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Green synthesis of nanoflower-like CuO nanoparticles using lotus leaf extract: Enhanced antibacterial and antioxidant activity

ABSTRACT

Copper oxide nanoparticles (CuO NPs) were successfully synthesized via a green route using aquatic lotus (Nelumbonucifera) leaf extract as a reducing and stabilizing agent. The synthesized CuO NPs were characterized using FT-IR, UV–Vis, XRD, SEM, TEM, HR-TEM, SAED, and EDX techniques. FT-IR confirmed Cu–O vibrations at 421 and 560 cm^{-1}, while UV–Vis spectra showed a characteristic absorption peak at 215 nm. XRD analysis revealed a crystalline monoclinic phase with an average crystallite size of 27.88 nm. Electron microscopy confirmed nanoflower-like morphology with an average particle size of ~24.98 nm.The biosynthesized CuO NPs exhibited strong antibacterial activity against Streptococcus pyogenes, Bacillus cereus, Escherichia coli, and Pseudomonas aeruginosa, with zones of inhibition comparable to the standard antibiotic ciprofloxacin. In addition, CuO NPs demonstrated high antioxidant activity (92.94%), which is comparable to ascorbic acid (92.27%) in DPPH assay.

These findings highlight that lotus leaf-mediated CuO nanoparticles are efficient, eco-friendly nanomaterials with promising biomedical applications.

Keywords: *Green approach, Sustainability, Copper Nanoparticles, antimicrobial, antioxidant analysis*

1. INTRODUCTION

Nanotechnology is expected to bring about a revolution in the twenty-first century. A rapid increase in the area has been seen across the world. Nanotechnology research has resulted in the fabrication of nano-sized particles. These are particles smaller than 100 nm. Nanomaterial-based formulations are essential to the global healthcare system [1-3]. Nanoparticles, particularly metal and metal oxide particles with diameters smaller than 100 nm, have been shown to successfully cure infectious disorders in the face of antibiotic failure owing to microbial resistance [4-6]. Therefore a confluence of nanotechnology and biology can address several biomedical problems and can revolutionize the field of health and medicine [7-8]. Biological synthesis can be carried out using plant parts, secondary metabolites from plants (leaf, root, stem, fruit, and flower secondary metabolites), and microbes and their secondary metabolites [9].

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Recently, metals such as copper (Cu), silver (Ag), zinc (Zn), iron (Fe), gold (Au), silicon (Si), nickel (Ni), and platinum (Pt) have been used in the green synthesis of nanoparticles for biomedical applications [10].

Green and sustainable approaches to nanoparticle synthesis are now the main emphasis due to the possible risks connected with chemical synthesis techniques and growing environmental concerns. In addition to removing the need for hazardous chemicals, high temperatures, and complex equipment, this biological synthesis makes use of the inherent bioactive substances found in these natural resources to improve the stability and shrinking of nanoparticles. Enzymes, photosynthesis, RNA synthesis, and plant development all depend on copper (Cu) [11]. Cu nanoparticles are widely utilized in commerce to create antioxidant, larvicidal, antibacterial, and anticancer goods. Copper nanoparticles (CuO NPs) have been synthesized using plants such Caesalpiniabonducella [12], Punicagranatum [13], Ocimumsanctum [14], Saussurealappa [15], and Ziziphusspina-christi [16] have been used for the synthesis of copper nanoparticles (CuO NPs). Using plant extracts to synthesize CuO NPs seems to be a viable and sustainable method in the field of nanotechnology [17]. Because it is environmentally benign and sustainable, the use of plant extracts as stabilizing and reducing agents for the green synthesis of nanoparticles have drawn a lot of interest recently [18].

Conventional techniques for manufacturing CuO nanoparticles usually involve the use of dangerous chemicals, high temperatures, and energy-intensive procedures, all of which can have negative effects on the environment and human health [19]. On the other hand, natural plant extracts that are high in bioactive substances including flavonoids, polyphenols, and phytochemicals are used in green synthesis techniques to help reduce the size and stabilize CuO NPs. Because these plant-derived chemicals serve as both capping and reducing agents, the associated synthesis procedure is safer for researchers and the environment [20]. There are several benefits to the green synthesis of CuO NPs utilizing plant extracts, including decreased energy usage, environmental contamination, economic effectiveness, and the possibility of large-scale manufacturing. Furthermore, using plant extracts gives the synthesis of nanoparticles a new dimension because various plant species and their extracts might provide the final CuO nanoparticles remarkable qualities and functions [21]. According to our hypothesis, CuO NPs have enormous potential for a variety of biological uses. Furthermore, CuO NPs' antibacterial qualities imply that they can effectively treat infections that are resistant to drugs and develop innovative therapeutic strategies.

In the current study, we used aquatic lotus plant leaves as both a bioreductant and a stabilizing agent for the green synthesis of CuO NPs. The aquatic lotus plant is rich in phytochemicals, including terpenoids, alkaloids, flavonoids, phenolic compounds, and polyphenols [22]. Hence, the leaf extract of the aquatic lotus plant can be utilized for the synthesis of CuO NPs. The CuO nanoparticles synthesized through green methods were analyzed using a variety of techniques, including UV–visible spectroscopy, FT-IR, XRD, SEM, HR-TEM, SAED, and EDX. Additionally, the antimicrobial potential of these synthesized CuO nanoparticles was tested against two gram-positive bacterial strains, Staphylococcus aureus (33591) and Staphylococcus Faecalis (19433), as well as two gram-negative bacterial strains, Escherichia coli (25922) and Pseudomonas aeruginosa (27853). The biosynthesized CuO nanoparticles also demonstrated significant antioxidant activity.

Therefore, the present study aims to develop a green and sustainable method for the synthesis of CuO nanoparticles using lotus leaf extract, followed by comprehensive physicochemical characterization and evaluation of their antibacterial and antioxidant activities in comparison with standard agents. This work emphasizes the role of lotus-derived phytochemicals in controlling nanoparticle morphology and enhancing biological performance.

2. EXPERIMENITAL

2.1. Materialsand Methods

Freshly aquatic Lotus plants were collected from the Department of Botany, Milind College of Science, Chh.Sambhajinagar (Aurangabad) M.H. India.

