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Green Synthesis and Characterization of Copper-Based Nanoparticles Using *Polyalthia longifolia and Catharanthus roseus* Extracts

*[1]Shenbagam Madhavan

*[1]Assistant Professor, Department of Biochemistry and Biotechnology, Annamalai University, Annamalai Nagar, Tamil Nadu, India.

Abstract

Green nanotechnology offers sustainable approaches for nanoparticle synthesis using plant-derived phytochemicals. This study presents a combined green synthesis of copper and zinc oxide nanoparticles (CuO/ZnO NPs) using hydrous leaf extracts of Polyalthia longifolia and Catharanthus roseus. Both plants contain bioactive compounds flavonoids, phenolics, alkaloids, terpenoids, and tannins that acts as natural reducing and neutralizing agents. The NPs were synthesized by reducing copper ions under controlled conditions and characterized using (FTIR), (XRD), and (SEM). FTIR confirmed the involvement of plant phytochemicals in capping, XRD revealed crystalline CuO phases with particle sizes 20–40 nm, and SEM images showed predominantly spherical nanoparticles. The biogenic nanoparticles demonstrate potential applications in antimicrobial activity, catalysis, environmental remediation, and biomedical systems. The dual-plant synthesis approach highlights the synergistic benefits of phytochemical diversity in controlling nanoparticle morphology and stability.

Keywords: Polyalthia longifolia, Catharanthus roseus, green synthesis, copper oxide nanoparticles, phytochemicals, FTIR, XRD, SEM.

1. Introduction

Nanotechnology focuses on engineering materials at the nanoscale, enabling unique physicochemical properties that differ from bulk materials (Sridhar *et al.*, 2023) [10]. Metal and metal oxide nanoparticles especially copper-based nanostructures offer high catalytic activity, antimicrobial effects, and optical functionality (Pawar *et al.*, 2024) [7]. Traditional chemical synthesis employs hazardous reagents, whereas green synthesis leverages plant-derived biomolecules as eco-friendly reducing agents (Osman *et al.*, 2024) [6].

Polyalthia longifolia and Catharanthus roseus (Madagascar periwinkle) are medicinal plants rich in alkaloids, flavonoids, phenolics, and terpenoids (Raza *et al.*, 2024) [9]. These phytochemicals reduce Cu^{2+} to Cu/CuO nanoparticles while simultaneously stabilizing the structures. Polyalthia longifolia exhibits antimicrobial and antioxidant activity, while Catharanthus roseus is widely known for anticancer indole alkaloids such as vincristine and vinblastine (Maulana *et al.*, 2022) [5]. Using both plants for nanoparticle synthesis provides a wider phytochemical palette, improving nanoparticle stability, morphology, and potential biological functions (Khan & Khan, 2023) [4].

2. Materials and Methods

i). **Plant Material Preparation:** Fresh leaves of Polyalthia longifolia and Catharanthus roseus were washed, shade-dried, and powdered. Aqueous extracts were prepared by boiling 10 g of plant powder in 100 mL distilled water for 20 minutes, followed by filtration.

ii). **Green Synthesis of Cu/CuO Nanoparticles:** Copper precursor solution and Zinc Precursor solution 1(mM ZnO)(1 mM $Cu(NO_3)_2$) was mixed with plant extract in a 9:1 ratio and heated at 60–80°C. A color change from pale blue to dark brown/black indicated nanoparticle formation. The colloid was centrifuged and dried to obtain powdered ZnO/CuO NPs.

iii). **Phytochemical Screening:** Standard qualitative tests identified alkaloids, tannins, flavonoids, saponins, terpenoids, and phenols in both plant extracts.

iv). **Characterization**

- FTIR was used to identify bioactive functional groups involved in reduction and capping.
- XRD was employed to determine crystalline structure and average particle size.
- SEM was used to analyze particle morphology and size distribution.

