

Recent Plant-Derived Bioactive Compounds for Nanoparticle Synthesis and applications: A Review

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ABSTRACT- Plant-mediated nanoparticle synthesis has emerged as an important approach in green nanotechnology because plant extracts provide naturally occurring reducing, capping and stabilizing molecules for nanoparticle formation. Plants contain diverse bioactive compounds, including phenolic acids, flavonoids, tannins, terpenoids, alkaloids, proteins, sugars and polysaccharides, which can participate in metal-ion reduction and subsequent nanoparticle stabilization. In addition to their role during synthesis, these phytochemicals can remain associated with nanoparticle surfaces and influence their physicochemical and biological properties. Recent studies have demonstrated the synthesis of silver, gold, zinc oxide, copper oxide, selenium and other nanoparticles using plant extracts, with promising antioxidant and antimicrobial activities. The biological activity of these nanoparticles is influenced by particle size, morphology, surface chemistry, crystallinity, phytochemical composition and synthesis conditions. This review discusses the role of plant-derived bioactive compounds in nanoparticle synthesis, mechanisms of nanoparticle formation, characterization, and application.

Keywords: plant extract; green synthesis; phytochemicals; metal oxide nanoparticles; green nanotechnology.

1. INTRODUCTION

Nanotechnology has developed rapidly because materials at the nanoscale exhibit unique physicochemical, optical, catalytic and biological properties. Metal and metal-oxide nanoparticles have attracted particular attention because of their high surface-area-to-volume ratio, tunable morphology and surface reactivity [1,2]. These characteristics have resulted in applications in medicine, environmental remediation, agriculture, food technology, catalysis and materials science. However, conventional physical and chemical methods for nanoparticle synthesis may require high temperatures, high energy input, organic solvents and potentially toxic reducing or stabilizing agents. These limitations have encouraged researchers to develop environmentally compatible synthesis strategies. Green synthesis using biological materials has therefore become an important alternative. Among biological sources, plants are especially attractive because they are readily available and contain a large diversity of metabolites capable of reducing metal ions and stabilizing the resulting nanoparticles. Plant extracts can function as natural reducing, capping and stabilizing systems, thereby reducing the requirement for additional synthetic chemicals [3]. Recent reviews have reported successful plant-mediated synthesis of Ag, Au and Cu nanoparticles as well as ZnO, MgO, Co₃O₄ and TiO₂ nanoparticles [4]. The chemical composition of the plant extract is particularly important in determining nanoparticle formation. Phenolic compounds, flavonoids, alkaloids, terpenoids, proteins, sugars and other biomolecules can participate in metal-ion reduction and surface stabilization. These compounds can also influence nucleation, particle growth, aggregation and surface functionality. Consequently, differences in plant species, plant part and extraction method can result in nanoparticles with substantially different sizes, shapes and biological properties. Recent research has increasingly focused on the relationship between plant phytochemicals, nanoparticle physicochemical characteristics and biological activity. A recent review of plant-mediated metal oxide nanoparticles reported that phenolics, flavonoids, alkaloids, terpenoids and proteins act as important reducing, capping and stabilizing agents, while parameters such as pH, temperature and extract concentration influence nanoparticle size, morphology and surface properties. Another recent review emphasized the importance of biological metabolites in controlling reduction, nucleation, growth and stabilization and linked these processes to antimicrobial behavior. The biological properties of plant-mediated nanoparticles are also receiving increasing attention. Antimicrobial activity is particularly important because nanoparticles can act against microorganisms through several mechanisms, including membrane disruption, reactive oxygen species generation and interference with DNA and protein synthesis [5]. Antioxidant activity is another important property, particularly where plant phytochemicals remain associated with the nanoparticle surface. Recent reviews have highlighted the potential of plant-derived nanoparticles in antimicrobial therapy, wound healing, drug delivery and other biomedical applications. Recent experimental research further demonstrates this trend. Carissa spinarum leaf extract has been used for the green synthesis of Ag nanoparticles, followed by evaluation of their antioxidant and antimicrobial properties [6]. CuO NPs synthesized using Rumex nepalensis Spreng., offering insights into their potential

applications in antimicrobial and antioxidant fields [7] an efficient and greener approach for the synthesis of copper oxide nanoparticles using *Rivina humilis* whole plant extract [8]. Similarly, *Dillenia indica* flower extract has been employed for the synthesis of Ag nanoparticles, with subsequent evaluation of their structural characteristics, antibacterial activity and antioxidant potential [9]. More recently, *Morus rubra* leaf extract was investigated for the phytosynthesis of selenium nanoparticles and evaluation of their antioxidant, antimicrobial and anticancer properties [10]. Therefore, plant-mediated nanoparticle synthesis is evolving from a simple green alternative to chemical synthesis into a multidisciplinary approach involving phytochemistry, nanomaterials science, microbiology and biotechnology. This review focuses on the role of plant-derived bioactive compounds in nanoparticle synthesis and summarizes recent advances in their applications of plant-mediated nanoparticles.