All chemicals (up to 98.99% purity) are acquired from Aldrich and Rankem chemical suppliers and used exactly as supplied. sodium hydroxide (NaOH) and copper (II) sulfate pentahydrate ($CuSO_4.5H_2O$)were utilized immediately in the reaction process, without additional purification.

2.2. Preparation of Leaves Extract (Lotus plants Leaves)

Lotus plant leaves were cleaned in double-distilled water to remove surface salts, then chopped into little pieces and dried in the shade. To homogenize 10 g of Lotus plant leaves, 100 mL of double distilled water was used, followed by two hours of boiling in a water bath at 90°C. The obtained aqueous leaf extract was cooled at room temperature. Finally, the extract was filtered using Whatman No. 1 paper. The filtrate is transferred to a glass air-tight bottle and kept in the refrigerator. The extract can then be utilized to conduct other studies, such as nanoparticle synthesis.

2.3. Biosynthesis of Copper Oxide Nanoparticles

The biosynthesis of copper oxide nanoparticles (CuO-NPs) was conducted following the method outlined by RutabaAmjad et al. [23], with minor modifications. To synthesize CuO-NPs, 100 mL of distilled water was mixed with 0.1 M copper(II) sulfatepentahydrate ($CuSO_4.5H_2O$) and stirred for 15 minutes. Then, 10 mL of leaf extract was added dropwise to the mixture. The solution was continuously stirred for 2 hour at a temperature of 70-80°C using a magnetic stirrer set at 2000 rpm within an oil bath. The solution shifted from a yellowish-brown to black, resulting in the formation of a precipitate. The mixture was then allowed to cool to room temperature. Once cooled, the solution was centrifuged at 4000 rpm for 10 minutes, and the precipitate was collected. This precipitate was subsequently calcined for 1 hour at 400°C in a muffle furnace, resulting in a fine black powder, which was carefully preserved for future research (see Figure 1).

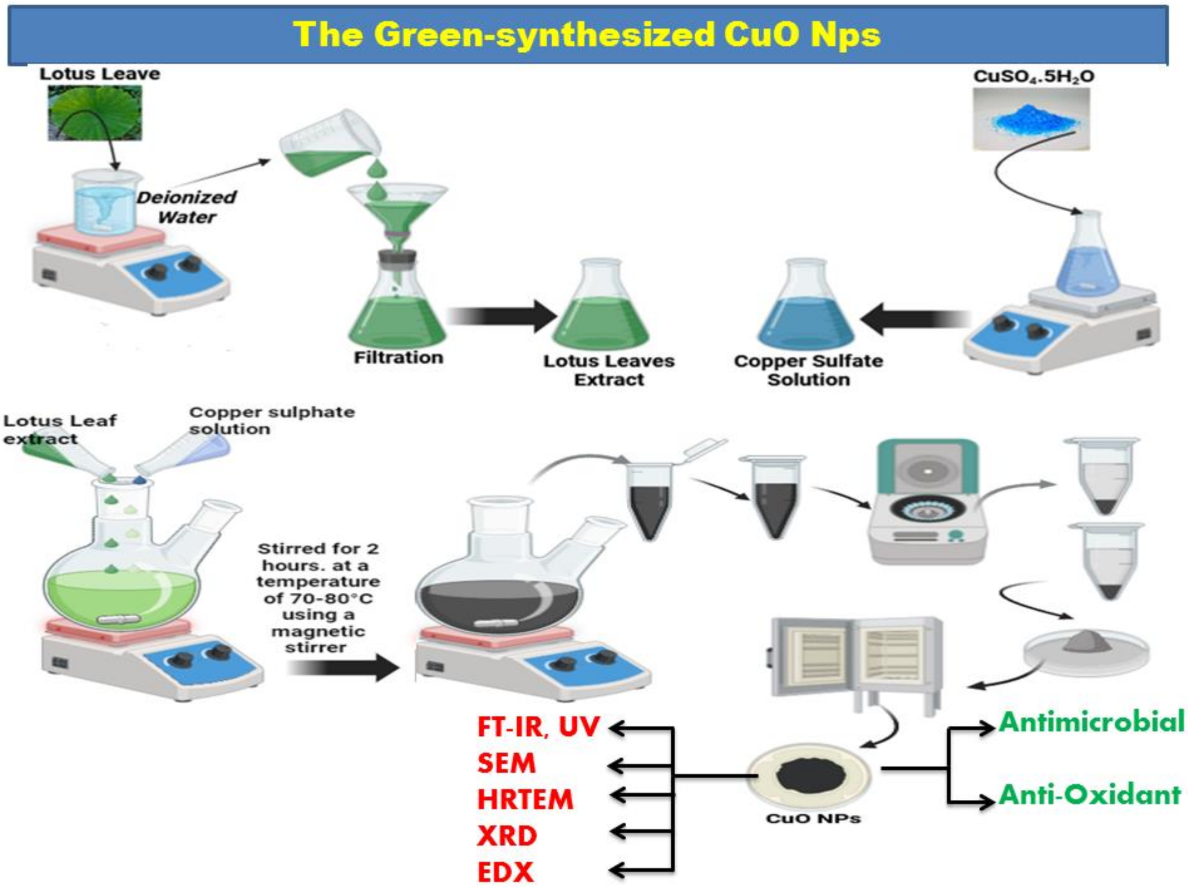


Figure 1. Schematic representation for Aquatic Lotus Plant Leaves mediated biosynthesis of CuO-NPs

2.4. Characterization Techniques

Fourier transform infrared (FTIR) spectroscopy (Thermo Nicolat 6700, U.S.) was used to characterize the manufactured materials. The examination was conducted within the wavenumber range of 4000 cm^{-1} to 400 cm^{-1}. The absorption spectra at the 400–200 nm scanning range were obtained using the UV-Visible absorption spectrophotometer (JASCO UV V-750). The characteristic absorption spectra demonstrate the continual production of CuO-NPs. X-ray diffraction (BrukarD8-Advanced Diffractometer) was used to crystallographically clarify CuONPs, and FE-SEM (Nova Nano-SEM NPEP303), SAED and HRTEM (PHILIPS CM200) were used to analyze morphological features, such as size and topology. The chemical purity and elemental composition were determined by energy dispersive X-ray spectroscopy (EDX, Bruker, XFlash6I30).