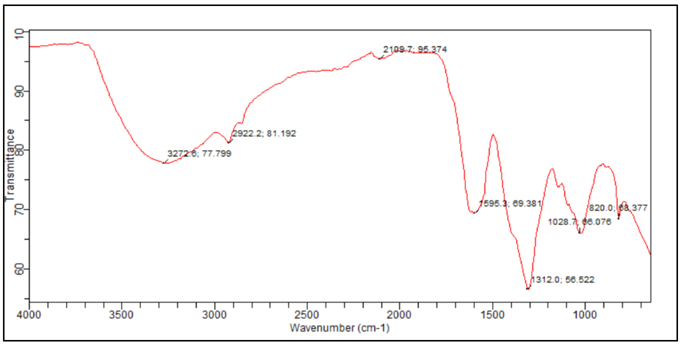
3. Results

i). Visual Observation

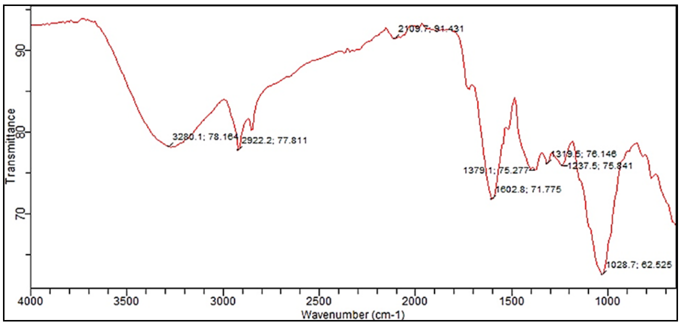
A rapid color change of green to blackish brown fluid confirmed nanoparticle formation due to phytochemical-mediated reduction.

***Corresponding Author:** Shenbagam Madhavan

ii). FTIR Analysis



Graph 1: FTIR Spectrum of Copper Oxide with Madagascar Periwinkle



Graph 2: FTIR Spectrum of Zinc Oxide with Polyalthia longifolia

FTIR spectra showed peaks corresponding to –OH, –C=O, –C–O, and aromatic groups, indicating their role in capping and stabilization.

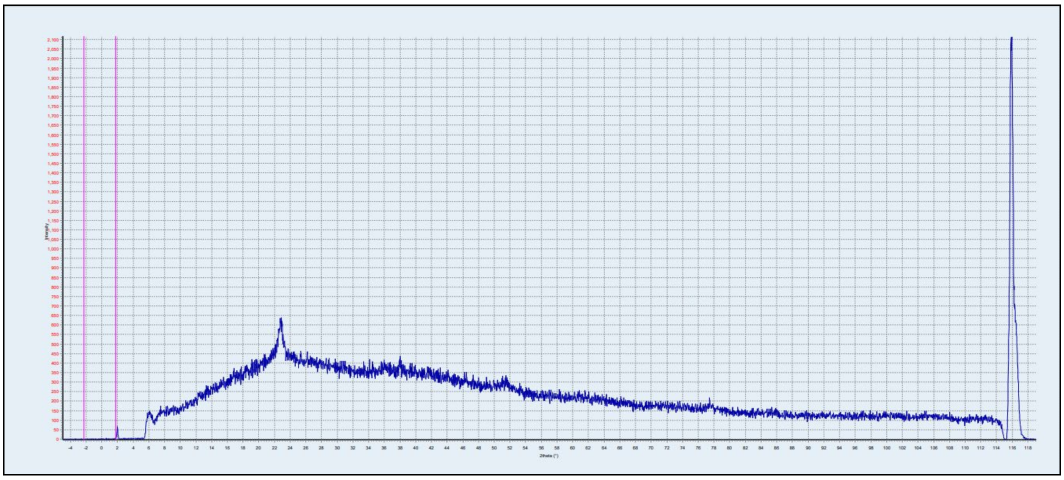
Table 1: Phytochemical Constituents of Copper Oxide- Madagascar Periwinkle

