

Green Synthesis of Copper and Nickel Nanoparticles Using Medicinal Plants Extracts: Characterization and their Applications

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Abstract: Nano-particles (NPs) are very important in many fields like science, agriculture, medical, electronics, industry etc because of their minute size and single properties. In recent years, copper and nickel nano-particles have been studied broadly due to their outstanding electrical conductivity, antimicrobial activity, and stability. However, traditional physical and chemical methods for making nano-particles are costly, use harmful chemicals, and are not eco-friendly. An alternative method is green synthesis, which uses plant extracts to produce nano-particles in a safer and more environmentally friendly way. Plant extracts contain natural chemicals like flavonoids and polyphenols that help in the reduction and stabilization of nano-particles. In this study, the medicinal plant extracts, known for its medicinal value, will be used. The main goal is to synthesize copper and nickel nanoparticles using the medicinal plant extract by using different parts (root, stem, leaves, flowers) and to analyze their physical and chemical properties using methods such as UV-Vis spectroscopy, FTIR, SEM, TEM, XRD, and more.

Keywords: Green Synthesis, Plant Extract, Copper Nano-Particles, Nickel Nanoparticles, Antimicrobial.

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I. INTRODUCTION

The term "nano" comes from the Greek word "nanos," which means dwarf, and refers to one-billionth (10^9) of a meter. Nanoparticles (NPs) are extremely small materials ranging in size from 1 to 100 nanometers (Murty et al., 2012). Nano-particles are divided into various types depending on their shape and dimensions. They are zero (0D), one (1D), two (2D), or three (3D) and have different shapes like rods, wires, tubes, films, and more (Tiwari et al., 2012; Khan et al., 2019). Based on their composition, nano-particles are classified into carbon-based NPs, metal-based NPs, polymeric NPs, ceramic NPs, semi-conductor NPs and lipid-based NPs (Khan et al., 2019).

Metal nanoparticles have attracted attention due to their applications in medicine, electronics, catalysis, and antimicrobial products (Li et al., 2001). These nanoparticles

have high surface area, are chemically reactive, and often show enhanced physical properties such as strength, conductivity, and antibacterial effects (Raveendran et al., 2003; Mali et al., 2020).

Common metals used for nano-particle synthesis include silver, gold, copper, zinc, nickel, aluminium, cerium and iron (Khan, 2019). Copper nanoparticles are known for their antimicrobial properties and good electrical conductivity (Mittal et al., 2013; Shobha et al., 2014). Nickel oxide nanoparticles (NiO NPs) are known for their p-type semiconductor nature, making them suitable for use in sensors, electronics, and biomedical devices (Roopan et al., 2019; Sabouri et al., 2021).

Nanoparticles can be formed using two main approaches: "top-down" and "bottom-up" methods. Top-down approaches

involve breaking down larger materials into nanoparticles using mechanical methods, while bottom-up methods build nanoparticles atom by atom or molecule by molecule (Murty et al., 2012; Singh et al., 2018). Green synthesis is a bottom-up method that uses biological agents like plant extracts, fungi, bacteria, or algae. This method is simple, inexpensive, and environmentally friendly (Mohammadi et al., 2016). Plant extracts are considered the best option because they contain bioactive molecules such as flavonoids, terpenoids, amino acids, and phenolics. These molecules act as natural reducing and stabilizing agents during nanoparticle synthesis (Makarov et al., 2014). The success of green synthesis depends on the plant part used, the temperature, pH, and concentration of the precursor (Makarov et al., 2014).

A. Objectives

The main goal of the present research is to investigate the green synthesis and characterization of copper and zinc nanoparticles using the phytochemically rich plant extracts (leaf, root, bark, and flower). The plant parts will act as natural reducing, stabilizing, and capping agents.

