

# Green Synthesis of Nanoparticles Using Plant Extract and Their Pharmacological Screening

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## Abstract

Nanotechnology has emerged as a transformative field with wide-ranging applications in medicine, agriculture, environmental science, and industry. Among its various branches, the synthesis of nanoparticles (NPs) using environmentally benign methods has attracted significant attention in recent years. Green synthesis, particularly employing plant extracts, offers an eco-friendly, cost-effective, and sustainable alternative to conventional physical and chemical synthesis methods, which often involve toxic reagents and high energy consumption. Plant-mediated synthesis utilizes phytochemicals such as flavonoids, phenolics, alkaloids, terpenoids, and proteins as reducing, stabilizing, and capping agents, enabling the formation of nanoparticles with controlled size and morphology. This research article comprehensively discusses the principles, mechanisms, and advantages of green synthesis of nanoparticles using plant extracts, with a particular focus on metallic and metal oxide nanoparticles such as silver, gold, zinc oxide, and iron oxide. Furthermore, the pharmacological screening of these green-synthesized nanoparticles is critically reviewed, highlighting their antimicrobial,

antioxidant, anti-inflammatory, anticancer, antidiabetic, and wound-healing activities. The article also integrates suggested tables and figures that summarize plant sources, synthesis conditions, characterization techniques, and pharmacological outcomes. Challenges, limitations, and future perspectives of plant-mediated nanoparticle synthesis in pharmaceutical and biomedical applications are also discussed.

## Keywords

Green synthesis; Nanoparticles; Plant extract; Phytochemicals; Pharmacological screening; Antimicrobial activity; Nanomedicine

## Introduction

Nanoparticles, typically defined as materials with at least one dimension in the range of 1–100 nm, possess unique physicochemical properties that differ significantly from their bulk counterparts. These properties include a high surface-area-to-volume ratio, enhanced reactivity, tunable optical characteristics, and improved biological activity. As a result, nanoparticles have found extensive applications in drug delivery, diagnostics, imaging,

catalysis, cosmetics, and environmental remediation.

Traditional methods for nanoparticle synthesis can be broadly classified into physical and chemical approaches. Physical methods such as laser ablation, evaporation–condensation, and ball milling require sophisticated instrumentation, high energy input, and often yield low productivity. Chemical methods, including chemical reduction, sol–gel, and microemulsion techniques, generally involve hazardous chemicals that pose environmental and biological risks. These limitations have driven the search for greener and safer alternatives.

Green synthesis of nanoparticles is an emerging approach that aligns with the principles of green chemistry, emphasizing the reduction or elimination of toxic substances, the use of renewable resources, and energy efficiency. Biological entities such as microorganisms (bacteria, fungi, algae) and plant extracts have been explored as reducing and stabilizing agents for nanoparticle synthesis. Among these, plant extracts are particularly advantageous due to their availability, ease of handling, rapid synthesis rate, and rich diversity of bioactive compounds.

Plant-mediated nanoparticle synthesis is a bottom-up approach wherein metal ions are reduced to zero-valent nanoparticles by phytochemicals present in the extract. These biomolecules not only facilitate reduction but also cap the nanoparticles, enhancing their stability and biocompatibility. Moreover, nanoparticles synthesized using medicinal plants often exhibit enhanced pharmacological activities due to synergistic effects between the nanoparticle core and surface-bound phytochemicals.

This article aims to provide a comprehensive account of green synthesis of nanoparticles using plant extracts and their subsequent pharmacological screening. The discussion encompasses synthesis mechanisms,

characterization techniques, and diverse biological activities, supported by appropriately integrated tables and figures.

## Review of Literature

Extensive research over the past two decades has demonstrated the feasibility and effectiveness of plant-mediated nanoparticle synthesis. Early studies reported the synthesis of silver nanoparticles using leaf extracts of *Azadirachta indica*, *Camellia sinensis*, and *Ocimum sanctum*. These studies revealed that plant extracts could rapidly reduce metal salts under ambient conditions, producing stable nanoparticles.

Subsequent investigations expanded the range of plant species and nanoparticle types. Gold nanoparticles synthesized using *Terminalia arjuna* bark extract exhibited strong antioxidant and anticancer activities. Zinc oxide nanoparticles produced using *Aloe vera* gel showed enhanced antimicrobial and UV-blocking properties, making them suitable for pharmaceutical and cosmetic applications.

