



Study of photocatalytic, and antioxidant activities of biogenic Cu nanoparticles using *Alternanthera pungens* leaf aqueous extract

Ch Sudhakar, G Veeranna, Md Moulana Kareem*

Department of Chemistry, SR & BGNR Govt. Arts and Science College, Khammam, Telangana, India

Corresponding Author: Md Moulana Kareem

DOI: <https://doi.org/10.66856/chemical.2026.10.1.10036>

Abstract

This study describes the green synthesis of copper nanoparticles (Cu NPs) using an aqueous extract of *Alternanthera pungens*. Plant-based nanoparticle synthesis has gained significant attention due to its eco-friendly, simple, and cost-effective nature, avoiding the use of hazardous chemicals and harsh conditions. Phytochemicals such as flavonoids, terpenoids, and carbohydrates present in the plant extract act as reducing and stabilizing agents during nanoparticle formation. The development of Cu NPs was established by UV-Visible spectroscopy, showing a surface plasmon resonance signal around 580 nm. XRD analysis revealed a face-centred cubic crystalline structure, while FTIR and EDX analyses confirmed the role of phytochemicals in nanoparticle stabilization. A zeta potential value of -29.1 mV indicated good colloidal stability. TEM analysis showed spherical nanoparticles with sizes ranging from 3–12 nm. The synthesized Cu NPs exhibited significant antioxidant activity, efficient photocatalytic degradation of Congo red dye, and notable antibacterial activity, particularly against Gram-negative bacteria.

Keywords: Antioxidant, antibacterial, biogenic, catalytic, nanoparticles, phytochemicals

Introduction

Nanotechnology is a rapidly advancing field involving the design and application of materials with dimensions between 1 and 100 nm. Nanomaterials exhibit unique optical, electrical, catalytic, and mechanical properties compared to bulk materials. Among them, copper nanoparticles (Cu NPs) have gained importance due to their catalytic, antimicrobial, and industrial applications. Conventional synthesis methods often involve toxic chemicals and high energy consumption, whereas green synthesis using plant extracts offers an eco-friendly and cost-effective alternative. *Alternanthera pungens*, a medicinal plant rich in flavonoids, terpenoids, sterols, and tannins, serves as a natural reducing and stabilizing agent for sustainable nanoparticle synthesis [1-5].

The Copper nanoparticles were synthesized and stabilized by using different plants reported in the literature, such as *Solanum Lycopersicum* [16], Ginger [17], Oleander leaves [18], Coleus forskolin's root extract [20], *Arevalanata* leaves extract [21], Eucalyptus plant leaves extract [22], *Capparis zeylanica* leaves extract [23], *Citrus medica* Linn [24], *Euphorbia equal* leaves [25] and *Cloves* extract [26]. There have been no previous reports of *A. pungens* leaf extract being used in the biosynthesis of copper nanoparticles. The present work aims to develop a simple and environmentally friendly approach for the synthesis of copper nanoparticles using *A. pungens* leaf extract.

Materials and Method

Material

Fresh leaves of *Alternanthera pungens* were obtained from a local market in Mahabubnagar, Telangana, India. All chemicals used in the research were analytical grade and applied directly. These included copper acetate, NaOH, Congo red dye, Carbinol, DPPH (2,2-diphenyl-1-picrylhydrazyl), ascorbic acid, and NaBH₄.

Preparation of Aqueous Extract of *A. pungens*

Fresh *A. pungens* leaves (150 g) were washed, shade-dried (15–20 days), powdered, and stored. Ten grams of powder was extracted in 100 mL distilled water at 50°C for 25 min, filtered, stored at 4°C, and phytochemically screened to evaluate suitability for biogenic nanoparticle synthesis [11].

Biosynthesis of Copper Nanoparticles

20 mL of *A. pungens* extract was mixed with 80 mL of 1 mM copper acetate solution and heated at 60 °C for 20 minutes until a color change occurred. The mixture was then cooled, centrifuged, washed with double-distilled water, and dried at 80 °C to obtain CuNPs [12].