2. Plant Bioactive Compounds Involved in Nanoparticle Synthesis

Plants contain numerous secondary metabolites that can participate in nanoparticle synthesis. Phenolic compounds and flavonoids are particularly important because their hydroxyl and other functional groups can facilitate electron-transfer reactions [11]. Phenolic acids such as gallic acid, caffeic acid, chlorogenic acid and ferulic acid can contribute to metal-ion reduction, while flavonoids such as quercetin, kaempferol, rutin and catechins can participate in both reduction and surface stabilization. Terpenoids, alkaloids, tannins, proteins, polysaccharides and sugars may also contribute to nanoparticle formation [12]. The relative contribution of these compounds depends on the plant species and extraction conditions. Because plant extracts contain multiple compounds, nanoparticle formation is generally considered a complex synergistic process rather than the action of a single reducing molecule. Flavonoids are of particular interest because a recent systematic review identified their important role in green synthesis of antimicrobial nanoparticles. Flavonoids can function as reducing and stabilizing molecules while also contributing biological activity to the resulting nanomaterials. This provides an important connection between phytochemistry and nanoparticle functionality [13].

3. Mechanism of Plant-Mediated Nanoparticle Synthesis

Plant-mediated nanoparticle synthesis can generally be described through the stages of reduction, nucleation, growth and stabilization. During the initial stage, phytochemicals present in the plant extract interact with metal ions and facilitate their reduction. The reduced species subsequently undergo nucleation and particle growth [14]. Biomolecules present in the extract can adsorb onto the newly formed nanoparticle surfaces and restrict uncontrolled aggregation. The overall process can be represented in fig.1.

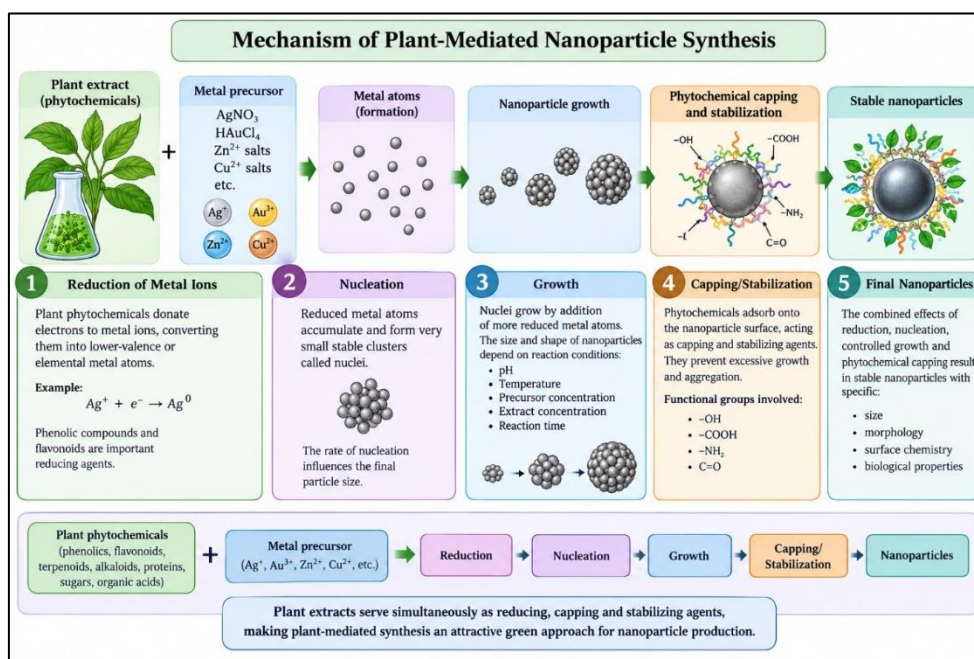


Figure:1. Mechanism of Plant-Mediated Nanoparticle Synthesis

The exact mechanism depends on the nature of the metal precursor and plant extract. For silver and gold nanoparticles, reduction of metal ions to elemental metal is generally involved [15]. In metal oxide systems such as ZnO and CuO, the plant metabolites participate in precursor conversion and stabilization followed by formation of the oxide phase. Synthesis parameters strongly influence the resulting nanoparticles. Changes in pH, temperature, extract concentration, precursor concentration and reaction time can modify the reduction rate and nucleation process and therefore influence particle size and morphology. Standardization of these parameters is consequently essential for reproducible synthesis.

