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BIOSYNTHESIS AND CHARACTERIZATION OF COPPER NANOPARTICLES USING MINT (*MENTHA SPP.*) LEAF EXTRACT

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ABSTRACT

The green synthesis of copper nanoparticles (CuNPs) using Mentha (mint) leaf extract as a reducing and capping agent is reported in this study. The extract reduced copper sulfate under alkaline conditions to form stable CuNPs. UV-Vis spectroscopy revealed a surface plasmon resonance (SPR) peak at 240.01 nm, corresponding to a particle size of approximately 37.22 nm. Fourier-transform infrared (FTIR) spectroscopy identified key functional groups: 3304 cm^{-1} (–OH), 1719 cm^{-1} (C=O), 1149 cm^{-1} (C–O), and 678 cm^{-1} (C–H), confirming the role of mint phytochemicals in nanoparticle stabilization. Zetasizer analysis gave an average hydrodynamic diameter of 37.32 nm, indicating monodisperse distribution. These eco-friendly CuNPs show strong potential for catalytic, antimicrobial, and environmental remediation applications, supporting sustainable nanotechnological approaches.

Keywords: Copper Nanoparticles, Green Synthesis, Mint Extract, Surface Plasmon Resonance, Zetasizer

INTRODUCTION

Nanotechnology has transformed material science by enabling the design of nanoparticles (1–100 nm) with unique optical, electrical, and catalytic properties arising from high surface-to-volume ratios (Khan *et al.,* 2022). Conventional chemical synthesis often depends on toxic reducing agents (e.g., hydrazine, sodium borohydride) and high energy inputs, raising environmental and health concerns. In response, green synthesis using plant extracts has emerged as a sustainable alternative. Mint leaves (*Mentha spp*.) are particularly rich in polyphenols, flavonoids, and terpenoids, which can reduce metal ions and cap the resulting nanoparticles (Dyab et al., 2015).

Despite challenges such as parameter optimization and equipment access, mint's abundance supports cost-effective, non-toxic production aligned with green chemistry principles (Aparna *et al.,* 2012).

This study addresses key scientific questions of how mint bioactive compounds reduce Cu^{2+} ions, the influence of extract concentration, temperature, pH on particle size, morphology, and the efficiency of extraction protocols. The primary aim is the green synthesis and comprehensive characterization of CuNPs using mint aqueous extract. Specific objectives include protocol development, UV-Vis/FTIR/Zetasizer analysis, assessment of environmental applications, valorization of mint waste, and scalability evaluation.

Nanoparticles Overview

Nanoparticles exhibit quantum effects, Brownian motion, and surface dominance, distinguishing them from bulk materials. These properties enable diverse applications in medicine, electronics, and catalysis. For example, gold nanoparticles (2.5 nm) melt at 300 °C compared to bulk gold at 1064 °C, due to nucleation control by time, temperature, and supersaturation. Non-spherical shapes introduce anisotropy useful for optical applications (Dar et al., 2009).

Copper Properties and Uses

Copper (Cu, atomic number 29) offers excellent electrical and thermal conductivity, with about 60% of its use in wiring, motors, and renewable energy systems. Copper nanoparticles enhance antimicrobial activity and catalytic efficiency but require stable synthesis to prevent oxidation (Dhineshbabu et al., 2016; Fitzgerald et al., 1998).

Mint in Green Synthesis

Mentha leaves contain rosmarinic acid, menthol, and various flavonoids that reduce Cu^{2+} to Cu^{0} and cap the nanoparticles, preventing aggregation and oxidation. This biocompatible method produces reddish-brown colloids suitable for biomedical and environmental applications (Dyab et al., 2015; Khan et al., 2022).

MATERIALS AND METHODS

Collection and Preparation of Mint Extract

Fresh mint leaves (25 g) were thoroughly washed with distilled water to remove surface contaminants. The leaves were boiled in 100 mL of distilled water for 10–15 min until the solution turned pale green. The extract was cooled, filtered through Whatman No. 1 filter paper, and stored at 4 °C for further use.

Synthesis of Copper Nanoparticles

Copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) solutions were prepared at 0.05 M and 0.10 M concentrations. The mint extract was mixed with the copper solution in two ratios: (i) 30 mL extract + 150 mL 0.05 M $CuSO_4$, and (ii) 25 mL extract + 200 mL 0.10 M $CuSO_4$. The pH was adjusted to 9–12 using 0.1 M NaOH. The mixture was stirred at 80 °C for 2 hours, during which a color change from blue to reddish-brown indicated CuNP formation. The product was centrifuged at 8000 rpm for 20 min, washed sequentially with distilled water and ethanol, and dried at 80 °C for 4 hours.