The literature also highlights the role of specific phytochemicals in nanoparticle formation. Phenolic compounds and flavonoids are widely recognized as potent reducing agents, while proteins and polysaccharides contribute to nanoparticle stabilization. Fourier-transform infrared (FTIR) studies have consistently demonstrated the involvement of hydroxyl, carbonyl, and amine functional groups in nanoparticle synthesis.

Pharmacological screening studies have revealed that green-synthesized nanoparticles often exhibit superior biological activities compared to chemically synthesized counterparts. For example, silver nanoparticles synthesized using *Curcuma longa* extract showed enhanced antibacterial and anti-inflammatory effects. Similarly, plant-mediated iron oxide nanoparticles demonstrated

promising antidiabetic and magnetic drug-targeting capabilities.

Despite these advances, challenges remain in standardizing synthesis protocols, controlling nanoparticle size and shape, and understanding long-term toxicity. Recent reviews emphasize the need for systematic studies correlating synthesis parameters with biological performance.

## Aim and Objectives

### Aim

The primary aim of this study is to comprehensively evaluate the green synthesis of nanoparticles using plant extracts and to assess their pharmacological potential.

### Objectives

1. To review various plant-mediated methods for nanoparticle synthesis.
2. To identify key phytochemicals involved in the reduction and stabilization of nanoparticles.
3. To summarize characterization techniques used for green-synthesized nanoparticles.
4. To evaluate the pharmacological activities of plant-based nanoparticles.
5. To discuss challenges, limitations, and future prospects of green nanotechnology in medicine.

## Materials and Methods

### Plant Material and Preparation of Extract

Fresh plant parts (leaves, stems, roots, bark, flowers, or fruits) are collected, washed thoroughly with distilled water, and air-dried. The dried material is powdered and extracted using water or hydroalcoholic solvents by boiling or maceration. The extract is filtered and stored at 4°C for further use. The concentration of the extract can be adjusted depending on the intended application or experimental requirements. Prior to use, the extract

may be subjected to further purification or standardization to ensure consistency in bioactive compound content. Proper labeling and documentation of the extract batch are essential for reproducibility in subsequent studies.

## Green Synthesis of Nanoparticles

An aqueous solution of metal salt (e.g., silver nitrate for AgNPs) is mixed with the plant extract under constant stirring. The reaction mixture is incubated at room temperature or mild heating. Formation of nanoparticles is indicated by a color change due to surface plasmon resonance. The nanoparticles are then characterized using techniques such as UV-Vis spectroscopy to confirm their formation and monitor the surface plasmon resonance peak. Additional analyses like transmission electron microscopy (TEM) and dynamic light scattering (DLS) may be employed to determine particle size, shape, and distribution. The synthesized nanoparticles are typically purified by centrifugation and washed to remove any unreacted components or impurities.

Figure 1: Mechanism of Plant-Mediated Nanoparticle Synthesis

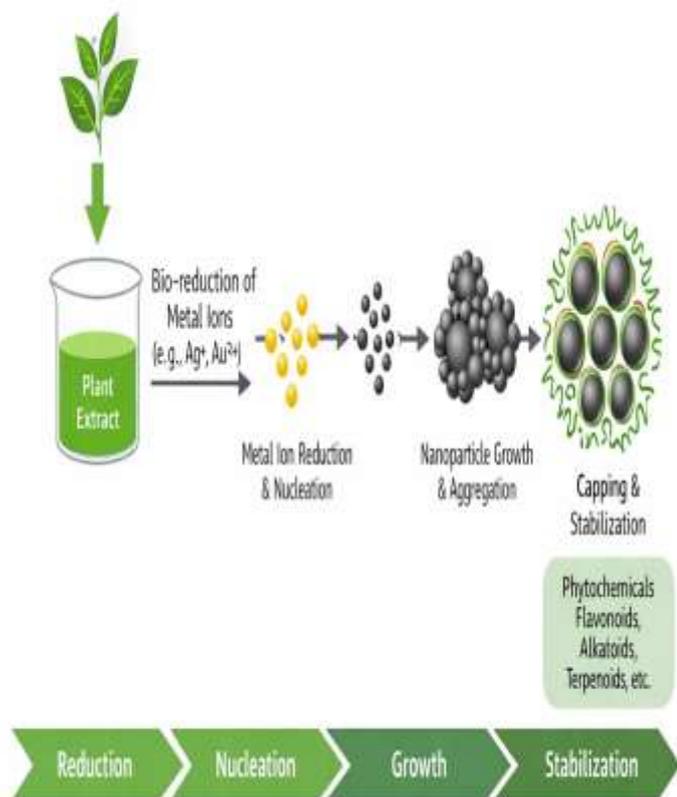


Figure 1 illustrates the general mechanism of plant-mediated nanoparticle synthesis, including reduction, nucleation, growth, and stabilization stages.

