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ECO-FRIENDLY FABRICATION OF METAL NANOPARTICLES USING PLANT EXTRACTS

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Abstract
Eco-friendly fabrication of metal nanoparticles using plant extracts is an emerging and sustainable approach in nanotechnology. This green synthesis method utilizes bioactive phytochemicals such as flavonoids, phenols, alkaloids, terpenoids, and proteins present in plant extracts as natural reducing and stabilizing agents. Unlike conventional physical and chemical methods, plant-mediated synthesis avoids toxic chemicals, high energy consumption, and hazardous by-products. The process is simple, cost-effective, and environmentally benign. Metal ions such as silver, gold, zinc oxide, and copper are reduced into nanoparticles through interaction with plant metabolites. The synthesized nanoparticles exhibit unique physicochemical properties and show significant applications in medicine (antimicrobial, anticancer), agriculture (nano-fertilizers), environmental remediation (pollutant degradation), and catalysis.

Keywords: *Green synthesis, Metal nanoparticles, Plant extracts, Phytochemicals, Eco-friendly, nanotechnology, Biomedical applications.*

1. INTRODUCTION

Green synthesis of nanoparticles has emerged as a sustainable and environmentally benign alternative to conventional physical and chemical methods. The articles collectively emphasize the use of plant extracts as efficient reducing, stabilizing, and capping agents in the synthesis of metal and metal oxide nanoparticles. This approach significantly minimizes the use of toxic chemicals, high energy consumption, and hazardous by-products. Various nanoparticles such as silver, gold, zinc oxide, titanium dioxide, palladium, and platinum have been successfully synthesized using plant-mediated routes. Phytochemicals including flavonoids, phenolics, alkaloids, proteins, and enzymes play a crucial role in nanoparticle formation and stabilization [1-4].

Green chemistry may be defined as chemical-supported pollution forest all strategies employed in specific disciplines similar as green logical chemistry, ecologically friendly logical chemistry and clean logical methodologies [5]. therefore, green conflation is regarded as a feasible approach for nanoparticle conflation since it's biocompatible, inert and environmentally safe [6]. Q wisdom and technology [7]. Nanotechnology deals with the conflation, characterization, and operations of a variety of NPs.

2.ECO-FRIENDLY SYNTHESIS OF NANOPARTICLES

During the last decade, the conception of "Green Chemistry" for "Sustainable Development" has been extensively delved. Sustainable development is described as development that meets the current demands while also balancing the capability of unborn generations to satisfy their requirements [8]. Due to its concern with the substantiation of pollution and the magpie use of natural coffers, sustainable development is especially important for colourful chemistry-grounded sectors [9]. The selection of a green or environmentally friendly detergent (the most extensively used are water, ethanol, and their fusions), a suitable on-toxic reducing agent, and a safe substance for stabilization are the three most important conditions for the green conflation of NPs. herbage conflation produces nanoparticles (NPs) using microorganisms, including mortal cell lines, fungi, bacteria, shops, algae, and biocompatible biomolecules. Herbal excerpts offer a implicit system to produce nanomaterials through safer pathways [10].

3. PRINCIPLES OF SUSTAINABLE AND GREEN CHEMISTRY

The 12 principles of green chemistry, developed by

Anastas and Warner, aim to reduce or eliminate the use and generation of hazardous substances throughout the lifecycle of chemical products and processes. Key goals include preventing waste rather than treating it, maximizing atom economy (incorporating all materials into final products), designing less hazardous syntheses, using safer solvents, and relying on renewable, non-depleting feedstocks [10].

4.ROLE OF BOTANICAL SOURCES IN NANOPARTICLE FORMATION

In the biosynthesis of nanoparticles environmentally accepted "green chemistry" concept has been applied for the development of clean and environment-friendly nanoparticles which involves bacteria, fungi, plants, actinomycetes, etc., which is said to be "green synthesis" (Pal et al. 2019). Biosynthesis of nanoparticles by using the above organisms epitomizes a green substitute for the invention of nanoparticles with innovative properties [11].

