



Green synthesis of silver nanoparticles using *Azadirachta Indica* (Neem): A review

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Abstract

Green synthesis of nanoparticles using plant extracts has become a sustainable and effective alternative to traditional chemical and physical methods. This review focuses on the use of *Azadirachta indica* (neem) extract, which contains bioactive compounds that act as natural reducing and stabilizing agents.

The paper discusses the synthesis of different nanoparticles such as silver, gold, copper, zinc oxide, and magnesium oxide. It also highlights their key properties, including controlled particle size (usually 10–80 nm), good stability, and useful optical features.

The findings show that plant-based nanoparticles have important applications in biomedicine, environmental cleanup, agriculture, and photocatalysis, including antimicrobial activity and the breakdown of organic pollutants. This review also points out that factors like synthesis conditions, plant extract composition, and related challenges are important. Overall, it shows that plant-based nanoparticle synthesis is a promising link between sustainable chemistry and modern nanotechnology.

Keywords: Green synthesis, Metal Nanoparticles, *Azadirachta indica* (neem) plant, Sustainability, Eco-friendly nanotechnology

Introduction

Metal nanoparticles have become an important area of research because of their very small size and large surface area, which give them unique physical and chemical properties. These properties make them useful in many fields such as medicine, environmental protection, agriculture, and material science. Among the different methods of synthesis, the use of plant extracts is gaining popularity as a green and sustainable approach. Plant extracts contain natural compounds like flavonoids, phenols, terpenoids, proteins, and alkaloids that help in converting metal ions into nanoparticles and also keep them stable. Today, Plant-based synthesis of nanoparticles is considered as an effective, low in cost, and eco-friendly technique in modern nanotechnology (Ahmed *et al.*, 2016)^[1].

Among various plants, *Azadirachta indica* (neem), a member of the Meliaceae family, is widely recognized for its medicinal value and is commonly found in tropical regions. It has traditionally been used to treat bacterial, fungal, and viral infections, as well as various skin-related disorders. Neem contains several bioactive compounds, including flavonoids, terpenoids, phenolic substances, nimbin, and azadirachtin playing as reducing and stabilizing agents in nanoparticle synthesis.

Researchers have shown that aqueous extracts of neem can effectively applied to produce a wide range of metal and metal oxide nanoparticles, such as silver, gold, copper, zinc, carbon, and iron nanoparticles. These nanoparticles often show improved biological activities, including antimicrobial, antioxidant, and catalytic properties, making them useful in medicine, environmental cleanup, and nanotechnology. Therefore, the present review focuses on the green synthesis of nanoparticles using different parts of the neem plant and explains the role of various metals, with special attention to their sustainable and environmentally friendly applications.

Objectives

1. To review and analyze the synthesis of various metal and metal oxide nanoparticles (such as silver, gold, copper, and zinc) using neem-mediated green synthesis methods.
2. To highlight the potential applications of Neem based nanoparticles in various fields.

Methodology

Fresh leaves of *Azadirachta indica* were collected, thoroughly washed with distilled water to remove dust and impurities, and air-dried at room temperature. The dried leaves were ground into a fine powder. Approximately 5–10 g of neem leaf powder was mixed with 100–200 mL of distilled water and heated at 60–80 °C for about 20–30 min with continuous stirring. The mixture was then cooled and filtered using Whatman filter paper to obtain a clear aqueous neem leaf extract, which acts as a natural reducing and stabilizing agent in nanoparticle synthesis (Iravani, 2011)^[4]. For nanoparticle synthesis (Fig.1), an aqueous solution of a suitable metal precursor salt (such as silver nitrate, zinc acetate, zinc nitrate, or copper sulfate) was prepared in distilled water. The prepared neem leaf extract was then slowly added to the metal salt solution under continuous magnetic stirring. The reaction mixture was maintained at room temperature or mild heating (50–70 °C) for 30–60 min. A visible color change in the reaction mixture indicated the reduction of metal ions and the formation of nanoparticles due to the action of phytochemicals present in the neem extract (Ahmed *et al.*, 2016; Sangeetha *et al.*, 2011)^[1, 18].