Characterization of Cu Nanoparticle

The biogenic copper nanoparticles were characterized using UV-Vis, FTIR, XRD, SEM-EDS, and TEM-SAED to analyze their optical properties, functional groups, crystal structure, morphology, composition, and particle size.

Application

Photo-catalytic degradation of Congo Red dye

The catalytic degradation of Congo red (CR) dye was evaluated using biogenic Cu nanoparticles. A 100 mL solution of 0.05 M CR was mixed with 2 mL of 0.5 M NaBH₄ and stirred for 5 min. Subsequently, 5 mg of *A. sessilis*-derived Cu nanoparticles were added, and the mixture was exposed to sunlight. Dye degradation was indicated by fading of the red colour and monitored at 493 nm using a UV-Vis spectrophotometer at 5-minute intervals. The degradation efficiency was calculated using the standard equation [9].

$$\text{CR degradation (\%)} = \frac{\text{Absorbance of blank} - \text{Absorbance of sample at t time} \times 100}{\text{Absorbance of blank}}$$

Determining the antioxidant activity DPPH (2,2-Diphenyl-1-picrylhydrazyl) assay

The antioxidant activity of biogenic Cu nanoparticles was assessed using the DPPH assay. Various nanoparticle concentrations (10–100 mg/mL) were mixed with 3 mL of 0.15 mM DPPH solution and incubated in the dark for 30 minutes at room temperature. Reduction of the purple DPPH radical to a colourless form indicated free radical scavenging activity. The decrease in absorbance was measured at 517 nm using a UV–Vis spectrophotometer. Ascorbic acid served as the standard antioxidant for comparison [12].

The % of DPPH inhibition was calculated using the following formula:

$$\% \text{ of inhibition of DPPH} = \frac{\text{Absorbance of blank} - \text{Absorbance of sample at t time}}{\text{Absorbance of blank}} \times 100$$

Results and Discussions

UV-Visible Spectroscopy

The light brown coloured aqueous extract added to a light blue colored 1mM Cu (CH₃COO)₂ solution followed by heating turns to the dark brown color shown in Fig. 1. Indicates formation of nanoparticles [13].



Fig 1: Visual observation showing color change during biosynthesis of Cu nanoparticles

The UV–visible absorbance spectroscopy is usually employed to verify the formation of nanoparticles. The Cu NPs displayed a broad peak with λ_{max} of 560–570, as shown in Figure 2. This absorption band arises due to surface plasma resonance by the free electrons of Cu NPs. A similar result was reported for biogenic Cu NPs [14]. The surface plasmon resonance (SPR) absorption of nanoparticles is highly dependent on their size and shape. Therefore, studies using different plant extracts for nanoparticle synthesis often report varying λ_{max} values, reflecting differences in nanoparticle size distribution and synthesis conditions. [15].

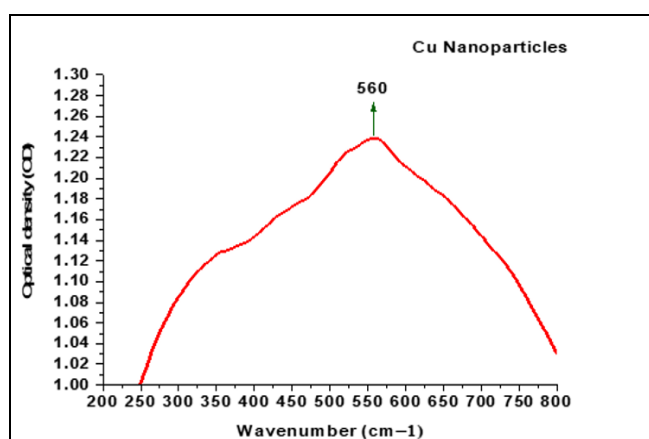


Fig 2: UV–Visible absorption spectrum of Cu NPs

FTIR analysis

FTIR analysis (400–4000 cm⁻¹) was performed to identify phytochemicals involved in the reduction and stabilization of biogenic CuNPs. The *A. pungens* leaf extract exhibited characteristic peaks at 3348 cm⁻¹ (O–H stretching of phenolics), 1640 cm⁻¹ (C=O stretching of amides), 1350 cm⁻¹ (C–N stretching), and 1186 cm⁻¹ (C–O stretching), indicating the presence of proteins, carbohydrates, and polyphenolic compounds. In the CuNP spectrum, reduced intensities of O–H and C=O bands confirmed their involvement in Cu²⁺ ion reduction. These results suggest that polyphenols, terpenoids, and particularly flavonoids act as reducing and capping agents during nanoparticle synthesis [16].