4. Recent Plant-Mediated Nanoparticle synthesis and applications

Recent studies demonstrate the growing diversity of plants and nanoparticle systems investigated using green synthesis.

Plant used	Plant part / extract	Nanoparticle synthesized	Major application / activity
<i>Uvaria narum</i>	Leaves	Silver nanoparticles	Antibacterial, antiangiogenic, anticancer and catalytic applications [16]
<i>Lasiosiphon eriocephalus</i>	Leaves	Gold nanoparticles	Antioxidant, antibacterial and anticancer [17]
<i>Ephedra alata</i>	Aqueous plant extract	Copper oxide NPs	Antibacterial, antifungal and photocatalytic applications [18]
<i>Trianthema portulacastrum</i>	Leaves	Silver nanoparticles	Larvicidal and antibacterial activity [19]
<i>Trigonella foenum-graecum</i>	Leaves	Silver nanoparticles	Dye degradation and metal-ion sensing [20]
<i>Angelonia angustifolia</i> ,	Whole plant	Copper oxide NPs	Antibacterial application
<i>Premna integrifolia</i>	Roots	Silver nanoparticles	Antibacterial and cytotoxic applications [22]
<i>Dillenia indica</i>	Flowers	Silver nanoparticles	Antibacterial and antioxidant applications [23]
Pomegranate, beetroot and seder	Fruit/plant extracts	Zinc oxide nanoparticles	Photocatalytic degradation of dyes [24]
<i>Piper betle</i>	Leaves	Copper oxide	Photocatalysis, antibacterial activity and energy storage [25]
<i>Carissa spinarum</i>	Leaves	Silver nanoparticles	Antibacterial, antifungal and antioxidant applications [26]
<i>Aesculus hippocastanum</i>	Fruits	Silver-decorated zinc oxide nanoparticles	Antibacterial, antioxidant and photocatalytic applications[27]
<i>Allium jacquemontii</i>	Plant extract	Silver nanoparticles	Antibacterial and antifungal applications [28]
<i>Uraria picta</i>	Whole plant	Cobalt oxide nanoparticles	Antibacterial and antioxidant applications [29]
<i>Morus rubra</i>	Leaves	Selenium nanoparticles	Antioxidant, antimicrobial and anticancer applications [30]

5. Characterization of Plant-Mediated Nanoparticles

Characterization is essential for confirming nanoparticle formation and understanding their physicochemical properties. UV–visible spectroscopy is commonly used to monitor nanoparticle formation and optical characteristics. FTIR spectroscopy provides information regarding functional groups associated with plant-derived molecules on nanoparticle surfaces. X-ray diffraction is used to determine crystalline structure and crystallinity, while SEM and TEM provide information about morphology and particle size. Energy-dispersive X-ray spectroscopy can confirm elemental composition, whereas dynamic light scattering provides hydrodynamic size and polydispersity. Zeta-potential measurements are useful for evaluating surface charge and colloidal stability [31]. Recent reviews emphasize that comprehensive characterization is essential for establishing relationships between synthesis conditions, nanoparticle properties and biological performance.

6. CONCLUSION

Plant-mediated nanoparticle synthesis has emerged as an environmentally friendly, cost-effective, and promising approach for producing biologically active nanomaterials. Plant extracts contain diverse phytochemicals, including phenolics, flavonoids, tannins, terpenoids, alkaloids, proteins, sugars, and organic acids, which participate in metal-ion reduction, nucleation, growth, capping, and stabilization of nanoparticles. Thus, plant extracts can act as natural reducing, capping, and stabilizing agents, reducing the dependence on hazardous chemicals used in conventional synthesis. The physicochemical characteristics of plant-mediated nanoparticles are influenced by the plant species, plant part, extraction method, phytochemical composition, metal precursor, pH, temperature, reaction time, and extract concentration. Optimization of these parameters is essential for controlling particle size, morphology, crystallinity, surface chemistry, and stability. Techniques such as UV–Visible spectroscopy, FTIR, XRD, SEM, TEM, EDX, and zeta-potential analysis are important for confirming nanoparticle formation and evaluating their properties. Plant-mediated nanoparticles demonstrate considerable antioxidant, antibacterial, antifungal, anticancer, anti-inflammatory, and

photocatalytic activities. Their biological effects may result from both nanoparticle-specific properties and phytochemicals present on their surfaces. plant-mediated nanoparticle synthesis represents an important integration of green chemistry, nanotechnology, and phytochemistry, with significant potential for sustainable biomedical, environmental, agricultural, and industrial applications.