The synthesized nanoparticles were separated by centrifugation at 8000–10,000 rpm for 10–15 min. The obtained precipitate was washed several times with distilled water or ethanol to remove residual impurities and then dried in a hot air oven at 60–80 °C to obtain purified nanoparticle powder (Singh *et al.*, 2018)^[21]. The formation

and properties of the nanoparticles were further analyzed using different characterization techniques such as UV–Visible spectroscopy, X-ray diffraction (XRD), Scanning Electron Microscopy (SEM/FESEM), and FTIR

spectroscopy to determine their optical properties, crystalline structure, morphology, and functional groups involved in nanoparticle stabilization (Singh *et al.*, 2018)^[21].



Fig 1: Neem (*Azadirachta indica*) mediated nanoparticles synthesis.

Neem (*Azadirachta indica*) derived nanoparticles

▪ Copper Oxide Nanoparticles (CuO NPs)

Copper oxide nanoparticles can be synthesized using *Azadirachta indica* (neem) leaf extract through eco-friendly methods such as precipitation and co-precipitation. In this green synthesis approach, the phytochemicals present in neem leaves act as natural reducing as well as stabilizing agents, converting Cu^{2+} ions into stable CuO nanoparticles. Nagar *et al.* (2018)^[13] reported the synthesis of copper nanoparticles using neem leaf extract and observed that the particles were crystalline, cubical in shape, and had an average size of approximately 48 nm under optimized conditions (pH 6.6 and 85 °C). The formation of nanoparticles was monitored using UV–VIS spectroscopy and further confirmed by X-ray diffraction (XRD) and scanning electron microscopy (SEM).

In another study, Dey *et al.* (2019)^[3] synthesized CuO nanoparticles using neem leaf extract and reported spherical particles with sizes ranging from 36–38 nm. Their findings also indicated significant cytotoxic activity against cancer cell lines, suggesting potential biomedical applications. The synthesized nanoparticles were characterized using techniques such as Fourier-transform infrared spectroscopy (FTIR), transmission electron microscopy (TEM), and dynamic light scattering (DLS), which confirmed their structure and stability.

▪ Magnesium Oxide Nanoparticles (MgO NPs)

Magnesium oxide nanoparticles (MgO NPs) can be synthesized using *Azadirachta indica* (neem) leaf extract. In this method, Magnesium nitrate ($\text{Mg}(\text{NO}_3)_2$) is commonly used as the precursor, while the bioactive compounds present in neem leaves act as natural reducing and stabilizing agents, facilitating the formation of MgO nanoparticles.

The synthesized MgO nanoparticles are typically characterized using techniques such as X-ray diffraction (XRD) to determine crystalline structure, field emission scanning electron microscopy (FE-SEM) to examine morphology, UV–Vis spectroscopy to analyze optical properties, and Fourier-transform infrared spectroscopy (FTIR) to identify functional groups involved in the synthesis. Sharma *et al.* (2014)^[20] reported that neem-mediated MgO nanoparticles generally fall within the nanoscale range of approximately 20–80 nm. In terms of optical properties, MgO nanoparticles show absorption peaks in the UV region (around 250–320 nm), indicating their potential use in optical and photocatalytic applications (Moorthy *et al.*, 2015)^[12].

▪ ZnO Nanoparticles (ZnO NPs)

Kapoor *et al.* (2024)^[6] reported that in the synthesis of ZnO nanoparticles parameters such as temperature, pH, precursor salt, and reaction time significantly influence nanoparticle formation. Optimal conditions were observed at 60 °C, pH 8, using zinc acetate as the precursor with a reaction time of 4 hours. Characterization using UV–Vis spectroscopy, transmission electron microscopy (TEM), and scanning electron microscopy (SEM) confirmed the formation of stable ZnO nanoparticles with an average size ranging from 30–70 nm. These nanoparticles typically exhibit strong UV absorption in the 350–380 nm range, reflecting their notable optical properties.

Due to their nanoscale size and enhanced surface activity, ZnO nanoparticles demonstrate significant photocatalytic, antimicrobial, and UV-blocking properties which make them highly suitable for applications in environmental remediation, wastewater treatment, cosmetics, and nanomedicine (Kundu *et al.*, 2014)^[8].