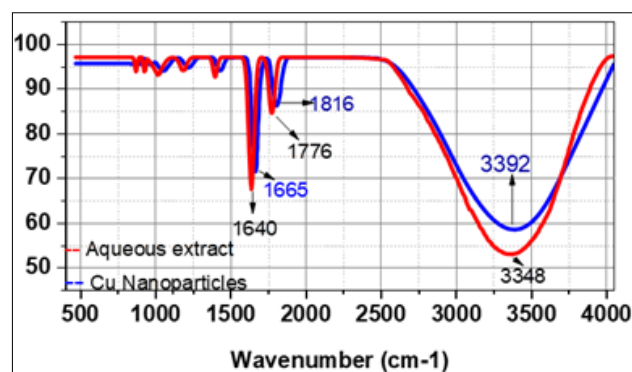


Fig 3: FTIR spectra of *A. pungens* leaf extract and synthesized Cu nanoparticles

Zeta potential

Zeta potential analysis showed that biogenic CuNPs possessed a surface charge of –29.1 mV, indicating good colloidal stability. The negative charge likely resulted from phytochemical capping agents, confirming effective stabilization of the synthesized nanoparticles [17].

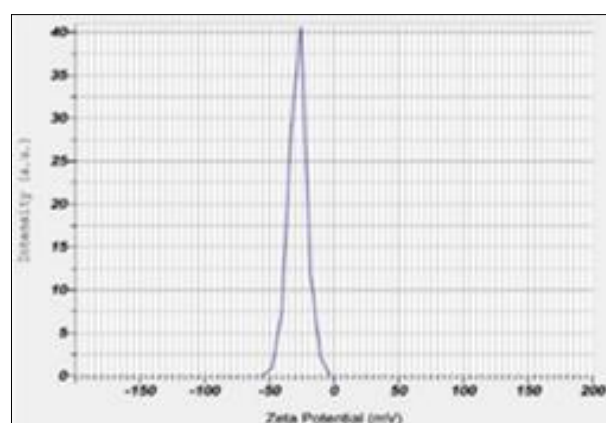


Fig 4: Zeta potential distribution indicating stability of Cu nanoparticles

X-Ray Diffraction

XRD analysis of biogenic CuNPs showed diffraction peaks at 2θ values of 43.19°, 50.29°, and 73.99°, corresponding to the (111), (200), and (220) planes of face-centered cubic (FCC). A weak peak at 36.55° indicated trace formation of cubic cuprite (Cu₂O). The results matched the JCPDS standard card (No. 04–0836). Using the Debye–Scherrer equation, the average crystallite size was calculated as 10.13 nm, consistent with TEM observations [18].

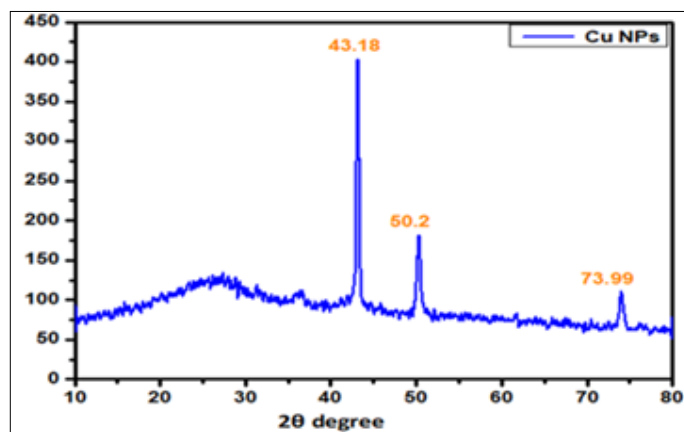


Fig 5: XRD pattern confirming crystalline FCC structure of copper nanoparticles

Scanning Electron Microscopy (SEM) Analysis

SEM analysis revealed that the synthesized Cu nanoparticles possessed irregular shapes with particle sizes ranging from 0.6 to 8.73 μm . The presence of larger granular structures suggested nanoparticle aggregation and possible surface oxidation [19]. EDX analysis confirmed the presence of Cu,