5.FACTORS AFFECTING PLANT MEDIATED NANOPARTICLE SYNTHESIS

During the biosynthesis of nanoparticles, the major difficulties often faced are maintaining the structure and size of particles in addition to obtaining mono-dispersity in the solution phase. Nevertheless, these problems can be solved by monitoring development factors, namely pH, temperature and incubation time

5.1.Effect of pH

Several scientists have reported that pH plays a crucial role in nanoparticles' biological

Synthesis. pH is an essential element for the plant-assisted preparation of silver nanoparticles and found that the size of nanoparticles increases with the decrease in pH.

5.2.Temperature Role in Plant-Assisted Synthesis

In most studies, regarding the influence of the reaction temperature, it was evaluated that the size of nanostructures is inversely proportional to the temperature. At room temperature (27 ◦C), NPs with a mean size of 49.91 nm and distorted spherical shape were found.

5.3 Contact or Incubation Role in Plant-Assisted Synthesis Many scientists have worked on nanoparticle synthesis and showed the effect of the incubation period. Bar et al.. evaluated the impact of reaction time on synthesis of Ag NPs using the optimized concentration of $AgNO_3$ (0.005 M) and latex extract (3%) of Jatropha circus [12].

6.FUNDAMENTALS OF NANO BASED DRUG DELIVERY SYSTEMS

Nanomedicine uses the science of nanotechnology using nanoscale material diagnosis, sensorial nanoparticles, and nanorobots for various applications, including diagnosis, sensory, delivery, or actuation purposes inside a living organism. Drugs with extremely slow solubility have a variety of biopharmaceutical delivery problems, such as limited bio accessibility following oral intake, reduced ability to diffuse into the outer membrane, needing more for intravenous intake, and unfavourable side effects [13-14].

7. USE OF PLANT PRODUCTS

Plant-based green synthesis utilizes plant extracts (leaves, roots, fruits, peels) as eco-friendly, cost-effective, and sustainable agents to reduce metal ions into nanoparticles. Biomolecules like polyphenols, flavonoids, and terpenoids in plants act as reducing, capping, and stabilizing agents, bypassing toxic chemicals. This method offers high efficiency, safety, and rapid synthesis for biomedical and industrial applications [15].

8.TYPES OF NANO PARTICLES

Different types of plant-derived NPs are presented, and their synthesis, characterization, and applications are discussed and published in this Special Issue. It is characterized by ultraviolet–visible spectroscopy, Fourier transform infrared spectroscopy (FTIR), Raman spectroscopy, photoluminescence analysis (PL), transmission electron microscopy (TEM), scanning electron microscopy (SEM), energy dispersion analysis of X-ray (EDAX), X-ray diffractometer (XRD), atomic force microscopy (AFM), field emission scanning electron microscopy (FE-SEM), thermal-gravimetric differential thermal analysis (TG-DTA), X-ray photoelectron microscopy (XPS), attenuated total reflection (ATR), dynamic light scattering (DLS) and UV–visible diffuse reflectance spectroscopy (UV-DRS) [16-17].

8.1 Ag nanoparticles

For the green synthesis of silver nanoparticles, the key requirements are silver metal ion solution and a reducing biological agent. The easiest and inexpensive method for silver nanoparticles production is silver ion's reduction and stabilization.

8.2 Au nanoparticles

Gold nanoparticles have attracted considerable attention among metallic nanoparticles due to their uniqueness in a high potential for use in medicine and biology field. In the mechanism of synthesis of gold nanoparticles, various chemical moieties in biogenic complexes treat as reducing agents and react with gold metal ion with the result of its reduction and preparation of nanoparticles.

8.3 Pd and Pt nanoparticle

Palladium and platinum both are silvery-white expensive metals having high density. Biosynthesis of both nanoparticles from plants has attracted wide attention of many researchers due to eco-friendly, sustainable, and economical nature.

8.4 Cu nanoparticles

Copper nanoparticles are synthesized by various plant extracts such as Aloe vera flower extract via the reduction of aqueous copper ions.

Copper (Cu) is a comparatively low-cost metal that is more cost-effective than Au and Ag, and Cu NPs have been synthesized by the reduction of aqueous Cu ions by different plant extracts . The existence of a 578-nm peak on a UV-visible spectrometer, in particular, confirms their formation [18-19].

8.5 Zn O nanoparticles

Zinc oxide nanoparticles have drawn considerable attention from researchers and scientists in the past 4–5 years due to its wide applications field of the biomedical field as well as in optics and electronics. These nanoparticles revealed various biomedical applications too such as antifungal, antibacterial, drug delivery, antidiabetic, anticancer [20].