FTIR No.	Peak Position (cm^{-1})	Group	Class	Peak Details/Interpretation
1	3280.1	O–H stretching	Alcohol	Broad, strong peak (3200–3550 cm^{-1}) indicating hydrogen-bonded hydroxyl groups from phenols, flavonoids, and polyols; responsible for reducing and stabilizing nanoparticles.
		O–H stretching	Carboxylic acid	Broad band (2500–3300 cm^{-1}) showing presence of organic acids that participate in capping.
2	2922.2	O–H stretching	Carboxylic acid	Broad band confirming hydrogen-bonded O–H from organic acids.
		O–H stretching	Alcohol	Weak, broad vibration associated with alcohol/polyol functional groups.
		N–H stretching	Amine salt	Strong broad band indicating protonated amines present in plant metabolites.
		C–H stretching	Alkane	Medium peak indicating CH_2/CH_3 groups from aliphatic compounds in extracts.
3	2109.7	C=C=O stretching	Ketene	Peak near 2150 cm^{-1} representing ketene groups possibly formed from plant metabolites.
		C≡C stretching	Alkyne	Weak absorption (2100–2140 cm^{-1}) indicating possible alkyne groups.
		N=C=S stretching	Isothiocyanate	Strong absorption from sulfur-containing metabolites.
4	1602.8	C=O stretching	δ-Lactam	Strong band at 1650–1600 cm^{-1} showing lactam carbonyl groups.
		C=C stretching	Conjugated alkene	Medium band indicating aromatic/conjugated double bonds.
		N–H bending	Amine	Medium band from primary/secondary amines in plant constituents.
		C=C stretching	Cyclic alkene	Medium band associated with cyclic hydrocarbons.
5	1379.1	C–H bending	Alkane	Medium peak from aliphatic C–H bending (CH_3/CH_2).
6	1319.5	C–H bending	Alkane	Medium band similar to CH bending vibrations of alkanes.
7	1237.5	C–F stretching	Fluoro compound	Strong peak in 1000–1400 cm^{-1} region; sometimes corresponds to plant-derived fluorinated metabolites or overlapping C–O vibrations.
		C–N stretching	Amine	Medium peak indicating proteinaceous/alkaloid components.
8	1028.7	C–F stretching	Fluoro compound	Strong peak in 1000–1400 cm^{-1} region (may also indicate strong C–O vibrations).
		C–N stretching	Amine	Medium band typical of aliphatic amines.
		C–O stretching	Aliphatic ether	Strong peak 1085–1150 cm^{-1} corresponding to C–O–C linkages.
		C–O stretching	Secondary alcohol	Strong peak 1087–1124 cm^{-1} from secondary alcohols in plant extracts.

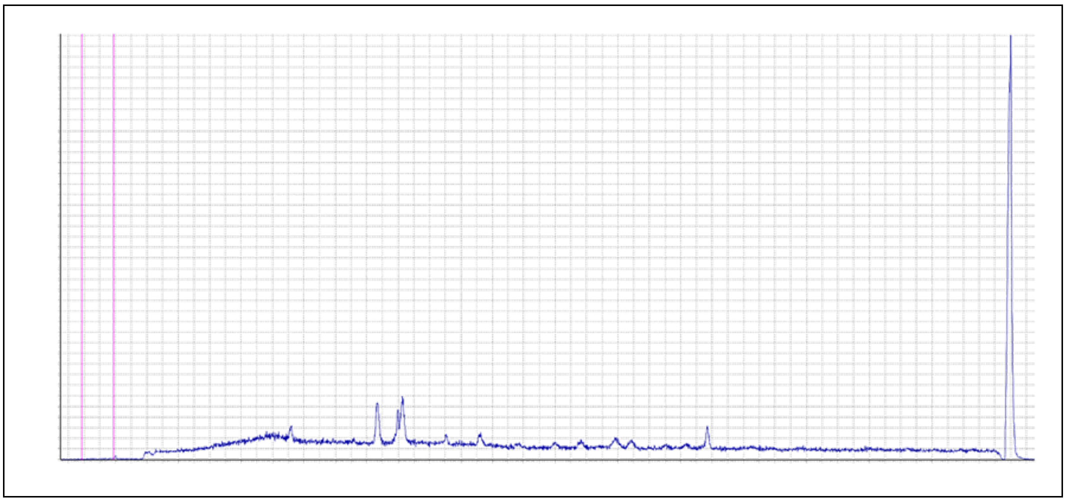
Table 2: Phytochemical Constituents of Zinc Oxide- Polyalthia longifolia