2.5. Antibacterial Efficacy of Biosynthesized CuO NPs

The antibacterial efficacy of the biosynthesized CuO NPs was assessed using a disk diffusion experiment against two Gram-negative bacteria, Escherichia coli and *Pseudomonas aeruginosa*, and two Gram-positive bacteria, Streptococcus pyogenes and Bacillus cereus. Streptomycin (10 micrograms per disk) was used as the reference standard to compare the results. Hi-media's nutritional agar was used to assess the antibacterial activity. composition (gL^{-1}). The composition includes 10.0 g/L of Penton, 10.0 g/L of beef extract, and 5.0 g/L of sodium chloride at a pH of 7.2. The Verniercaliper is used to measure the zone's diameter.

2.6. DPPH free radical scavenging assay (Antioxidant Activity)

The free radical scavenging effect of synthesized compounds CuO NPs was screened by a well-known *2,2-diphenyl-1-picrylhydrazyl* (DPPH) assay. The solution of standard and synthesized compounds was prepared in methanol. Firstly, 4 mg DPPH was dissolved in 100 ml methanol and covered with aluminum foil before keeping in a dark place to avoid photo-decomposition of the DPPH solution. After that, 100 µl of methanol (blank) in each well of the 96 microtiter plate was transferred, followed by 100 µl of synthesized compounds and a standard (ascorbic acid 10 mg/ml) into each well. Likewise, 100 µl of DPPH solution were also added in every well except the blank, where only plain methanol was added. The microtiter plate was kept at 37°C for 30 min in a dark place. The absorbance was determined by using a Shimadzu UV-1601 spectrophotometer at 517 nm, and the percent of inhibition of free radical production from DPPH was calculated by the below equation. The experiment was carried out in triplicate. The equation was employed to calculate the percentage of DPPH radical scavenging activity.

% DPPH radical scavenging activity =
= [(A0 – A1)/A0] × 100

Where:

A0: absorbance of DPPH solution

A1: absorbance of test drug solutions

Initially, the radical-scavenging potential of synthesized compounds was evaluated to ensure the therapeutic potency of targeted molecules. The easiest yet more feasible DPPH (*2,2-diphenyl-1-picrylhydrazyl*) assay method was used to demonstrate the antioxidant potency.

3. RESULTS AND DISCUSSION

3.1. Visible Observation

The extract is normally yellowish-brown prior to reaction due to the presence of chlorophyll, flavonoids, and polyphenols. After reaction with copper (II) sulfate solution and NaOHsolution the color changes from yellowish-brown to black. This color change confirms the reduction of copper ions and the formation of CuO-NPs [24].

3.2. Characterization

3.2.1.Transform Infrared Spectroscopy (FT-IR)

The FTIR spectra of CuO NPs showed peaks at 3663, 2347, 560, and 421 cm^{-1} (Figure 2).

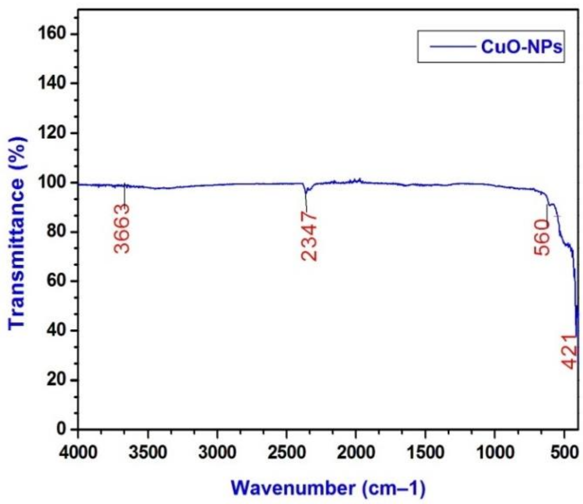


Figure 2. FT-IR spectra of CuO NPs

Peaks at 421 cm^{-1} and 560 cm^{-1} suggest CuO nanostructure and Cu-O stretching. Atmospheric CO_2 causes a stretching vibration at 2347 cm^{-1} [25, 26]. An FTIR band at about 3663 cm^{-1} in CuO nanoparticles is often linked with the stretching vibration of the O-H bond, most commonly attributed to the presence of surface-adsorbed or structural hydroxyl groups and/or water molecules bound to the surface of the nanoparticles [27].

3.2.2. Ultraviolet (UV) Visible Spectra

The UV–Visible absorption spectrum of the synthesized CuO nanoparticles was recorded in the wavelength range of 200–400 nm (Figure 3). The spectrum exhibits a distinct absorption peak at 215 nm, which is attributed to the characteristic electronic transitions in CuO nanoparticles, confirming their successful formation. Similar absorption behavior has been reported in earlier studies for CuOnanomaterials, indicating consistency with reported results [28].

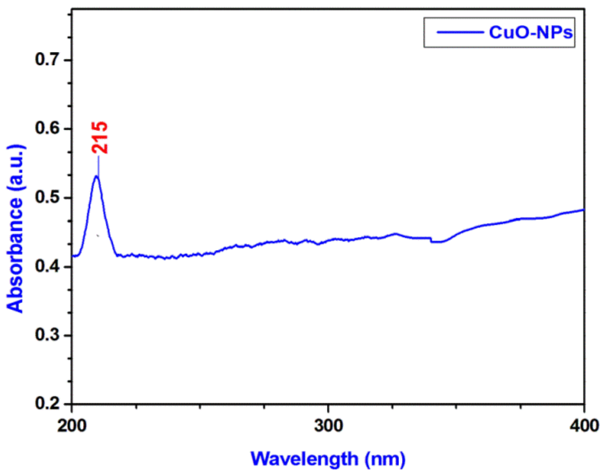


Figure 3.UV-visible absorbance spectrum of CuO-NPs

The optical properties of nanoparticles are highly dependent on their size, shape, and surface characteristics. These parameters are significantly influenced by synthesis conditions such as precursor concentration, pH of the reaction medium, and calcination temperature. Variations in these factors can lead to changes in particle size distribution and surface morphology, thereby affecting the optical absorption behaviour [29].

The optical band gap of CuO nanoparticles is typically determined using the Tauc plot method, assuming an indirect electronic transition. However, in the present study, the absorption spectrum does not show a well-defined absorption edge, and the variation in absorbance with wavelength is gradual over the measured range. This makes accurate determination of the band gap energy difficult using the available data. Such behavior is commonly observed in green-synthesized nanoparticles due to the presence of surface defects, size dispersion, and phytochemical capping agents derived from plant extracts [30].