▪ **Silver Nanoparticles (AgNPs)**

Verma and Mehata (2016) [23] reported that the synthesized AgNPs exhibited a characteristic surface plasmon resonance (SPR) peak around 400–450 nm in UV–Vis spectroscopy, confirming nanoparticle formation. The synthesis process was influenced by parameters such as pH, temperature, and reaction time. Particle size in neem-mediated AgNP synthesis has been reported to vary depending on experimental conditions. Ahmed *et al.* (2016) [1] observed that AgNPs synthesized using neem leaf extract were predominantly spherical with sizes ranging from approximately 10–35 nm, indicating good stability and dispersion. Similarly, Manik *et al.* (2014) [10] reported the green synthesis of silver nanoparticles using leaf extracts of *Artocarpus heterophyllus* and *Azadirachta indica* showed that the synthesized nanoparticles exhibit an average size ranging from 20–40 nm. The combination of controlled particle size, distinct optical properties, and biological effectiveness makes neem-based silver nanoparticle synthesis a promising alternative to conventional chemical methods.

▪ **Gold Nanoparticles (AuNPs)**

Green synthesis of gold nanoparticles (AuNPs) using neem (*Azadirachta indica*) extract has been reported as a rapid and

efficient biological method. Shankar *et al.* (2004) [19] demonstrated that neem leaf extract can reduce both silver (Ag⁺) and gold (Au³⁺) ions, leading to the formation of nanoparticles under ambient conditions. The study also reported the formation of bimetallic nanoparticles with a gold core and silver shell structure, which were confirmed using transmission electron microscopy (TEM).

▪ **Copper Nanoparticles (CuNPs)**

Nasrollahzadeh *et al.* (2018) [15] reported the successful synthesis of CuNPs using plant extracts, where the resulting nanoparticles were generally in the nanoscale range (around 40–50 nm) and exhibited good stability. The formation and characteristics of these nanoparticles were confirmed using techniques such as UV–Vis spectroscopy, X-ray diffraction (XRD), and scanning electron microscopy (SEM).

Multifunctional Applications of Neem-Based Green Synthesized Nanoparticles

Green synthesis approach highlights the potential of neem-based methods as a sustainable and economical alternative to conventional chemical techniques, with applications in catalysis, antimicrobial activity, and environmental remediation (Table:1).

Table 1: Applications of Neem-Based Green Synthesized Nanoparticles

Nanoparticle	Application Area	Specific Application	Key Outcome / Observation	Reference
Silver nanoparticles (AgNPs)	Biomedical	Antibacterial, wound healing Antimicrobial properties.	Strong inhibition of pathogenic bacteria such as <i>E. coli</i> and <i>S. aureus</i>	Verma & Mehata, 2016 [23] Roy <i>et al.</i> (2017) [17].
Gold nanoparticles (AuNPs)	Biomedical	Drug delivery, cancer therapy	Biocompatible nanoparticles suitable for targeted drug delivery and imaging	Shankar <i>et al.</i> , 2004 [19]
Zinc oxide nanoparticles (ZnO-NPs)	Biomedical / Cosmetics	Antibacterial, antioxidant	ZnO NPs exhibit antimicrobial activity and are used in cosmetic and biomedical formulations	Sangeetha <i>et al.</i> , 2011 [18]
Copper oxide nanoparticles (CuO-NPs)	Agriculture	Antifungal, crop protection	Effective against plant pathogens and improves post-harvest fruit storage	Joshi <i>et al.</i> , 2025 [5]
Iron nanoparticles (Fe-NPs)	Environmental	Wastewater treatment	Efficient removal of heavy metals and toxic pollutants from wastewater	Singh <i>et al.</i> , 2018 [21]
Titanium dioxide nanoparticles (TiO ₂ -NPs)	Environmental	Photocatalytic degradation	Degradation of organic pollutants and dyes in contaminated water	Narayanankutty <i>et al.</i> , 2023 [14]
Carbon nanoparticles	Biomedical / Environmental	Bioimaging, antioxidant activity	Fluorescent nanoparticles useful for biosensing and imaging	Singh <i>et al.</i> , 2024 [6]
Nickel oxide nanoparticles (NiO-NPs)	Catalytic	Electrochemical applications	Used in catalytic reactions and energy storage systems	Iravani, 2011 [4]
Magnesium oxide nanoparticles (MgO-NPs)	Environmental	Antimicrobial and pollutant removal	Effective antimicrobial agent and adsorbent for pollutants	Ahmed <i>et al.</i> , 2016 [1]
Bimetallic Au–Ag nanoparticles	Biomedical	Antimicrobial and catalytic activity	Core–shell nanoparticles show enhanced catalytic and antimicrobial properties	Shankar <i>et al.</i> , 2004 [19]
Copper nanoparticles (CuNPs)	Catalytic / Environmental	Dye degradation	Catalytic reduction of industrial dyes and pollutants	Singh <i>et al.</i> , 2018 [21]
Iron oxide nanoparticles (Fe ₃ O ₄ -NPs)	Environmental / Agricultural	Soil remediation, nutrient delivery	Used in environmental cleanup and nano-fertilizer systems	Narayanankutty <i>et al.</i> , 2023 [14]