FTIR Number	Peak Position (cm⁻¹)	Functional Group	Class	Peak Details/Interpretation
1	3272.6	O–H stretching	Alcohols/Phenols	Broad peak indicating hydrogen-bonded O–H groups from phenolics, flavonoids, or plant polyols acting as reducing and capping agents.
2	2922.2	C–H stretching	Alkanes	Asymmetric stretching of aliphatic C–H bonds (CH_2, CH_3) from organic compounds in plant extract.
3	2109.7	C≡C or N=C=O stretching	Alkynes/Isocyanates	Weak–medium peak often associated with alkynes or atmospheric CO contamination; sometimes linked to plant metabolites.
4	1595.1	C=C stretching/N–H bending	Aromatic compounds/Amides	Aromatic ring vibrations from flavonoids or amide groups from proteins—often stabilizing nanoparticles.
5	1312.0	C–N stretching/O–H bending	Aliphatic amines/Phenols	Indicates presence of amines or phenolic compounds involved in reducing Cu^{2+}/Zn^{2+} ions.
6	1028.7	C–O–C/C–O stretching	Alcohols/Ethers/Polysaccharides	Strong indicator of plant-based carbohydrates, glycosides acting as capping agents.
7	820.0	C–H bending (aromatic)	Aromatic rings	Out-of-plane bending of aromatic C–H, confirming presence of polyphenols.
8	623.3	Metal–O vibration	Cu–O/Zn–O	Confirms formation of metal oxide nanoparticles (CuO/ZnO).

iii). XRD Analysis



Graph 3: XRD Wavelength of Zinc oxide - Polyalthia longifolia



Graph 4: XRD Wavelength of Copper Oxide - Madagascar Periwinkle

XRD patterns confirmed monoclinic CuO phases with crystallite sizes ranging between 20–40 nm and Zinc Oxide nanostructures.

iv). SEM Analysis

SEM images revealed mostly spherical nanoparticles with moderate aggregation due to phytochemical coating.

