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Review Article

Green Synthesis of Metal Nanoparticles Using Plant Extracts

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ABSTRACT

The green synthesis of metal nanoparticles (MNPs) has become a viable, economical, and environmentally beneficial substitute for traditional physical and chemical processes. The rich phytochemical profile of plants, which includes flavonoids, phenolics, alkaloids, tannins, and other bioactive chemicals, is utilized in this biogenic approach to serve as stabilizing, capping, and reducing agents. Many plant species, such as Camellia sinensis, Ocimum sanctum, Aloe vera, and Azadirachta indica, have shown exceptional effectiveness in creating stable and useful silver, gold, and other metal nanoparticles. A number of variables, including pH, temperature, the concentration of metal salts, and the content of the extract, affect the synthesis process.While the green route offers clear advantages in terms of safety, simplicity, and environmental impact, several challenges persist. These include batch-to-batch variability in plant extract composition, difficulties in large-scale production, limited understanding of the underlying biosynthetic mechanisms, and issues related to nanoparticle stability. Notwithstanding these obstacles, developments in biotechnology and nanotechnology keep improving green synthesis techniques. This study emphasizes the primary plant species employed in the production of nanoparticles, their modes of action, and the difficulties and opportunities facing this exciting field, which has the potential to completely transform industrial, environmental, and medicinal applications.

INTRODUCTION

Several plant extracts have demonstrated excellent efficiency in the green synthesis of metal nanoparticles due to their rich content of bioactive compounds such as flavonoids, tannins, alkaloids, and phenolics. Some of the most effective plant extracts include:

1. Azadirachta indica (Neem) – Used for synthesizing silver and gold nanoparticles with strong antibacterial and antifungal properties.

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2. Ocimum sanctum (Tulsi/Holy Basil) – Known for its antioxidant-rich extract, effective in producing silver nanoparticles with antimicrobial and catalytic properties.
3. Moringa oleifera (Drumstick tree) – Used for gold and silver nanoparticle synthesis, offering excellent stability and biological activity.
4. Aloe vera – Contains polysaccharides and phenolic compounds that help in the rapid synthesis of nanoparticles, particularly silver and zinc oxide.
5. Camellia sinensis (Green Tea) – Rich in polyphenols and catechins, making it effective for the synthesis of gold and silver nanoparticles with strong antioxidant properties.
6. Eucalyptus globulus – Used for silver and gold nanoparticles due to its high tannin and flavonoid content, resulting in efficient reduction and stabilization.
7. Curcuma longa (Turmeric) – Contains curcumin, which plays a key role in reducing and stabilizing nanoparticles, particularly gold and silver.
8. Cinnamomum zeylanicum (Cinnamon) – Rich in cinnamaldehyde and polyphenols, making it effective in the synthesis of highly stable and bioactive nanoparticles.
9. Mentha piperita (Peppermint) – Used for silver and copper nanoparticles, offering antimicrobial and catalytic activities.
10. Phyllanthus niruri (Stonebreaker) – Effective in gold and silver nanoparticle synthesis, widely studied for its medicinal applications.

several regulatory bodies worldwide are focusing on the safety, risk assessment, and regulation of nanoparticles, including plant-mediated ones. These organizations establish guidelines for nanoparticle synthesis, usage, and environmental impact.[2,4]

Utilising plant extracts to synthesise nanoparticles:-

while employing plant extracts to create nanoparticles. The extract is simply combined with a room-temperature metal salt solution. Within minutes, the reaction is finished. This method has been used to create silver, gold, and numerous other metal nanoparticles. The pace of creation of the nanoparticles, their number, and other features are known to be influenced by the type of plant extract, its concentration, the concentration of the metal salt, pH, temperature, and contact time. [3]

Recent studies on the biosynthesis of nanometals from plant extracts have ushered in a new era of quick and safe nanoparticle production techniques. The manufacture of metal nanoparticles using plant leaf extracts and their possible uses have been documented by numerous studies. Sastry et al. investigated the bioreduction of gold and silver ions using Azadirachta indica and Pelargonium graveolens leaf broth. "Moreover, they have explored the formation mechanism of triangular gold nanoprisms by Cymbopogon flexuosus (lemongrass) extracts, the nano-triangles seemed to grow by a process involving rapid bioreduction, assembly and room-temperature sintering of 'liquid-like" gold nanoparticles that are spherical.

Additionally, stable gold nanotriangles could be synthesised quickly by employing tamarind leaf extract (Tamarindus indica) as a reducing agent.