➤ *The Specific Objectives of the Study Include:*

- To synthesize copper, nickel, and bimetallic Cu-Ni nanoparticles of varying morphology and size using plant extracts and analyses their applications.
- To study how reaction parameters (time, temperature, pH, and precursor concentration) affect the synthesis and quality of the nanoparticles.
- To characterize nanoparticles by using analytical tools such as UV-Visible spectroscopy, FTIR (Fourier transform infrared spectrometry), XRD (X-ray Diffraction), TEM (Transmission electron microscopy), SEM (Scanning Electron Microscopy), EDX (Energy dispersive X-ray spectroscopy), and Zeta-sizer to understand their structure and behavior.

II. LITERATURE REVIEW

Nanotechnology, the manipulation of matter at the nanoscale, is revolutionizing science and technology. It was first conceptualized by Richard P. Feynman in 1959 and formally termed by Norio Taniguchi in 1974 to describe precision fabrication at the nanometer level (Murty et al., 2012; Khan et al., 2019). Metal and metal oxide nanoparticles, due to their size-dependent optical, magnetic, and catalytic properties, have been widely explored for numerous applications (Akintelu et al., 2020).

NPs are typically synthesized using either top-down or bottom-up strategies. Top-down approaches involve physical methods such as laser ablation, mechanical milling, and plasma techniques, which often require expensive instrumentation and consume considerable energy (Satyanarayana, 2018). Although these methods yield high-purity NPs with uniform morphology, they are not sustainable. On the other hand, bottom-up methods, especially green synthesis using plant extracts, have emerged as a viable eco-friendly alternative (Singh et al., 2018).

The biological synthesis of NPs employs microorganisms or plant derived phytochemicals to reduce metal ions into nanoparticles. Plant-mediated synthesis is preferable over microbial synthesis because it avoids issues related to microbial toxicity and complex culturing processes (Chand Mali et al., 2019). Plant extracts derived from parts like leaves, stems, roots, flowers, and bark, contain a variety of biomolecules such as flavonoids, terpenoids, polyphenols, saponins, alkaloids, and proteins that act as reducing and stabilizing agents (Makarov et al., 2014; Akintelu et al., 2020).

Numerous plant species have been used for the green synthesis of copper (Cu) and copper oxide (CuO) NPs, including *Carica papaya* (Sankar et al., 2014), *Ocimum sanctum* (Mekala et al., 2016), and *Passiflora foetida* (Fatma et al., 2017). These biosynthesized nanoparticles have demonstrated significant antimicrobial and photocatalytic potential. Despite the growing number of studies, research gaps remain. Most green synthesis studies focus only on copper or silver NPs using limited plants part, mainly leaves. There is a need to investigate less explored species and other plant parts like flowers, bark, or roots. Furthermore, studies rarely optimize reaction parameters such as pH, temperature, and precursor concentration. There is also insufficient data on the synthesis of bimetallic nanoparticles like Cu-Ni or on their dual photocatalytic and antimicrobial functions.

Various methods have been developed for synthesizing metal and metal oxide nanoparticles (NPs), among which green synthesis has gained significant attention as a promising alternative. This environmentally friendly method utilizes natural plant extracts and offers several benefits: it is simple, cost-effective, non-toxic, and can be performed under mild conditions, such as room temperature and atmospheric pressure. Compared to traditional physical and chemical approaches, green synthesis avoids the use of hazardous chemicals and energy-intensive procedures, making it a more sustainable and eco-conscious technique.

Despite its advantages, there is still a need to refine and standardize green synthesis methods. Achieving uniform nanoparticle size and shape is essential for consistent results, which requires precise control over various factors. Key parameters such as reaction time, temperature, pH level, and the concentrations of plant extract and metal salt solutions play a crucial role in determining the size, shape, and stability of the nanoparticles. Therefore, systematic optimization of these factors is necessary to produce nanoparticles with desired and reproducible properties.

Moreover, more research should focus on the phytochemical and antimicrobial potential of nanoparticles synthesized through green methods. These biologically derived nanoparticles have shown promising properties due to their large surface area and high reactivity, especially in applications such as antimicrobial treatments and phytochemical analysis.

III. METHODS AND MATERIALS

High-purity chemicals such as copper (II) sulfate (CuSO_4), nickel (II) sulfate (NiSO_4), sodium hydroxide (NaOH), and methanol will be used. Fresh and healthy medicinal plants parts (roots, leaves, bark, flowers) collect from the different regions. All glassware used in the experiments will be properly washed and sterilized to avoid contamination.