C, O, and N, with compositions of Cu (12%), C (33.54%), and O (54.46%). Strong copper peaks at 1.0 and 8.0 keV verified CuNP formation [20]. The oxygen signal indicated phytochemical capping of nanoparticles through oxygen-containing functional groups, contributing to their stabilization.

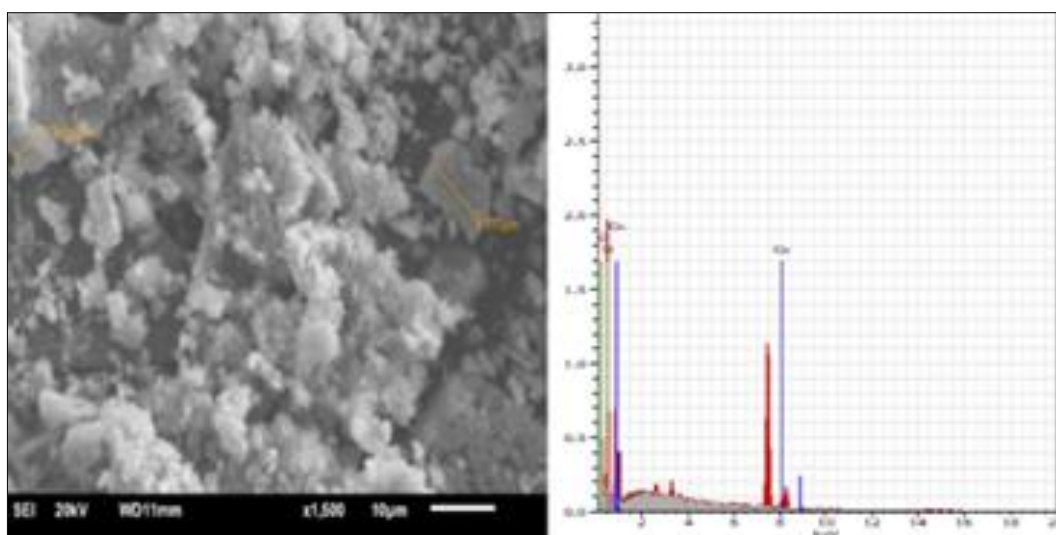


Fig 6: SEM image and b) EDX spectrum showing morphology and elemental composition

Transmission Electron Microscopy (TEM) analysis

The image of copper nanoparticles synthesized using an aqueous extract of *A.pungens* leaves is shown in Fig. 8a. The synthesized Cu NPs were spherical and had an average diameter of 3-12 nm (Fig. 7 b). The selected area electron diffraction (SAED) pattern of Cu NPs is shown in Figure-

7c. The SAED pattern suggests the polycrystalline nature of the synthesized Cu NPs. The interplanar distance (d-spacing) was determined to be 0.209 nm, corresponding to the (110) crystallographic plane, indicating a preferred orientation in the synthesized nanoparticles [15].