According to the literature, CuO nanoparticles generally exhibit a band gap in the range of 1.2–2.1 eV, depending on particle size and synthesis conditions. Therefore, while the UV–Vis analysis confirms the formation of CuO nanoparticles, further detailed spectroscopic investigation is required for precise band gap determination.

3.2.3.Powder X-Ray Diffraction (XRD)

X-ray diffraction was used to evaluate the phase purity and crystallinity of CuO NPs produced using a green method. An XRD study of CuO NPs produced from lotus leaf extract validated the nanoparticles' crystalline structure.

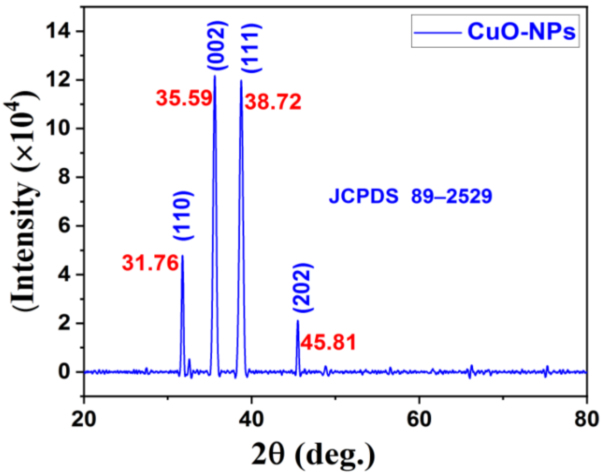


Figure 4. XRD plot of BiosynthesizedCuO NPs.

Figure 4 shows the usual XRD pattern of green-synthesized CuO NPs, with diffraction peaks at 2θ values of 31.76$^{\theta}$, 35.59$^{\theta}$, 38.72$^{\theta}$, and 45.81$^{\theta}$. These peaks correspond to CuO NPs' planes (1 1 0), (0 0 2), (1 1 1), and (2 0 2).This pattern confirms the crystallinity of the green synthesized CuO nanostructures. The monoclinicphase of CuO-NPs (JCPDS card no. 89-2529) [31].The XRD pattern confirms the formation of monoclinic CuO nanoparticles, consistent with standard JCPDS data.

The average crystallite size of the CuO-NPs was found to be 27.88 nm using Scherrer's equation (Table 2). The size of the nanocrystals was determined using the Debye-Scherrer equation, which indicated that the surface-area-to-volume ratio was high. The equation is as follows:

$$D = K\lambda / \beta cos\theta$$

In this equation, where D represents nanoparticle crystalline size, and K is the crystallite size. Shape factor approximation of 0.9. The wavelength of the X-rays (λ), β is the whole breadth at half maxima (FWHM) of peaks, and θ is the Bragg's angle (deg.).

Table 2.XRD results and crystallographic data of the CuO Nanoparticles.

Peak Position (2θ)	FWHM (β)	Crystalline Size	Average Crystalline Size (nm)
31.76	0.246	33.48	27.88
35.59	0.409	20.38	
38.72	0.474	17.73	
45.81	0.215	39.88	

3.2.4.Scanning Electron Microscopy (SEM)

The SEM micrographs of the biosynthesized CuO NPs (Figures 5A and 5B) demonstrate a heterogeneous morphology with rough surfaces, comprising predominantly spherical, flower-like, and petal-like nanostructures.

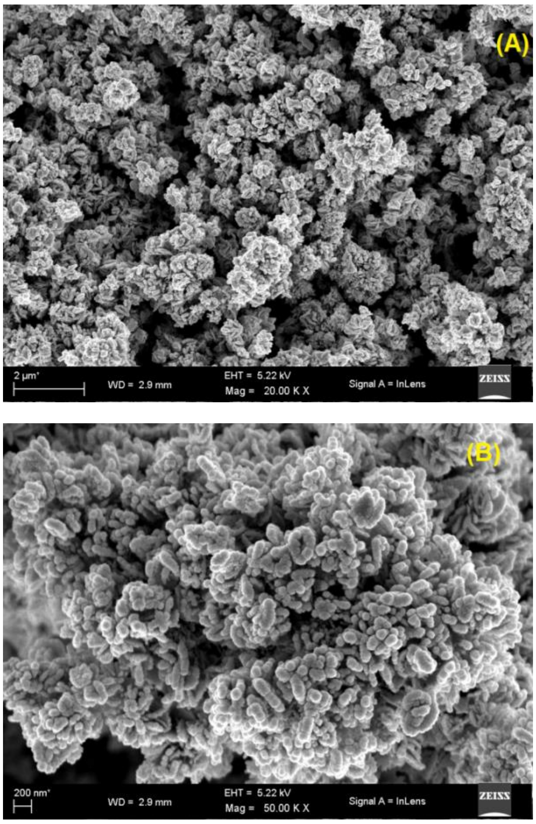
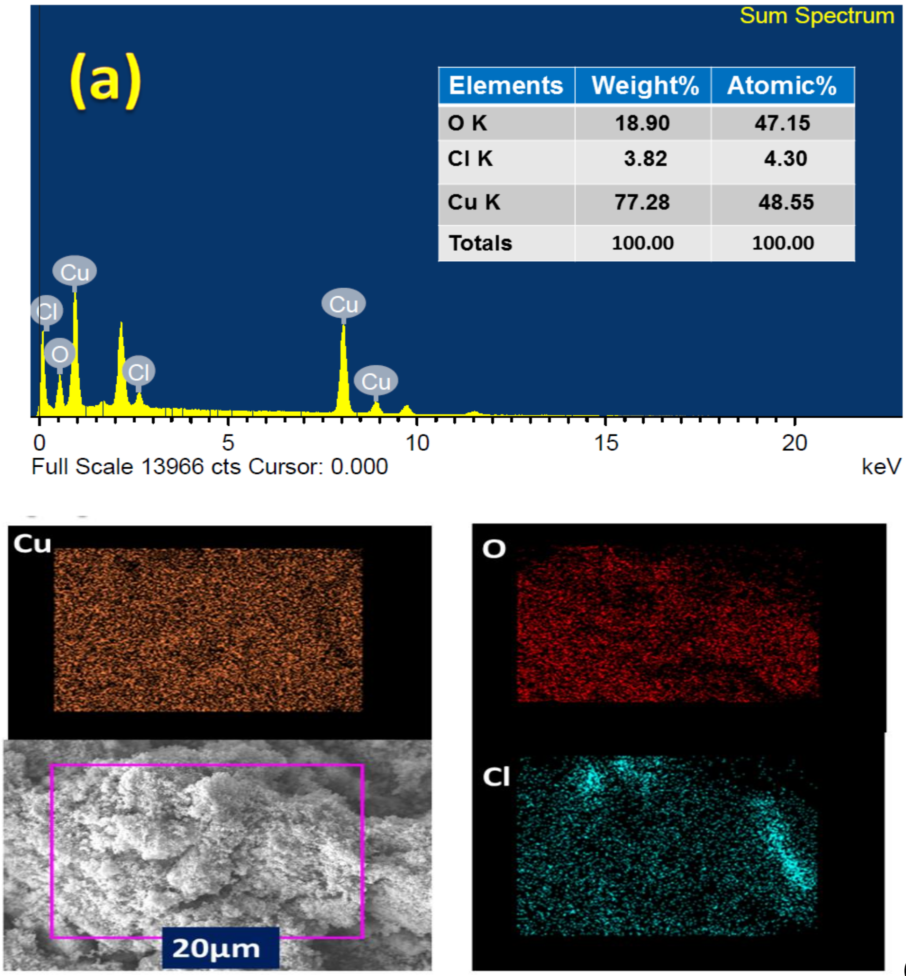