### Characterization Techniques

Synthesized nanoparticles are characterized using:

- UV–Visible spectroscopy (optical properties)
- Fourier-transform infrared spectroscopy (functional groups)
- X-ray diffraction (crystalline structure)
- Scanning and transmission electron microscopy (size and morphology)
- Dynamic light scattering and zeta potential (size distribution and stability)

Characterization Technique	Purpose / Information Obtained	Typical Outcome
UV–Visible Spectroscopy (UV–Vis)	Confirms nanoparticle formation through surface plasmon resonance (SPR)	Characteristic absorption peak (e.g., AgNPs: 400–450 nm)
Fourier Transform Infrared Spectroscopy (FTIR)	Identifies functional groups involved in reduction and capping of nanoparticles	Presence of –OH, –NH, –CO, and other phytochemical-associated groups
X-ray Diffraction (XRD)	Determines crystalline structure, phase purity, and average crystallite size	Diffraction peaks corresponding to face-centered cubic (FCC) or hexagonal structures
Scanning Electron Microscopy (SEM)	Examines surface morphology and particle shape	Spherical, rod-shaped, cubic, or irregular nanoparticles

Characterization Technique	Purpose / Information Obtained	Typical Outcome
Transmission Electron Microscopy (TEM)	Provides detailed particle size, shape, and internal structure	Nanoparticles typically in the range of 5–100 nm
Dynamic Light Scattering (DLS)	Measures hydrodynamic particle size distribution	Mean particle size and polydispersity index (PDI)
Zeta Potential Analysis	Assesses surface charge and colloidal stability	Values $> \pm 25$ mV indicate good stability
Energy Dispersive X-ray Analysis (EDX/EDS)	Confirms elemental composition of nanoparticles	Presence of metal ions (Ag, Au, Zn, Fe, etc.)
Atomic Force Microscopy (AFM)	Provides three-dimensional surface topography	Height, roughness, and particle distribution
Thermogravimetric Analysis (TGA)	Evaluates thermal stability and organic content	Weight loss associated with phytochemical capping agents

**Table 1** summarizes commonly used characterization techniques and their purpose.

## Pharmacological Screening

### Antimicrobial Activity

The antimicrobial activity is evaluated using agar well diffusion or broth dilution methods against bacterial and fungal strains. The zone of inhibition is measured to determine the effectiveness of the antimicrobial agent. Minimum inhibitory concentration (MIC) values are also established to quantify the lowest concentration that inhibits visible microbial growth. These methods provide essential data for assessing the potential use of compounds in controlling microbial infections.

### Antioxidant Activity

Free radical scavenging assays such as DPPH and ABTS are employed. These assays measure the ability of antioxidants to neutralize free radicals by donating electrons or hydrogen atoms. The DPPH assay involves a stable free radical that changes color upon reduction, allowing quantification of scavenging activity. Similarly, the ABTS assay generates a radical cation whose decolorization reflects the antioxidant capacity of the sample.

### Anticancer Activity

In vitro cytotoxicity is assessed using MTT or SRB assays on cancer cell lines. These assays measure cell viability by quantifying metabolic activity (MTT) or total protein content (SRB) after treatment with test compounds. Results are typically expressed as a percentage of control cell viability to determine cytotoxic effects. Data obtained help evaluate the potential anticancer properties of the substances under investigation.

## Results and Discussion

### Synthesis and Characterization

Successful synthesis of nanoparticles is confirmed by UV–Vis spectra showing characteristic absorption peaks. FTIR analysis indicates the presence of phytochemicals on the nanoparticle surface. Electron microscopy reveals predominantly spherical nanoparticles with sizes ranging from 10–50 nm.