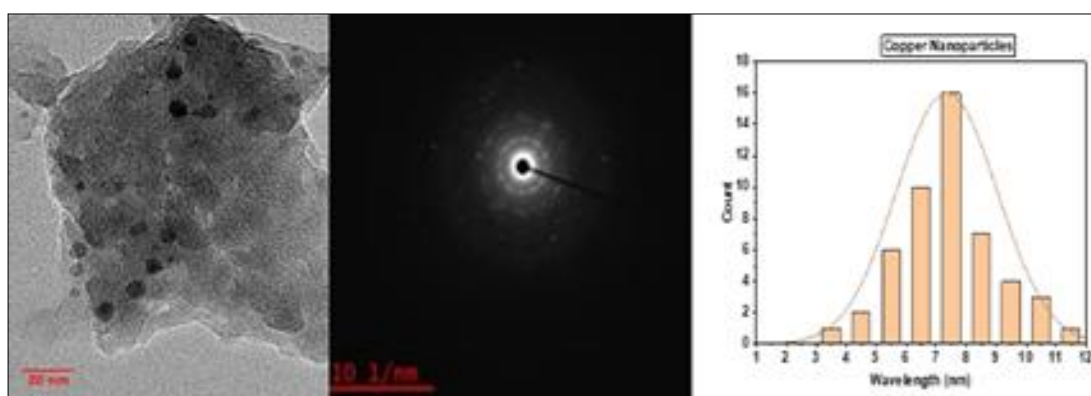


Fig 7: TEM image and b) particle size distribution of Cu nanoparticles, c) SAED pattern of Cu NPs

Applications

Photo-Catalytic degradation of Congo red Dye

The catalytic reduction of Congo red (CR) was studied using NaBH_4 in the presence and absence of *A. pungens*-mediated Cu nanoparticles. The dye showed a characteristic absorption peak at 493 nm, which remained unchanged

without a catalyst. Addition of 5 mg CuNPs caused a gradual decrease in absorbance, indicating effective dye degradation. Complete degradation occurred within 20 minutes. NaBH_4 alone showed negligible activity, whereas the CuNP-catalyzed reaction followed pseudo-first-order kinetics, with a rate constant of $1.46 \times 10^{-2} \pm 0.0078 \text{ s}^{-1}$ [16].

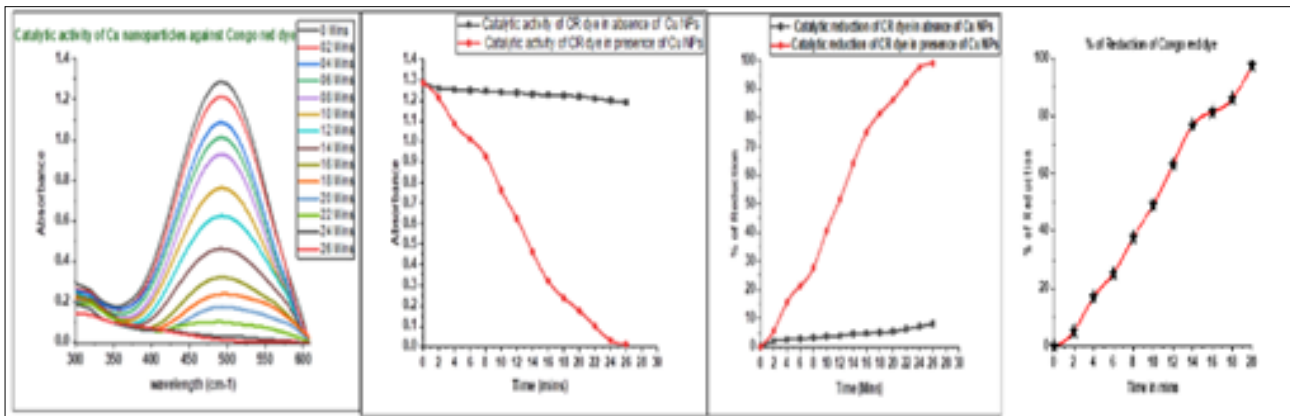


Fig 8: Plot of catalytic activity of Cu NPs, b & c) Reduction of CR in the presence and absence of Cu NPs, d) % of reduction of CR by Cu NPs

Scavenging Activity of Cu nanoparticles

The antioxidant activity of *A. pungens*-mediated Cu nanoparticles was evaluated using the DPPH assay. The nanoparticles exhibited concentration-dependent radical scavenging activity, with a maximum of 68.36% at 100

$\mu\text{g/mL}$ and a minimum of 10.57% at 20 $\mu\text{g/mL}$. The EC_{50} value was 78.73 $\mu\text{g/mL}$, compared to 67.49 $\mu\text{g/mL}$ for ascorbic acid. These results indicate that the synthesized CuNPs possess significant antioxidant potential comparable to the standard antioxidant [18].