REFERENCES

- Joshi, N., Pandey, D. K., Mistry, B. G., & Singh, D. K. (2023). Metal oxide nanoparticles: Synthesis, properties, characterization, and applications. In *Nanomaterials: Advances and applications* (pp. 103–144). Springer Nature Singapore.
- Olawade, D. B., Wada, O. Z., Egbewole, B. I., Fapohunda, O., Ige, A. O., Usman, S. O., & Ajisafe, O. (2024). Metal and metal oxide nanomaterials for heavy metal remediation: Novel approaches for selective, regenerative, and scalable water treatment. *Frontiers in Nanotechnology*, 6, 1466721.
- Villagrán, Z., Anaya-Esparza, L. M., Velázquez-Carriles, C. A., Silva-Jara, J. M., Ruvalcaba-Gómez, J. M., Aurora-Vigo, E. F., & Martínez-Esquivias, F. (2024). Plant-based extracts as reducing, capping, and stabilizing agents for the green synthesis of inorganic nanoparticles. *Resources*, 13(6), 70.
- Parveen, S., Rahman, F. R., Krishnan, S. T., Kalaiarasi, G., Dinesh, A., Priya, L. S., & Santhoshkumar, S. (2025). Green synthesis of metal oxide nanoparticles via plant extracts for biological applications: A review. *Trends in Sciences*, 22(6), 9592.
- El Shafey, A. M. (2020). Green synthesis of metal and metal oxide nanoparticles from plant leaf extracts and their applications: A review. *Green Processing and Synthesis*, 9(1), 304–339.
- Firdous, H., Khan, R. T., Manzoor, M., et al. (2025). Green synthesis and characterization of Ag nanoparticles using *Carissa spinarum* L. leaf extract: Evaluation for their antimicrobial and antioxidant activities. *Microscopy Research and Technique*, 88(8), 2285–2296.
- Abhimanyu, P., Arvind, M., & Kishor, N. (2023). Biosynthesis of CuO nanoparticles using plant extract as a precursor: Characterization, antibacterial, and antioxidant activity. *Nano Biomedicine & Engineering*, 15(4), 369.
- Sheikh, S., Mungole, A. J., Pandhurnekar, C. P., Kanfade, H. P., Pandhurnekar, H. C., & Pawar, A. P. (2024). Greener synthesis of copper oxide nanoparticles using *Rivina humilis* L. plant extract, characterization and their biological evaluation for anti-microbial and anti-oxidant activity. *ChemistrySelect*, 9(31), e202401219.
- Tiwari, et al. (2024). Biosynthesis of silver nanoparticle from flower extract of *Dillenia indica* and its efficacy as antibacterial and antioxidant. *Microbial Pathogenesis*.
- Rocha, L. V. M., et al. (2026). Phytosynthesis of selenium nanoparticles from *Morus rubra* (L.) and evaluation of its bioactive potential: Antioxidant, antimicrobial, and anticancer. *Anticancer Agents in Medicinal Chemistry*.
- Hussein, R. A., & El-Anssary, A. A. (2019). Plants secondary metabolites: The key drivers of the pharmacological actions of medicinal plants. *Herbal Medicine*, 1(3), 11–30.
- Perumalsamy, H., Balusamy, S. R., Sukweenadhi, J., Nag, S., MubarakAli, D., El-Agamy Farh, M., & Rahimi, S. (2024). A comprehensive review on *Moringa oleifera* nanoparticles: Importance of polyphenols in nanoparticle synthesis, nanoparticle efficacy and their applications. *Journal of Nanobiotechnology*, 22(1), 71.
- Santana Junior, C. C., Santos, A. M., Oliveira, A. M. S., Nascimento Junior, J. A. C., Picot, L., Frank, L. A., & Serafini, M. R. (2025). Green synthesis of antimicrobial nanotechnology using flavonoids: A systematic review. *Journal of Microencapsulation*, 42(4), 392–405.
- Khan, F., Shariq, M., Asif, M., Siddiqui, M. A., Malan, P., & Ahmad, F. (2022). Green nanotechnology: Plant-mediated nanoparticle synthesis and application. *Nanomaterials*, 12(4), 673.
- Shah, M., Fawcett, D., Sharma, S., Tripathy, S. K., & Poinern, G. E. J. (2015). Green synthesis of metallic nanoparticles via biological entities. *Materials*, 8(11), 7278–7308.
- Ajaykumar, A. P., et al. (2023). Green synthesis of silver nanoparticles using the leaf extract of the medicinal plant, *Uvaria narum*, and its antibacterial, antiangiogenic, anticancer and catalytic properties. *Antibiotics*, 12, 564.
- Datkhile, K. D., et al. (2023). Biogenic nanoparticles: Synthesis, characterization, and biological potential of gold nanoparticles synthesized using *Lasiosiphon eriocephalus* Decne plant extract. *Pharmaceutical Nanotechnology*, 11, 303–314.
- Atri, A., et al. (2023). Green synthesis of copper oxide nanoparticles using *Ephedra alata* plant extract and a study of their antifungal, antibacterial activity and photocatalytic performance under sunlight. *Heliyon*, 9, e13484.
- Rameshkumar, K., Ananthi, V., Arun, A., Prema, P., Veeramanikandan, V., Nguyen, V. H., & Balaji, P. (2023). *Trianthema portulacastrum* leaf extract mediated synthesis of silver nanoparticles and elucidation of their larvicidal and antibacterial activities. *Materials Today Communications*, 35, 105980.
- Parwate, K. L., Mungole, A. J., Pawar, A. P., Kanfade, H. P., & Yerpude, A. N. (2026). Green synthesis and characterization of CuO nanoparticles using *Angelonia angustifolia* Benth. plant extract for antibacterial applications. *Chemical Papers*, 1–11.