Figure 5. SEM images of green synthesized CuO NPs at 2 µm and 200 nm.

Such morphological diversity may be attributed to the influence of phytochemicals present in the plant extract, which act as reducing and stabilizing agents during synthesis. Imaging at multiple magnifications enabled detailed observation of surface features and particle distribution. The particle size (17–40 nm) obtained from SEM analysis is in close agreement with XRD and TEM results, confirming the consistency and reliability of the synthesized nanostructures. Comparable studies have reported agglomerated spherical CuO NPs synthesized using Solanumtuberosum starch extract, demonstrating promising anticancer activity [32].

3.2.5. Energy Dispersive X-Ray (EDX)and Mapping Images

Energy-dispersive X-ray (EDX) spectral analysis of the biosynthesized CuO nanoparticles confirmed the presence of copper (Cu), oxygen (O), and chlorine (Cl) (Fig. 6a). The results of EDX elemental image mapping shown in (Fig. 6b) revealed the atomic percentages of Cu, O, andCl in the biosynthesized CuO nanoparticles.It shows a peak for Cu-O linkage at 11.492 keV. The formation of CuO NPs is confirmed by the elemental peaks of copper and oxygen.



(b)

Figure 6. (a) EDX pictures of and Compositions Major Elements, (b) EDX elemental mapping image of CuO-NPs

The formation of CuO NPs is confirmed by the elemental peaks of copper and oxygen. These EDX features are consistent with previous studies [34,35]. The presence of chlorine (Cl) may originate from precursor salts or residual plant biomolecules and does not significantly affect nanoparticle properties.

3.2.6.Transmission Electron Microscopy (TEM), High-Resolution Transmission Electron Microscopy (HR-TEM), and Selected area electron diffraction (SAED)Analysis

TEM, HRTEM, and SAED studies were used to determine the shape, size, and crystalline nature of the CuO NPs. The TEM images of the biosynthesized CuO NPs (Figure 7a and b) demonstrate that the majority of the synthesized NPs had a nanoflower morphology [36]. One such plane is presented with a d-spacing of 0.520 nm, as shown in Figure 7(c). Moreover, Fig. 7(d) SEAD pattern of the biosynthesized CuO NPs confirmed the crystalline nature of the nanoparticles [37]. The varied shapes and sizes of these nanoparticles enhance their performance in various catalytic and biological studies because of their large surface area and increased number of reactive sites [38]. The histogram analysis average particle size of CuO NPs was approximately 24.98 nm, as determined by the ImageJ application, as shown in Figure 7(e), supporting the XRD results.