The collected medicinal plant parts (leaves, roots, bark, flowers) will be washed thoroughly with running water and rinsed with distilled water to remove dust and dirt. The plant parts will then be dried in the shade for 10–14 days and ground into fine powder using a clean blender. About 10 grams of this powder will be boiled in 400 mL of distilled water until the volume reduces to one-fourth (100 mL). After cooling, the solution will be filtered through Whatman No.1 filter paper. The filtrate will then be centrifuged at 5,000 rpm for 15 minutes to remove heavy particles. The clear extract will be collected in sterilized bottles and stored at 4°C for later use (Abubakar, A. R., & Haque, M., 2020).

A. Green Synthesis of Metal/Metal Oxide Nanoparticles

➤ Synthesis of Copper Nanoparticles (Cu-NPs):

A known concentration of copper (II) sulfate will be dissolved in distilled water. This solution will be slowly added drop wise into the prepared plant extract with continuous stirring and mild heating. A change in color will indicate the formation of nanop articles. The mixture will be kept for incubation at room temperature (at 31°C) for 24 hours (Younas et al., 2021).

➤ Synthesis of Nickel and Nickel Oxide Nan particles (Ni/NiO-NPs):

Nickel sulfate solution will also be mixed with the plant extract under similar conditions. The appearance of a new color will confirm nanoparticle formation. The product will be purified by centrifugation and drying (Uddin, S., et al. 2021).

➤ Synthesis of Bimetallic Cu-Ni Nanoparticles:

Equal parts of copper and nickel salt solutions will be mixed and then added to the plant extract (prepared in methanol). Different concentrations will be tested to optimize nanoparticle formation. UV-Visible spectrophotometry will be used to monitor the reaction. After synthesis, the nanoparticles will be collected by centrifugation and drying (Younas et al., 2021).

B. Characterization of Nanoparticles

To confirm and study the synthesized nanoparticles, the following techniques will be used:

- UV–Visible Spectrophotometric Analysis: To monitor the formation and stability of nanoparticles.
- FTIR (Fourier Transform Infrared Spectrophotometry): To identify functional groups responsible for reduction and stabilization.
- Scanning Electron Microscopy (SEM) & Transmission electron Microscopy (TEM): To observe size, shape, and surface of nanoparticles.
- Energy-Dispersive X-ray Spectroscopy (EDX): To analyze elemental composition.
- X-ray Diffraction (XRD): To determine crystal structure and purity.
- Scanning Tunnelling Microscopy (STM) and Atomic Force Microscopy (AFM): To analyze the size, morphology and surface structure of the nanoparticles.
- Zeta Potential Analyzer: To measure surface charge and stability of nanoparticles.

IV. RESULT AND ANALYSIS

All experiments will be carried out in triplicate. Results will be shown as mean $\pm$ standard error (SEM). Statistical software like SPSS and ANOVA will be used to analyze the significance of the data. Graphs and visual results will be prepared using Origin Pro 2019 software from experimental data.

A. Applications

➤ Agriculture & Plant Growth

- NiO Nanoparticles: Synthesized from the stem extract of *Berberis balochistanica*, these nanoparticles have been shown to enhance seed germination and seedling growth. They also possess antioxidant and antimicrobial properties, which contribute to plant health (Awan, S. Z., et. al. 2020).
- Cu Nanoparticles: Derived from Eucalyptus and Mint leaves, these nanoparticles are effective against plant pathogens. At a concentration of 1000 ppm, they demonstrated up to ~99.78% inhibition of *Colletotrichum capsici*, a significant fruit rot pathogen in chili plants (Arockiam, V. A. et. al. 2021).
- NiO–CuO–ZnO Nanometal Oxides: These were synthesized via a green combustion method and have been used for the photocatalytic degradation of AR88 dye, which, while primarily an environmental application, can also be relevant to agriculture for treating contaminated water sources (Arockiam, V. A. et. al. 2021).