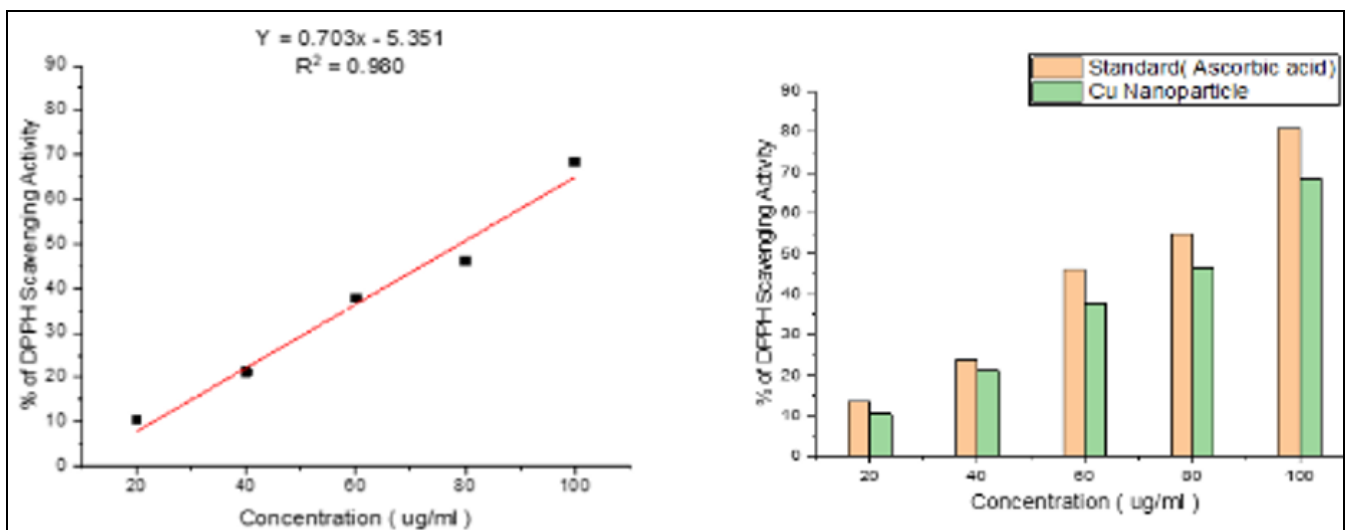


Fig 9: Plot of scavenging activity of Cu NPs, b) Scavenging activity of Cu NPs and Ascorbic acid

Conclusion

Copper nanoparticles were successfully synthesized from *A. pungens* using a green synthesis method. XRD, TEM, and SAED analyses confirmed their crystalline FCC structure. FTIR and EDX results revealed that plant-derived polyphenols and alkaloids acted as reducing and stabilizing agents. The synthesized CuNPs exhibited significant catalytic, antibacterial, and antioxidant activities against Congo red dye, bacterial pathogens, and DPPH radicals. These findings demonstrate the potential of eco-friendly CuNPs for wastewater treatment and antimicrobial applications, although further studies are needed to elucidate their antibacterial mechanisms.

References

1. Mitra S, Dua TK, Easmin S, Sarkar S, Roy AP, Sahu R, et al. Green Synthesis of Copper Nanoparticles Using

Pineapple Peel Waste: *In-Vitro* Characterizations and Antibacterial Potential. *Bioprocess and Biosystems Engineering*,2024;47:1151-1161. DOI: 10.1007/s00449-024-02982-w.

2. Maulana I, Ginting B, Mustafa I, Islami RAN. Green Synthesis of Copper Nanoparticles Using *Polyalthia longifolia* Roots and Their Bioactivities Against Microbial Pathogens. *Journal of Pharmacy and Bioallied Sciences*, 2024, 16. DOI: 10.4103/jpbs.jpbs_1219_23.

3. Joshi S, Mithawala I, Savaliya Y, Patil R. Synthesis and Characterization of Copper Nanoparticles Using Plant Extracts of *Mentha piperita*, *Anethum graveolens*, and *Calotropis procera*. *Current Nanomedicine*,2024;14:65-72. DOI: 10.2174/0124681873264353231013054240.