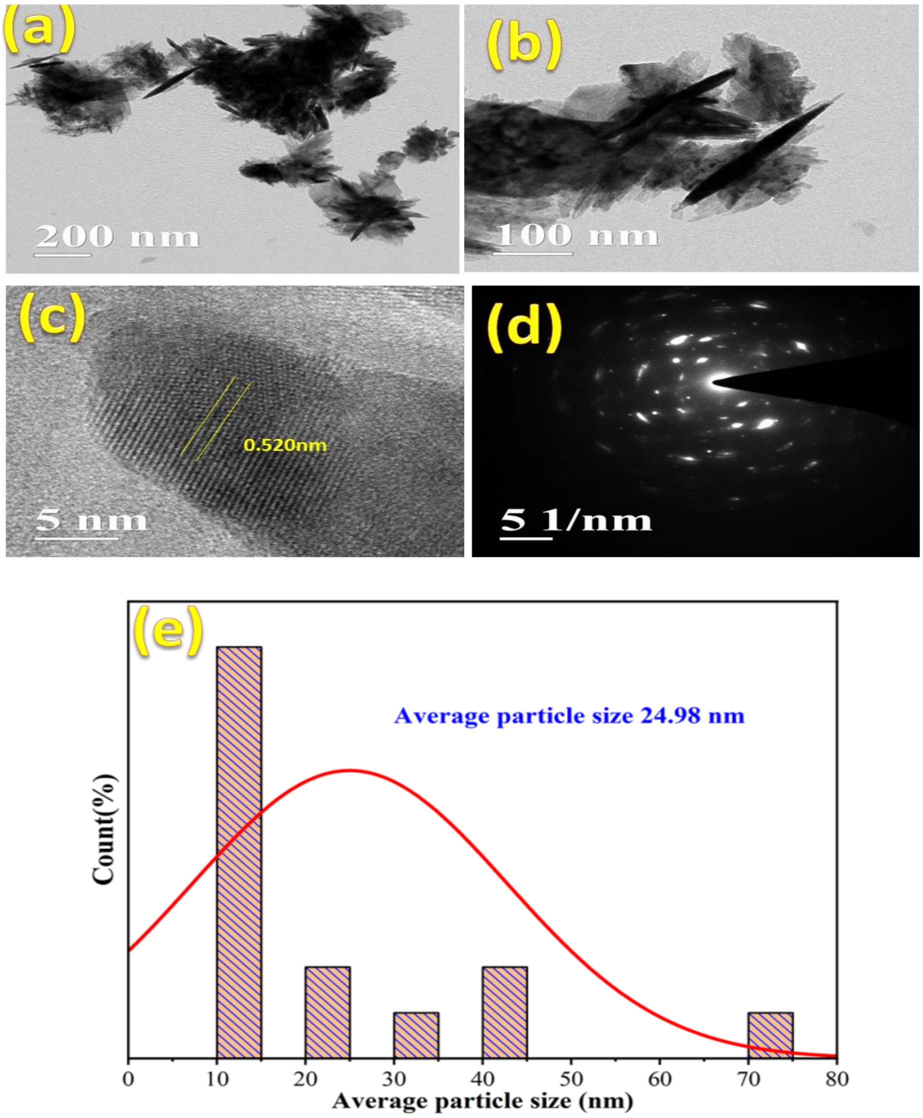


Figure 7. (a) TEM morphology images 200 nm, (b) TEM morphology images 100 nm, (c) Calculating Interplanar Spacing-d from HR-TEM image, (d) SAED image and (e) Histogram Analysis Average Particle Size

4. ANTIMICROBIAL ACTIVITY

The antimicrobial activity of the biosynthesized copper oxide nanoparticles (CuO NPs) was evaluated against selected Gram-positive and Gram-negative bacterial strains, including *Streptococcus pyogenes*, *Bacillus cereus*, *Escherichia coli*, and *Pseudomonas aeruginosa*, using the agar well diffusion method at a concentration of 1 mg/mL.The CuO NPs exhibited significant antibacterial activity against all tested pathogens, with zones of inhibition measuring 16.4 mm for *Streptococcus pyogenes*, 16.5 mm for *Bacillus cereus*, 17.3 mm for *Escherichia coli*, and 16.8 mm for *Pseudomonas aeruginosa* (Table 3). The observed antibacterial efficacy of the synthesized nanoparticles was found to be comparable to the standard antibiotic, Ciprofloxacin. These results indicate that CuO NPs possess broad-spectrum antibacterial activity against both Gram-positive and Gram-negative bacteria. The enhanced antimicrobial effect may be attributed to the nanoscale size, high surface area, and the ability of CuO NPs to generate reactive oxygen species (ROS), leading to disruption of bacterial cell membranes and intracellular components.

The pronounced zones of inhibition (Figure 8) further confirm the strong antimicrobial potential of the synthesized CuO nanoparticles. Overall, the findings suggest that lotus leaf–mediated CuO NPs can serve as effective antimicrobial agents and hold promise for applications in controlling bacterial infections. All experiments were performed in triplicate, and average values are reported.

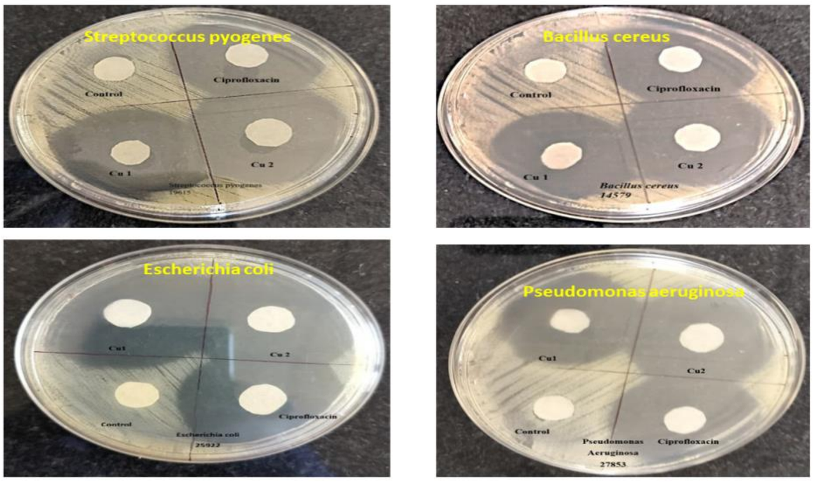


Figure 8. Antimicrobial effect of biosynthesized CuO NPs against, Streptococcus pyogenes, Bacillus cereus, Escherichia coli, and Pseudomonas aeruginosa

Table 3. Antimicrobial activity of biosynthesized CuO nanoparticles against pathogenic bacteria

Microbes	Zone of Inhibition[mm]	
	Concentration 1mg/ml	
	Ciprofloxacin Standard	CuONPs
Streptococcus pyogenes	16.3mm	16.4mm
Bacillus cereus	16.5mm	16.5mm
Escherichiacoli	17.0mm	17.3mm
Pseudomonas aeruginosa	16.6mm	16.8mm

4.1. Antioxidant assays

The antioxidant potential of the biosynthesized copper oxide nanoparticles (CuO NPs) was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay [41–43], a widely accepted and reliable method for assessing free radical scavenging activity.The results revealed that the CuO NPs exhibited strong antioxidant activity, with a maximum radical scavenging efficiency of 92.94%. Notably, this activity was slightly higher than that of the standard antioxidant, ascorbic acid (92.27%), under similar experimental conditions (Table 4).The enhanced antioxidant performance of the CuO NPs may be attributed to their nanoscale size, high surface area, and the presence of bioactive phytochemicals from the plant extract, which facilitate effective free radical neutralization.

These findings indicate that the green-synthesized CuO nanoparticles possess significant antioxidant potential and could be considered as promising candidates for applications in biomedical and pharmaceutical fields.

Table 4. Scavenging effect on DPPH radical and % inhibition of CuO NPs.

Concentration in µg/ml									
Compound Code	**3.9**	**7.8**	**15.6**	**31.3**	**62.5**	**125**	**250**	**500**	Mean
Cu1	88.38	90.78	91.62	92.46	93.39	95.79	96.59	98.96	92.94 %
Cu2	87.47	88.97	89.45	90.52	92.59	94.54	96.79	98.87	
Ascorbic acid 1	85.69	86.78	88.6	92.94	94.73	95.02	97.02	98.76	92.27 %
Ascorbic acid 2	85.21	85.47	88.44	92.37	94.36	95.32	97.22	98.53	

5. CONCLUSIONS

The present study demonstrates a cost-effective and eco-friendly green synthesis of copper oxide nanoparticles (CuO NPs) using aquatic lotus (*Nelumbonucifera*) leaf extract as a reducing and stabilizing agent. The synthesized nanoparticles exhibited a monoclinic crystalline structure with nanoflower-like morphology and an average particle size of ~25 nm, as confirmed by XRD and electron microscopy analyses.