21. Tessema, B., Gonfa, G., Hailegiorgis, S. M., Prabhu, S. V., & Manivannan, S. (2023). Synthesis and characterization of silver nanoparticles using reducing agents of bitter leaf (*Vernonia amygdalina*) extract and tri-sodium citrate. *Nano-Structures & Nano-Objects*, 35, 100983.
22. Singh, C., Anand, S. K., Upadhyay, R., Pandey, N., Kumar, P., Singh, D., & Tilak, R. (2023). Green synthesis of silver nanoparticles by root extract of *Premna integrifolia* L. and evaluation of its cytotoxic and antibacterial activity. *Materials Chemistry and Physics*, 297, 127413.
23. Gupta, A., Pandey, B. C., Verma, J., et al. (2024). Biosynthesis of silver nanoparticle from flower extract of *Dillenia indica* and its efficacy as antibacterial and antioxidant. *Microbial Pathogenesis*, 193, 106779.
24. Mousa, S. A., Wissa, D. A., Hassan, H. H., et al. (2024). Enhanced photocatalytic activity of green synthesized zinc oxide nanoparticles using low-cost plant extracts. *Scientific Reports*, 14, 16713.
25. Ahmad, A., Khan, M., Osman, S. M., Haassan, A. M., Javed, M. H., Ahmad, A., & Luque, R. (2024). Benign-by-design plant extract-mediated preparation of copper oxide nanoparticles for environmentally related applications. *Environmental Research*, 247, 118048.
26. Firdous, H., Khan, R. T., Manzoor, M., et al. (2025). Green synthesis and characterization of Ag nanoparticles using *Carissa spinarum* L. leaf extract: Evaluation for their antimicrobial and antioxidant activities. *Microscopy Research and Technique*, 88, 2285–2296.
27. Mortazavi-Derazkola, S., Samadipour, M., Mohammadparast-Tabas, P., & Yousefi, M. (2025). *Aesculus hippocastanum* extract-mediated biosynthesis of silver-decorated zinc oxide nanoparticles and investigation of their photocatalytic, antibacterial, and antioxidant properties. *Bioprocess and Biosystems Engineering*, 48, 1533–1546.
28. Kamal, A., et al. (2025). Biogenic synthesis of silver nanoparticles (AgNPs) from *Allium jacquemontii* extract and its assessment in different biological activities. *Scientific Reports*, 15, 27559.
29. Sheikh, S., Mungole, A. J., Bhat, A. R., et al. (2025). Sustainable plant mediated synthesis of cobalt oxide nanoparticles using *Uraria picta* extract with enhanced biological activity. *Scientific Reports*, 15, 44017.
30. Rocha, L. V. M., Lishanthi, R., Begum, M. S., et al. (2026). Phytosynthesis of selenium nanoparticles from *Morus rubra* (L.) and evaluation of its bioactive potential: Antioxidant, antimicrobial, and anticancer. *Anticancer Agents in Medicinal Chemistry*, 26, 1283–1296.
31. Rajeshkumar, S., & Bharath, L. V. (2017). Mechanism of plant-mediated synthesis of silver nanoparticles: A review on biomolecules involved, characterisation and antibacterial activity. *Chemico-Biological Interactions*, 273, 219–227.