Metal nanoparticles' optical and electrical characteristics were significantly altered by their form. Using plant extracts from Aloe vera, they have also shown how to synthesise gold and silver nanoparticles in a range of sizes and forms, including spherical and triangular. Gold nanotriangles were formed as a result of the reduction of chloroaurate ions, which was described to be limited to biomolecules with molecular weights less than 3 kDa. However, only in the presence of ammonia did the bioreduction of silver ions continue. When exposed to Coriandrum sativum leaf extract, the aqueous solution of gold ions decreased and produced gold nanoparticles with spherical, triangle, truncated triangle, and decahedral geometries that ranged in size from 6.75 nm to 57.91 nm.

For a month at room temperature, these nanoparticles remained stable in solution.[3,7]

Synthesis of Metal Nanoparticles:-

Numerous physical and chemical processes can be used to synthesise MNPs with the desired properties, but they are complex, costly, time-consuming, and potentially harmful to living things and the environment. The need to reduce the potential negative effects of the nanomaterials synthesised via physical and chemical routes has prompted research into biological entities, and the ability of plants and microorganisms to convert metal ions into MNPs has shown a straightforward, quick, economical, and environmentally friendly method for synthesising nanoparticles. Bacteria, fungi, and yeasts are among the microorganisms that can convert metallic salts into nanoparticles (NPs). These microorganisms are important in the reduction of metallic salts into MNPs because they produce proteins, enzymes, reducing cofactors, peptides, and organic compounds. These compounds have the ability to act as capping or reducing agents. MNPs have been synthesised using a variety of bacteria, such as Candida albicans, Escherichia coli, Pseudomonas aeruginosa, and Klebsiella pneumoniae. Compared to other biological sources, plants are the most significant biological component for MNP synthesis because of their widespread abundance and non-pathogenicity. With the phytochemicals and bioactive components of plants serving as reducing, capping, and stabilising agents, plant-mediated synthesis is comparatively gentle, environmentally benign, economical, and time-efficient. As a result, chances for sustainable growth are created while also conserving natural resources. The effective synthesis of biogenic NPs utilising various plant species has been documented in numerous investigations. When compared to their bulk equivalent, the NPs show notably different properties at the nanoscale size, along with enhanced bioactivity. Even though plant-mediated NPs are becoming more well-known and have shown encouraging results, this field of study is still lacking. In actuality, over 80% of people worldwide use medicinal plants and herbs to cure a variety of illnesses, including as diabetes, high blood pressure, cancer, and tuberculosis. The importance of medicinal plants is further supported by the fact that around 60% of all synthetic medications used in clinical settings are derived from plants.[4,1]

1.**Variability in Plant Extract Composition •**

Plant extracts contain a complex mixture of biomolecules (e.g., polyphenols, alkaloids, flavonoids, proteins), which vary depending on species, growth conditions, and extraction methods. • This variability affects the reproducibility and consistency of nanoparticle synthesis.

2. Optimization of Synthesis Parameters

The synthesis process depends on factors such as pH, temperature, reaction time, and extract-to-metal precursor ratio. Standardization of these parameters is challenging as different plants have different reducing and stabilizing capabilities.

3. Stability and Aggregation Issues

Metal nanoparticles tend to aggregate due to their high surface energy, leading to instability over time. • Proper capping and stabilizing agents from the plant extract need to be optimized to prevent aggregation.

4.Scaling Up for Industrial Applications

Scaling up from lab-scale to large-scale production while maintaining consistency in size, shape, and functionality of nanoparticles is challenging. Controlling reaction conditions on a large scale is more difficult compared to small-scale synthesis.

5. Understanding the Mechanism of Biosynthesis

The exact mechanisms by which plant biomolecules reduce and stabilize nanoparticles are not fully understood. • Detailed studies are required to identify active phytochemicals responsible for nanoparticle formation.\

Challenges and Future:-

Prospects Despite numerous advantages, green synthesis faces challenges such as variability in plant extract composition, scalability, and reproducibility. Future research should focus on optimizing synthesis parameters, understanding nanoparticle-plant interactions at the molecular level, and exploring novel plant sources.

Choice of Metal Precursors and Environmental Impact: -

The use of metal salts as precursors raises concerns about cost, availability, and environmental impact. • Sustainable alternatives for metal precursors should be explored.[1,2]

CONCLUSION: -

Green synthesis of metal nanoparticles using plant extracts is a promising, eco-friendly, and sustainable approach. With advancements in nanotechnology and biotechnology, plant-mediated synthesis has the potential to revolutionize various industrial and biomedical applications.[6].

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