The CuO NPs showed significant antibacterial activity against both Gram-positive and Gram-negative bacterial strains, including *Streptococcus pyogenes*, *Bacillus cereus*, *Escherichia coli*, and *Pseudomonas aeruginosa*, with performance comparable to standard antibiotics. In addition, strong antioxidant activity was observed, which was comparable or marginally higher than ascorbic acid.

The enhanced biological activity can be attributed to the nanoscale size, high surface area, and bioactive phytochemicals from the lotus extract, which may facilitate improved interaction with microbial cells and free radicals.

Overall, these findings highlight that lotus leaf-mediated CuO nanoparticles are promising, sustainable nanomaterials for biomedical applications. However, further investigations on detailed mechanisms, toxicity, and large-scale applicability are necessary to explore their practical potential.

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6. REFERENCES

[1] C.K. Singh, K.K. Sodhi (2023) The emerging significance of nanomedicine-based approaches to fighting COVID-19 variants of concern: A perspective on nanotechnology's role in COVID-19 diagnosis and treatment, Front. Nanotechnol., 4, 1084033. https://doi.org/10.3389/fnano.2022.1084033

[2] S. Sim, N.K. Wong (2021) Nanotechnology and its use in imaging and drug delivery, Biomed. Rep., 14, 42. https://doi.org/10.3892/br.2021.1418

[3] J.K. Patra, G. Das, L.F. Fraceto et al. (2018) Nano-based drug delivery systems: Recent developments and future prospects, J. Nanobiotechnol., 16, 71. https://doi.org/10.1186/s12951-018-0392-8

[4] A.J. Cole, A.E. David, J. Wang et al. (2011) Polyethylene glycol modified, cross-linked starch-coated iron oxide nanoparticles for enhanced magnetic tumor targeting, Biomaterials, 32, 2183–2193doi: 10.1016/j.

[5] J.Albadi, A.Mansournezhad, H.Abbaszadeh (2013) CuO-CeO_2nanocomposite: a highly efficient recyclable catalyst, J. Chin. Chem. Soc., 60, 1193–1196

[6] M.S. Usman, M.E. El Zowalaty, K. Shameli et al. (2013) Synthesis, characterization, and antimicrobial properties of copper nanoparticles, Int. J. Nanomed., 8, 4467–4479.doi: 10.2147/IJN.S50837

[7] S. Naz, A. Gul, M. Zia, R. Javed (2023) Synthesis, biomedical applications, and toxicity of CuO nanoparticles, Appl. Microbiol. Biotechnol., 107, 1039–1061. https://doi.org/10.1007/s00253-023-12364-z

[8] A. Curtis, C. Wilkinson (2001) Nanotechnology in biomedicine, Trends Biotechnol., 19, 97. https://doi.org/10.1016/S1369-7021(01)80035-3

[9] L.N. Nthunya, S. Mbakop, B. Makgabutlane et al. (2023) Fungal synthesis of copper nanoparticles and applications, Elsevier, pp. 91–114m doi:10.1016/B978-0-323-99922-9.00026-X

[10] A.S. Abed, Y.H. Khalaf, A.M. Mohammed (2023) Green synthesis of gold nanoparticles, Results Chem., 5, 100848, https://doi.org/10.1016/j.rechem.2023.100848

[11]L.G. Gemin, G.B. de Lara, Á.F. Mógor et al. (2023) Polysaccharides combined to copper and magnesium improve plant growth, Sci. Hortic., 310, 111758, DOI:10.1016/j.scienta.2022.111758

[12] S. Sukumar, A. Rudrasenan, D. Padmanabhan Nambiar (2020) Green-synthesized CuO nanoparticles, ACS Omega, 5, 1040–1051, https://doi.org/10.1021/acsomega.9b02857

[13] V.U. Siddiqui, A. Ansari, R. Chauhan et al. (2021) Green synthesis of CuOnanoparticles, Mater. Today Proc., 36, 751–755, https://doi.org/10.1016/j.matpr.2020.05.504

[14]V. Ramadhan, Y. Ni'Mah, E. Yanuar et al. (2019) Synthesis of copper nanoparticles, AIP Conf. Proc., 2202, 020067https://doi.org/10.1063/1.5141680

[15] L.A. Kolahalam, K. Prasad, P.M. Krishna et al. (2022) Bio-inspired CuO nanoparticles, Heliyon, 8, e09726. DOI: 10.1016/j.heliyon.2022.e09726

[16] R. Khani, B. Roostaei, G. Bagherzade et al. (2018) Green synthesis of copper nanoparticles, J. Mol. Liq., 255, 541–549.doi:10.1016/j.molliq.2018.02.010

[17] H.N. Cuong, S. Pansambal, S. Ghotekar et al. (2022) Plant extract mediated synthesis of CuO nanoparticles, Environ. Res., 203, 111858 10. 1016/j. envres.2021.111858

[18] S.F. Adil, M.E. Assal, M. Khan et al. (2015) Biogenic synthesis of metallic nanoparticles, Dalton Trans., 44, 9709–9717https://doi.org/10.1039/C4DT03222E

[19] E.A. Mohamed (2020) Green synthesis of copper nanoparticles, Heliyon, 6, e03123. https://doi.org/10.1016/j.heliyon.2019.e03123

[20] D. Rehana, D. Mahendiran, R.S. Kumar et al. (2017) Antioxidant activity of CuOnanoparticles, Biomed. Pharmacother., 89, 1067–1077. doI: 10.1016/j.biopha.2017.02.101

[21] S.A. Akintelu, A.S. Folorunso, F.A. Folorunso et al. (2020) Green synthesis of CuO nanoparticles, Heliyon, 6, e04508, https://doi.org/10.1016/j.heliyon.2020.e04508

[22] A. Bishayee, P.A. Patel, P. Sharma et al. (2022) Lotus phytocompounds and biomedical role, Cancers. https://doi.org/10.3390/cancers