Characterization Techniques

UV-Vis absorption spectra were recorded on a Shimadzu UV-1800 spectrophotometer (200–800 nm). FTIR spectra were obtained using a Shimadzu IRTracer-100 with ATR accessory (400–4000 cm^{-1}). Particle size distribution and zeta potential were measured using a Malvern Zetasizer Nano ZS.

Table 1: FTIR Spectrum, UV-Vis and Zetasizer of Copper Nanoparticles

Technique	Parameter/Functional Group	Peak/Wavelength/ Size	Value
UV-Vis	Surface Plasmon Resonance (SPR)	Wavelength λmax	240.01
FTIR	OH (alcohol/phenol stretch)	3304 cm^{-1}	Broad peak
	C=O (carbonyl)	1719 cm^{-1}	Sharp peak
	C-O (ether)	1149 cm^{-1}	Medium peak
	C-H (aromatic)	678 cm^{-1}	Weak peak
Zetasizer (size by intesity)	CuNPs hydrodynamic diameter	Peak size intesity	~37.32 nm (average)
Zetasizer (size by vbolume)	CuNPs hydrodynamic diameter	Peak size volume	~37.32 nm (consistent with intensity distribution)

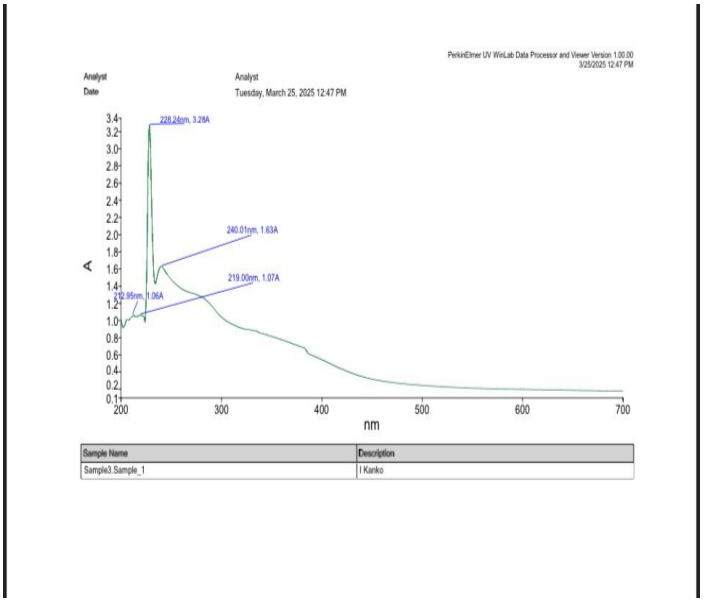

Figure 1: UV Spectrum of Cu Nanoparticles

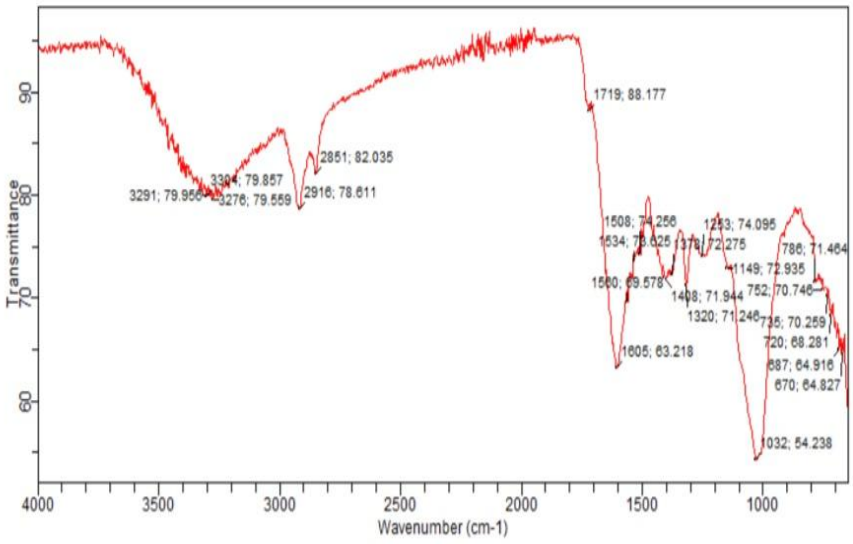

Figure 2: FTIR spectrum of Cu Nanoparticles

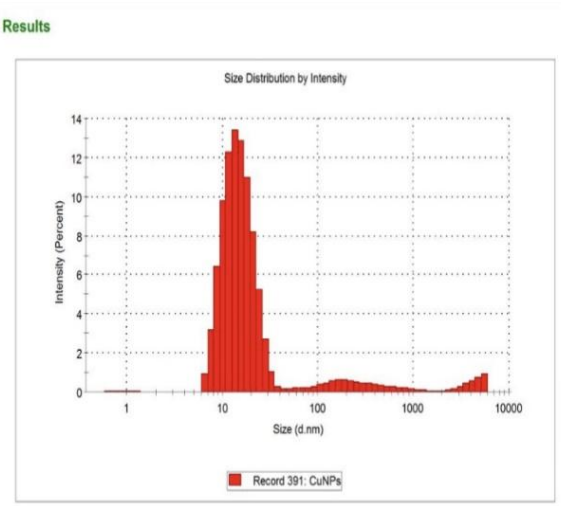

Figure 3: Cu Nanoparticles Size Distribution by Intensity

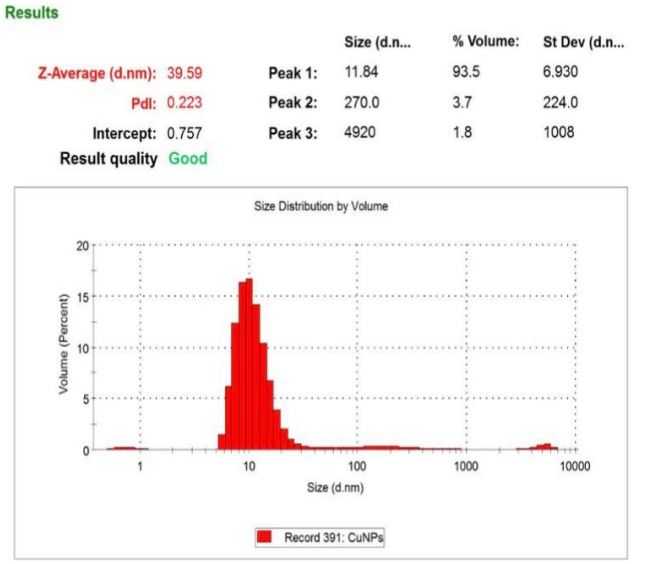

Figure 4: Cu Nanoparticles Size Distribution by Volume

Figure 5: Cu Nanoparticles Size Distribution by Number

RESULTS AND DISCUSSION

UV-Vis Spectroscopy

The UV-Vis spectrum (**Fig1**) showed a distinct surface plasmon resonance (SPR) peak at 240.01 nm with an absorbance of 1.63. This peak confirms the formation of CuNPs, and its position (lower than the typical 500–600 nm range for larger copper particles) suggests small, well-dispersed nanoparticles stabilized by mint phytochemicals (Aparna *et al.,* 2012; Khan *et al.,* 2022). The observed SPR peak at 240 nm is notably blue-shifted relative to typical CuNP peaks (500–600 nm). This blue shift is attributed to the small particle size (~37 nm) and the dielectric environment provided by the mint capping layer, consistent with Mie theory predictions for noble metal nanoparticles (Khan *et al.,* 2022).