9. DRUG DESIGN AND MECHANISM OF DRUG DELIVERY

Several treatment procedures have been suggested to improve the drug specificity and diagnostic accuracy, and conventional clinical diagnostic approaches have been investigated. These developments in nanomedicine, drug discovery/design, and drug-delivery systems have all contributed to these developments. For example, new medication administration methods are being investigated, and emphasis is being placed on ensuring that they function specifically in designated areas, minimizing their toxicity and enhancing their accessibility to cells in the organism. Drug designing has emerged as a promising aspect of identifying novel lead medications based on understanding a biological target in this context [21].

10. APPLICATIONS OF NANOPARTICLES

Nanotechnology has attracted researchers' interest because of the microscopic size and high surface-to-volume ratio of nanoparticles, which results in chemical and physical changes in the characteristics. Due to these properties, nanoparticles have a great variety of applications in several biomedical, environmental and agricultural sectors Hydrophilic (water-soluble) nanoparticles have been employed as drug carriers for many years. The most efficient nanoparticles used for this purpose are polyethylene oxide nanoparticles. Their ability to deliver drugs in an optimum range has enhanced therapeutic efficiency and patient compliance.

10.1. Anti-Cancer Potential

Nanomedicine is the use of nanotechnology in the treatment, screening, and diagnosis of a variety of diseases, including cancer. It adds complete procedures and effective approaches against cancer through cancer prediction and diagnostics, prevention and medication, as well as possible individualized therapy.

10.2. Anti-Leishmanial Potential

Leishmaniasis is a protozoan vector-borne illness that affects almost 350 million people worldwide. Chemotherapeutic medicines were initially used to treat leishmaniasis, but they had adverse side effects. Due to their unique properties, such as bioavailability, reduced toxicity, targeted drug delivery, and biodegradability, a variety of nanotechnology-based techniques and products have emerged as anti-leishmanial drugs, including liposomes, lipid nano-capsules, metal and metallic oxide nanoparticles, polymeric nanoparticles, nanotubes, and nano vaccines.

10.3. Antimicrobial Potential

Antibiotic resistance is one of the most pressing issues of recent years, and it is only going to become worse. Bacteria have developed resistance to antimicrobial agents as a result of the rapid evolution of the bacterial genome [21].

11. RECENT ADVANCES

There are now 51 products that utilize this technology being used in clinical practice in the present-day medical nanotechnology landscape. Notably, these nanomedicines are generally created for pharmaceuticals with limited aqueous dissolution and highly toxic effects, and they frequently could increase the pharmacokinetic features of the drug in consideration while lowering its toxicity.

12. LIMITATIONS

Green synthesis of plant-based nanoparticles is limited by significant challenges in controlling particle size, shape, and stability, resulting in high inconsistency and polydispersity. Key limitations include variation in plant extract composition, low yield rates, complex purification processes, and lack of standardized, scalable production protocols.

13. FUTURE ASPECTS

Large-Scale Production

Development of standardized protocols for large-scale green synthesis to meet industrial demand while maintaining eco-friendliness.

Advanced Biomedical Applications

Targeted drug delivery systems. Cancer therapy (photo thermal and photodynamic therapy).

Antimicrobial coatings for medical devices

- Agricultural Applications
- Nano-fertilizers and nano-pesticides for improved crop yield
- Plant disease control with minimal environmental impact
- Integration with Green Chemistry & Nanotechnology
- Combining plant-based synthesis with advanced nanomaterial engineering for sustainable nanotechnology development.

14. CONCLUSION

Eco-friendly fabrication of metal nanoparticles using plant extracts is a sustainable and cost-effective alternative to conventional chemical and physical methods. Plant phytochemicals act as natural reducing and stabilizing agents, eliminating the need for toxic chemicals. This green approach reduces environmental pollution, enhances biocompatibility, and supports safer applications in medicine, agriculture, and environmental management. Although challenges such as standardization and large-scale production remain, continued research and technological advancements will strengthen its industrial and clinical potential.

15. AUTHOR CONTRIBUTIONS

All authors are contributed equally.

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None

17. DECLARATION COMPETING INTEREST

The authors have no conflicts of interest to declare.

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