➤ Environmental Remediation

- Cu–Ni Bimetallic Nanoparticles: Synthesized using *Zingiber officinale* (ginger) rhizome extract, these nanoparticles are highly effective in the removal of nitrophenols and organic dyes from water, making them valuable for wastewater treatment. (Sharma, S., et. al. 2020).
- NiO–CuO–ZnO Nanometal Oxides: As mentioned above, these nanoparticles, created through a green combustion process, have been specifically applied for the photocatalytic degradation of AR88 dye, demonstrating their utility in environmental cleanup (Sharma, S., et. al. 2020).

➤ Biomedical Applications

- NiO Nanoparticles: Synthesized from *Populus ciliata* leaves, these nanoparticles exhibit antibacterial, antifungal, and antioxidant properties, making them promising for various biomedical uses (Ali, M. A., et. al. 2021).
- Cu Nanoparticles: Derived from *Cicer arietinum* (chickpea) leaves, these nanoparticles show significant antimicrobial activity against bacterial pathogens that affect fish, which can be useful in aquaculture (Ahmed, S., et.al. 2020).
- CuO Nanoparticles:
 - ✓ From *Cissus quadrangularis* fruit: These exhibit antifungal activity against common molds like *Aspergillus niger* and *Aspergillus flavus* (Shafi, F., et. al. 2021).
 - ✓ From *Gloriosa superba* leaves: These nanoparticles demonstrate antibacterial activity specifically against urinary tract pathogens (Sharma, K., et.al. 2020).
 - ✓ From *Tinospora cordifolia*: These possess photocatalytic, antioxidant, and antibacterial properties, offering a multifunctional approach to biomedical applications (Sahu, D., et. al. 2020).

➤ Sensors & Electronics

- Cu–Ni Bimetallic Nanoparticles: Synthesized through laser ablation, these nanoparticles have been used in sensor applications due to their unique optical properties, which can be tuned for specific detection tasks (Zhang, C., et. al. 2021).
- Cu–Ni–Zn Nanometal Oxides: These nanoparticles are also utilized in sensor applications. Their tunable properties allow for superior multifunctional performances, making them versatile components in electronic devices (Jha, S., et. al. 2021).

➤ Corrosion Inhibition & Materials Protection

- Cu–Ni Bimetallic Nanoparticles: These nanoparticles have been applied to inhibit microbiologically influenced corrosion, which is a significant issue in many industries. Their use helps protect materials and extend the lifespan of infrastructure (Yang, G., 2020).

➤ Catalysis & Photocatalysis

- Cu–Ni Bimetallic Nanoparticles: These nanoparticles have been utilized for the photocatalytic degradation of AR88 dye, highlighting their strong catalytic properties in breaking down complex organic molecules (Sharma, S., et. al. 2020).
- Cu–Ni–Zn Nanometal Oxides: Synthesized via a green combustion method, these nanometal oxides are also used for the photocatalytic degradation of AR88 dye, demonstrating their effectiveness as catalysts in environmental and chemical processes (Sharma, S., et. al. 2020).

V. CONCLUSION

The green synthesis of Ni, Cu, and Ni–Cu nanoparticles represents a sustainable and eco-friendly approach for developing multifunctional nanomaterials with applications in agriculture, medicine, environmental remediation, electronics, and corrosion protection. Their demonstrated antimicrobial, photocatalytic, and protective capabilities underline their importance as alternatives to conventionally produced nanoparticles.

Comprehensive characterization using UV–Vis spectroscopy, XRD, FTIR, SEM/TEM, and EDX provides critical insights into nanoparticle formation, crystallinity, morphology, and elemental composition. Complementary analyses, including zeta potential and TGA, further ensure stability and thermal performance, thereby establishing strong correlations between synthesis, structure, and functionality.

Despite these promising outcomes, challenges remain in scalability, stability, and biosafety, particularly concerning long-term environmental impacts. Future research should emphasize optimizing synthesis protocols, advancing field-scale validation, and ensuring safe implementation. Overall,

green-synthesized Ni, Cu, and Ni–Cu nanoparticles stand as versatile and sustainable candidates for next-generation nanotechnology applications.

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