[23] R. Amjad, B. Mubeen, S.S. Ali et al. (2021) Green synthesis of copper nanoparticles, Polymers, 13, 44364. https://doi.org/10.3390/polym13244364

[24] G.F. Aaga, S.T. Anshebo (2023) Green synthesis of CuO nanoparticles, Heliyon, 9, e16067. https://doi.org/10.1016/j.heliyon.2023.e16067

[25] D. Berraa, S. Laouinia, B. Benhaoua et al. (2018) Green synthesis of CuO nanoparticles, Dig. J. Nanomater. Biostruct., 13, 1231–1238. https://www.researchgate.net/publication/329881371

[26] K.J. Arun, A. Batra, M. Aggarwal et al. (2015) Hydrothermal synthesis of CuO nanoparticles. https://doi.org/10.5923/s.materials.201502.06

[27] A.A. Radhakrishnan, B.B. Baskaran (n.d.) Structural analysis of CuO nanoparticles. doi: 10.1007/s11664-015-3867-5

[28] D.R.A. Preethi, A. Philominal (2022) Green synthesis of CuO nanoparticles, Mater.Lett.X, 13, 100122. https://doi.org/10.1016/j.mlblux.2022.100122

[29] H. Le Tu (2019) Biosynthesis of copper oxide nanoparticles, Compos. Mater., 3, 30–35. DOI:10.2147/IJN.S255398

[30] R.H. Abbas, A. Kadhim, A.M. Haleem (2023) Antibacterial activity of CuO nanoparticles, J. Renew. Mater., 11, 2109–2123. https://doi.org/10.32604/jrm.2023.025112

[31] S. Prakash et al. (2018) Green synthesis of CuO nanoparticles, Adv. Powder Technol., 29, 3315–3326, https://doi.org/10.1016/j.apt.2018.09.009

[32] H. Alishah, S. Pourseyedi, S.Y. Ebrahimipour et al. (2017) Starch-mediated CuO nanoparticles, Rend. Lincei Sci. Fis. Nat., 28, 65–71. DOI:10.1007/s12210-016-0574-y

[33] K. Sahithya, A.K. Ekanayake, R. Sindhu et al. (2024) Mycosynthesis of CuO nanoparticles, Nano Biomed. Eng. https://doi.org/10.26599/nbe.2025.9290114

[34] Y.P. Liang, Y.B. Chan, M. Aminuzzaman et al. (2025) Green synthesis of CuO nanoparticles, Catalysts, 15, 30275. https://doi.org/10.3390/catal15030275

[35] R.P. Patil, V.A. Kalantre, D.K. Pawar et al. (2024) Ultrasound-assisted synthesis, Indian J. Chem., 63, 1141–1154. https://doi.org/10.56042/ijc.v63i11.12945

[36] B. Kumar, K. Smita, L. Cumbal et al. (2017) Biofabrication of CuO nanoparticles, J. Saudi Chem. Soc., 21, S475–S480. https://doi.org/10.1016/j.jscs.2015.01.009

[37] M.A. Khan, N. Nayan, M.K. Ahmad et al. (2021) Nanoscale characterization of CuOnanoflowers, Molecules, 26, 9-16. https://doi.org/10.3390/molecules26092700

[38] R. Katwal, H. Kaur, G. Sharma et al. (2015) Electrochemical synthesis of CuO nanoparticles, J. Ind. Eng. Chem., 31, 173–184. DOI:10.1016/j.jiec.2015.06.021

[39] M.I. Din, F. Arshad, Z. Hussain et al. (2017) Green synthesis of copper nanoparticles, Nanoscale Res. Lett., 12, 1. DOI: 10.1186/s11671-017-2399-8

[40] W.W. Andualem, F.K. Sabir, E.T. Mohammed et al. (2020) Synthesis of CuO nanoparticles, J. Nanotechnol., 2020. https://doi.org/10.1155/2020/2932434

[41] D.J. Manasa et al. (2021) Green synthesis of CuO nanoparticles, Arab. J. Chem., 14, 1–16. https://doi.org/10.1016/j.arabjc.2021.103184

[42] A. Muthuvel, M. Jothibas, C. Manoharan (2020) Synthesis of CuO nanoparticles, Nanotechnol. Environ.Eng.,5,14. https://doi.org/10.1007/s41204-020-00078-w

[43] K. Velsankar et al. (2021) Ecofriendly synthesis of CuO nanoparticles, J. Environ. Chem. Eng., 9. https://doi.org/10.1016/j.jece.2021.106299

IZVOD

ZELENA SINTEZA CuO NANOČESTICA KORIŠĆENJEM EKSTRAKTA LISTA LOTOSA: POBOLJŠANA ANTIBAKTERIJSKA I ANTIOKSIDATIVNA AKTIVNOST

Nanočestice bakarnog oksida (CuO NP) su uspešno sintetizovane „zelenim“ putem koristeći ekstrakt lista vodenog lotosa (Nelumbonucifera) kao redukciono i stabilizujuće sredstvo. Sintetizovane CuO NP su okarakterisane korišćenjem FT-IR, UV-Vis, XRD, SEM, TEM, HR-TEM, SAEDiEDX tehnika. FT-IR je potvrdio Cu-O vibracije na 421 i 560 cm $^{-1}$, doksu UV-Vis spektri pokazali karakterističan apsorpcioni pik na 215 nm. XRD analiza je otkrila kristalnu monokliničnu fazu sa prosečnom veličinom kristalita od 27,88 nm. Elektronska mikroskopija je potvrdila morfologiju sličnu nano cvetu sa prosečnom veličinom čestica od ~24,98 nm. Biosintetizovane CuO NP su pokazale jaku antibakterijsku aktivnost protiv Streptococcus pyogenes, Bacillus cereus, Escherichia coli i Pseudomonas aeruginosa, sazonama inhibicije uporedivim sa standardnim antibiotikom ciprofloksacinom. Pored toga, CuO NP su pokazale visoku antioksidativnu aktivnost (92,94%), što je uporedivo sa askorbinskom kiselinom (92,27%) u DPPH testu. Ovi nalazi ukazuju na to da su CuO nanočestice posredovane listovima lotosa efikasni, ekološki prihvatljivi nanomaterijali sa obećavajućim biomedicinskim primenama.

Ključnereči: *Zeleni pristup, održivost, nanočestice bakra, antimikrobna i antioksidativna analiza*

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