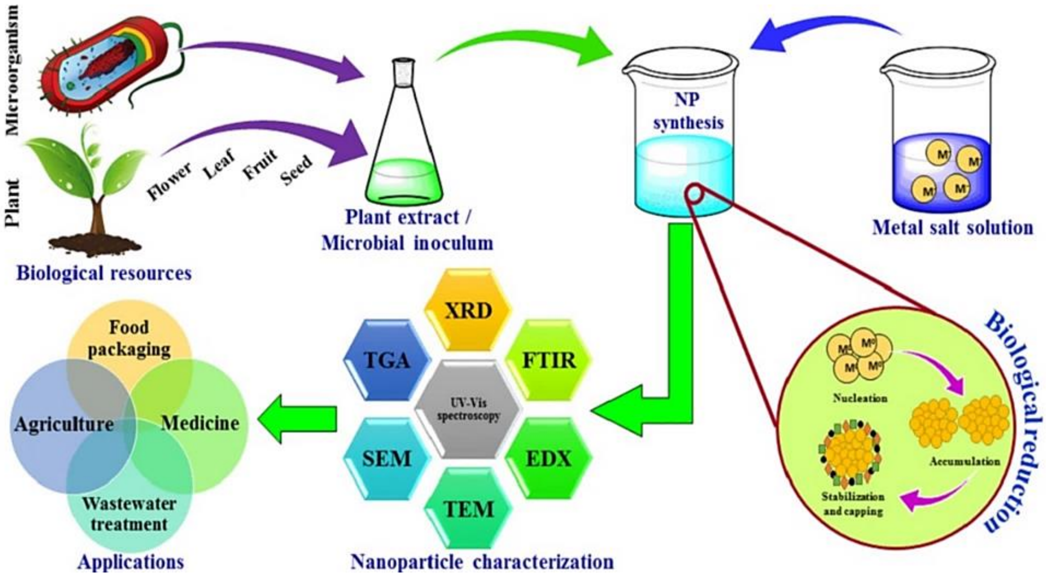

Figure 2. Schematic representation for plant-mediated biosynthesis of nanoparticles [18].

Different techniques are used to create the plant extracts, including hot extraction, cold extraction, and Soxhlet apparatus, which were later employed in the synthesis of NPs. The ease of scaling up and downstream processing make this approach of NPs synthesis superior to the intracellular method. This technique is also eco-friendly, non-toxic, biocompatible, and renewable [30], [31]. These NPs are recognized to have numerous biological applications due to their biocompatibility. By adding the plant extract to the metal precursor solution that contains the salts of the appropriate metals, the synthesis of metal NPs is started [32].

3 Conclusions

Green chemistry has paved a pathway to developing chemical processes that do not use hazardous substances or decrease the dependence on such elements. Because of the widespread availability of plant extracts and biologically active biomolecules, the biosynthesis of nanoparticles has proven to be a far more reliable pathway when compared to its contemporaries.

Much research has been carried out on plant extract-mediated nanoparticles synthesis and their potential applications in various fields due to their cost-effectiveness, non-toxic route, easy availability, and environment-friendly nature. Moreover, they have a wide area of applications such as catalysis, medicine, water treatment, dye degradation, textile engineering, bioengineering sciences, sensors, imaging, biotechnology, electronics, optics, and other biomedical fields.

A multitude of analytical techniques, including UV-Visible spectroscopy, XRD, FTIR, SEM, AFM, TEM, DLS, and zeta potential analysis is used to examine the size, surface charge, distribution, surface morphology (shape), and aggregation of the sample.

Additionally, plants contain some unique compounds which help in synthesis as well as increase the rate of synthesis. The use of plants for green synthesis of NPs is an exciting and developing part of nanotechnology and has a noteworthy effect on the environment toward sustainability and further development in the field of nanoscience.

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