Table 2: Phytochemicals of *Azadirachta indica* and Their Role in Green Nanoparticle Formation

Phytochemical	Plant Part	Function in Nanoparticle Synthesis	Type of Nanoparticles Reported	Reference
Azadirachtin	Seeds, fruit tissues	Participates in the reduction of metal ions and helps maintain nanoparticle stability	Silver (AgNPs), Gold (AuNPs)	Morgan, 2009 [11]
Nimbin	Seeds, leaves	Contributes to stabilization and prevents aggregation of particles during synthesis	Silver (AgNPs), Zinc oxide (ZnO NPs)	Biswas <i>et al.</i> , 2002 [2]
Nimbolide	Leaves	Bioactive compound that assists in the conversion of metal salts into nanoparticles	Copper oxide (CuO NPs), ZnO NPs	Paul <i>et al.</i> , 2011 [16]
Quercetin	Seeds, leaves	Flavonoid with strong reducing ability that promotes nanoparticle formation	Silver (AgNPs), Gold (AuNPs)	Biswas <i>et al.</i> , 2002 [2]
Gallic acid	Bark, rind	Phenolic compound acting as an electron donor	Silver (AgNPs), Copper	Kim <i>et al.</i> , 2010 [7]

		during nanoparticle synthesis	oxide (CuO NPs)	
Catechin	Bark	Helps in controlling particle size and improving nanoparticle stability	Silver (AgNPs)	Subapriya & Nagini, 2005 ^[22]
Ascorbic acid	Leaves	Natural antioxidant that supports reduction of metal ions in solution	Silver (AgNPs), Zinc oxide (ZnO NPs)	Subapriya & Nagini, 2005 ^[22]
Gedunin	Seeds	Supports nanoparticle stabilization and improves bioactivity	Gold (AuNPs), Silver (AgNPs)	MacKinnon <i>et al.</i> , 1997
Nimbidin	Seeds	Helps in reduction and stabilization during nanoparticle formation	Copper oxide (CuO NPs)	Biswas <i>et al.</i> , 2002 ^[2]

Conclusion

Neem leaves contain a wide range of bioactive phytochemicals that act as natural reducing and stabilizing agents, enabling the synthesis of various metal and metal oxide nanoparticles such as silver, gold, zinc oxide, and copper oxide. These nanoparticles have multifunctional applications in diverse fields, along with advantages such as low cost, reduced toxicity, simple synthesis procedures, and minimal environmental impact.

However, despite these benefits, several challenges still remain. Further research is needed to better understand the relationship between metal salt concentration and nanoparticle formation, as well as to optimize synthesis conditions for controlling particle size and reducing polydispersity.

Moreover, a clearer understanding of the role and quantity of phytochemicals involved in the synthesis process is also essential before their large-scale application. Overall, neem-mediated green synthesis offers a promising and sustainable approach for the future development of nanotechnology and it is hoped that this review paper will serve as a valuable resource for researchers and encourage further exploration and innovation in the rapidly growing field of plant-based nanotechnology and biodiversity.

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