Plant Name	Plant Part Used	Major Phytochemicals Involved	Type of Nanoparticles Synthesized	Reported Applications
<i>Azadirachta indica</i> (Neem)	Leaves	Flavonoids, terpenoids, polyphenols	Silver nanoparticles (AgNPs)	Antimicrobial, wound healing
<i>Aloe vera</i>	Gel / Leaves	Polysaccharides, phenolics	Zinc oxide nanoparticles (ZnO NPs)	Antibacterial, UV protection
<i>Ocimum sanctum</i> (Tulsi)	Leaves	Eugenol, rosmarinic acid	Silver nanoparticles (AgNPs)	Antimicrobial, antioxidant
<i>Camellia sinensis</i> (Green tea)	Leaves	Catechins, polyphenols	Gold nanoparticles (AuNPs)	Antioxidant, anticancer
<i>Curcuma longa</i> (Turmeric)	Rhizome	Curcumin, phenolic compounds	Silver nanoparticles (AgNPs)	Anti-inflammatory, anticancer
<i>Terminalia arjuna</i>	Bark	Tannins, flavonoids	Gold nanoparticles (AuNPs)	Cardioprotective, antioxidant
<i>Moringa oleifera</i>	Leaves	Ascorbic acid, flavonoids	Iron oxide nanoparticles (Fe <sub>3</sub> O <sub>4</sub> NPs)	Antidiabetic, drug delivery
<i>Punica granatum</i> (Pomegranate)	Peel	Ellagitannins, polyphenols	Silver nanoparticles (AgNPs)	Antimicrobial, antioxidant
<i>Hibiscus rosa-sinensis</i>	Flowers	Anthocyanins, flavonoids	Zinc oxide nanoparticles (ZnO NPs)	Antibacterial, anti-inflammatory
<i>Eucalyptus globulus</i>	Leaves	Terpenoids, phenolics	Silver nanoparticles (AgNPs)	Antimicrobial, antifungal

**Table 2** presents a list of plants used for nanoparticle synthesis and the type of nanoparticles produced.

### Pharmacological Activities

Green-synthesized nanoparticles exhibit significant antimicrobial activity against both Gram-positive and Gram-negative bacteria. Antioxidant assays demonstrate dose-dependent free radical scavenging. Anticancer studies reveal

selective cytotoxicity toward cancer cells while sparing normal cells. These nanoparticles demonstrate enhanced biocompatibility, making them suitable for biomedical applications. Mechanistic studies suggest that their antimicrobial action involves disruption of bacterial cell membranes and induction of oxidative stress.

Further in vivo experiments are warranted to confirm their therapeutic potential and safety profile.

Figure 2: Comparative Antimicrobial Activity of Plant-Synthesized Nanoparticles

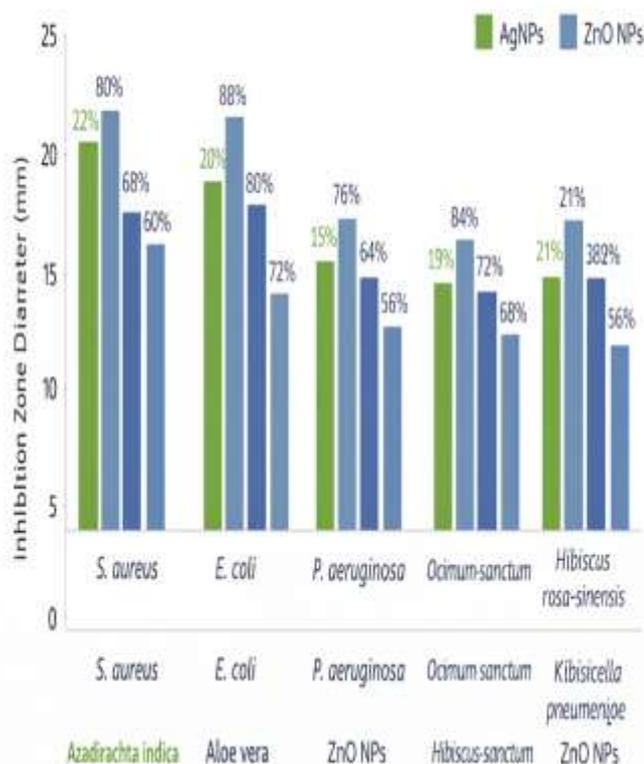


Figure 2 depicts comparative antimicrobial activity of plant-synthesized nanoparticles.

The enhanced pharmacological activity is attributed to synergistic interactions between nanoparticles and surface-bound phytochemicals.

### Conclusion

Green synthesis of nanoparticles using plant extracts represents a promising and sustainable approach in nanotechnology. The integration of phytochemicals not only facilitates eco-friendly synthesis but also enhances pharmacological efficacy. Despite challenges in scalability and standardization, continued research is expected to advance the application of green nanoparticles in drug development and therapeutics. These nanoparticles exhibit unique physicochemical

properties, including enhanced stability and biocompatibility, which are critical for biomedical applications. Additionally, the use of plant extracts reduces the reliance on hazardous chemicals, aligning with green chemistry principles. Ongoing optimization of synthesis parameters aims to improve yield and reproducibility, facilitating broader industrial adoption.

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