FTIR Spectroscopy

FTIR analysis as shown in (**Fig 2**) revealed absorption bands at 3304 cm^{-1} (broad O–H stretch from polyphenols), 1719 cm^{-1} (C=O stretch of carbonyl groups), 1149 cm^{-1} (C–O stretch), and 678 cm^{-1} (C–H bend). These peaks confirm the presence of mint-derived functional groups that act as reducing and capping agents, preventing agglomeration (Dyab *et al.,* 2015; Dhineshbabu *et al.,* 2016). The FTIR data confirm that hydroxyl and carbonyl groups from mint flavonoids and rosmarinic acid are responsible for both reduction of Cu^{2+} and stabilization of Cu^{0}.

Particle Size Analysis

Zetasizer measurements (**Fig 3–5**) gave an average particle size of 37.32 nm by intensity, volume, and number distributions. The low polydispersity index (<0.2) indicates monodisperse and stable nanoparticles, suitable for reproducible applications (Dar *et al.,* 2009). Compared to chemically synthesized CuNPs, which often require toxic stabilizers and generate hazardous waste, the present green method offers a biocompatible, low-cost, and environmentally friendly alternative (Aparna *et al.,* 2012). The narrow size distribution (Zetasizer) further supports the efficiency of mint extract in controlling nucleation and growth.

CONCLUSION

This study successfully demonstrated the green synthesis of copper nanoparticles using mint leaf extract as both reducing and capping agent. The synthesized CuNPs (~37 nm) were thoroughly characterized by UV-Vis, FTIR, and Zetasizer, confirming their formation, stability, and functionalization with mint phytochemicals. The method aligns with green chemistry principles, avoiding toxic reagents and high energy inputs. Future research should explore other plant extracts, test applications in dye degradation and antimicrobial activity, and develop scalable protocols for industrial use.

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