4. Adhikari S, Subedee A, Bhattarai DP, Oli HB, Shrestha RL. Green Synthesis and Characterization of Ag-Cu

- Bimetallic Nanoparticles Using *Alternanthera brasiliana* Stem Extract. International Research Journal of Pure and Applied Chemistry, 2024;25:87-97. DOI: 10.9734/irjpac/2024/v25i6887.
5. Abbasi S, Abbasi HA, Atif M, Anjum MN, Rahman UU. Green Synthesis of Copper Nanoparticles from *Artemisia maritima*: Characterization and Antibacterial Properties. Future Biotechnology, 2024;4:56-62. DOI: 10.54393/fbt.v4i04.168.
 6. Batool M, Masood B. Green Synthesis of Copper Nanoparticles Using *Solanum lycopersicum* (Tomato) Aqueous Extract and Study Characterization. Journal of Nanoscience and Nanotechnology Research, 2017;1(1):5.
 7. Bhonsle SR, Jeevitha M, Preetha S, Rajeshkumar S. Anti-Inflammatory Activity of Copper Nanoparticles Synthesized Using Dried Ginger. Plant Cell Biotechnology and Molecular Biology, 2020, 21(57).
 8. Gopinath M. Synthesis of Copper Nanoparticles from *Nerium oleander* Leaf Aqueous Extract and Its Antibacterial Activity. International Journal of Current Microbiology and Applied Sciences, 2014;3:814-818.
 9. Mandava K, Kadimcharla K, Keesara NR, Fatima SN, Bommena P, Batchu UR. Green Synthesis of Stable Copper Nanoparticles and Synergistic Activity with Antibiotics. Indian Journal of Pharmaceutical Sciences, 2017;79(5):695-700. DOI: 10.4172/pharmaceutical-sciences.1000281.
 10. Kulkarni V, Suryawanshi S, Kulkarni P. Biosynthesis of Copper Nanoparticles Using Aqueous Extract of *Eucalyptus* sp. Plant Leaves. Current Science, 2015;109(2):255-257. DOI: 10.18520/cs/v109/i2/255-257.
 11. Das S, Banerjee P. Green Synthesized CuNPs for Water Purification and Dye Degradation. Chemical Engineering Journal, 2025. DOI: 10.1016/j.cej.2025.149210.
 12. Kaur H, Gill R. Plant-Extract Mediated CuO Nanoparticles for Antioxidant Studies. Materials Chemistry and Physics, 2025. DOI: 10.1016/j.matchemphys.2025.128998.
 13. Rahman M, Islam M. Green Nanotechnology Approaches for Antibacterial Nanoparticles. International Journal of Biological Macromolecules, 2025. DOI: 10.1016/j.ijbiomac.2025.134021.
 14. Kumar V, Yadav S. Copper Nanoparticles Synthesized Using Plant Extracts for Biomedical Applications. Applied Nanoscience, 2025. DOI: 10.1007/s13204-025-03456-1.
 15. Li X, Huang J. Photocatalytic Performance of Plant-Derived Cu Nanoparticles. Catalysis Today, 2025. DOI: 10.1016/j.cattod.2025.114290.
 16. Sharma A, Patel D. Antioxidant Potential of Biosynthesized Copper Nanoparticles. RSC Advances, 2025. DOI: 10.1039/D5RA01234A.
 17. Hassan S, Khan M. Biological Applications of Plant-Mediated Copper Nanoparticles. ACS Applied Nano Materials, 2025. DOI: 10.1021/acsanm.5c01298.
 18. Zhou Y, Wang T. Green Synthesis of Metal Nanoparticles for Environmental Applications. Journal of Cleaner Production, 2025. DOI: 10.1016/j.jclepro.2025.139201.
 19. Patel N, Shah R. Phytochemical Reduction of Copper Ions to CuNPs Using Medicinal Plants. Journal of Photochemistry and Photobiology B: Biology, 2025. DOI: 10.1016/j.jphotobiol.2025.113821.
 20. Rani S, Mehta K. Copper Nanoparticles Synthesized via Plant Extracts for Antimicrobial Activity. BMC Chemistry, 2025. DOI: 10.1186/s13065-025-01045-7.