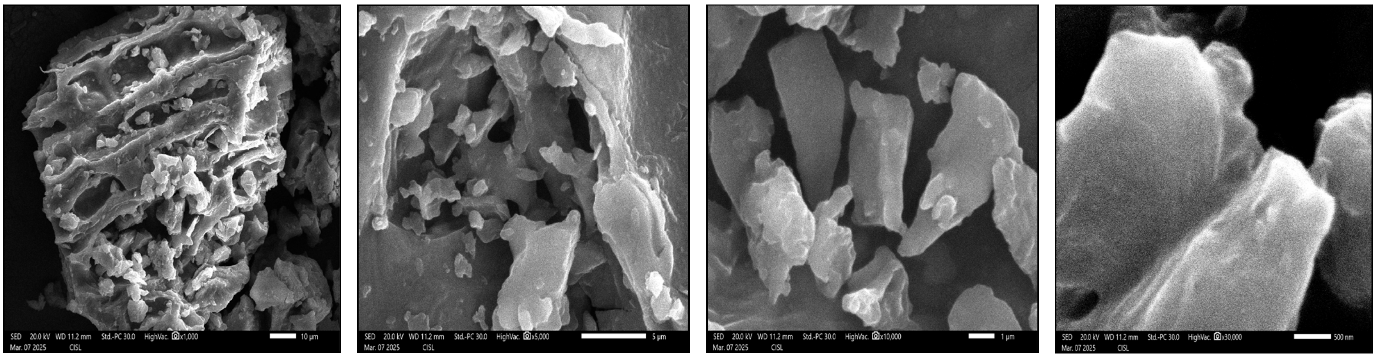


Fig 1: SEM Crytal structures of Zinc Oxide- Polyalthia longifolia

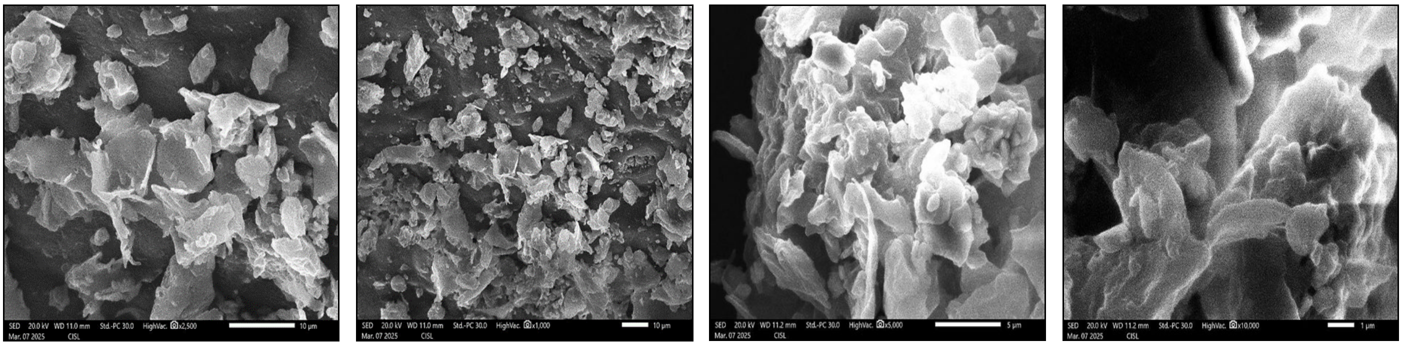


Fig 2: SEM Crytal structures of Copper Oxide- Madagascar Periwinkle

Table 3: Phytochemical Contribution of Polyalthia longifolia & Madagascar Periwinkle

Phytoconstituents	ZnO	CuO
Proteins	Present	Present
Carbohydrates	Present	Present
Phenols and Tannins	Negative	Negative
Saponins	Present	Present
Glycosides	Present	Present
Steroids	Negative	Negative
Alkaloids	Negative	Present
Tannins	Present	Negative

Flavonoids and phenolics served as the primary reducing agents, while alkaloids and terpenoids acted as stabilizers, enhancing nanoparticle uniformity.

4. Discussion

The dual-plant approach improved reduction efficiency and particle stability due to the complementary phytochemical profiles of P. longifolia and C. roseus. The resulting ZnO/CuO nanoparticles exhibited desirable morphology and crystallinity comparable to chemically synthesized counterparts but without hazardous reagents. The spherical nature and nanoscale size range suggest suitability for biomedical and catalytic applications. The combined phytochemical diversity improved size control and reduced agglomeration, demonstrating enhanced biogenic synthesis efficiency

Phytochemicals present in the plant extract acted as reducing and stabilizing agents, facilitating nanoparticle formation without the use of toxic chemicals.

The synthesized nanoparticles showed effectiveness in reducing the phytochemical activity to form nanoparticles with other metallic combinations to enhance their efficacy, supporting their potential applications in biomedicine and environmental sanitation. The use of *C. roseus* for nanoparticle synthesis offers an eco-friendly, low-cost, and sustainable alternative to conventional chemical methods.

5. Conclusion

This study successfully demonstrates the green synthesis of Cu/CuO nanoparticles using Polyalthia longifolia and Catharanthus roseus leaf extracts. The nanoparticles were stable, spherical, and crystalline, with size ranges suitable for biological and industrial applications. The synergistic use of two phytochemically rich plants enhances nanoparticle formation, making this approach a promising model for sustainable nanomaterial synthesis.

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