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RESEARCH

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Synthesis, characterization, and antimicrobial activity of copper oxide nanorods

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ABSTRACT

This study focuses on the synthesis and characterization of copper oxide (CuO) nanorods, which have attracted considerable interest due to their diverse applications in catalysis, electronics, and biomedicine. CuO nanorods were synthesized *via* a co-precipitation method, employing copper sulfate and sodium hydroxide as precursor materials. The synthesis was optimized by maintaining a pH of 12 and by carefully regulating the calcination temperature, yielding nanoparticles with an average crystallite size of 10.538 nm and a rod-like morphology with a diameter of approximately 25 nm. Structural and morphological features of the synthesized nanoparticles were confirmed through X-ray diffraction and field emission scanning electron microscopy. The antibacterial efficacy of CuO nanorods against *Staphylococcus aureus* was also assessed, revealing pronounced activity attributed to their nanoscale dimensions and positive surface charge, which facilitate interactions with bacterial membranes. Although the synthesized CuO nanorods exhibit strong potential across multiple domains, limitations related to scalability and particle size uniformity must be addressed in future studies. Overall, this study underscores the antimicrobial promise of CuO nanorods and calls for further research in order to improve their applicability.

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1. Introduction

Copper oxide nanoparticles (CuO) are increasingly important materials across industry, environmental science, and medicine, owing to their distinctive physicochemical properties (including excellent electrical conductivity, notable antibacterial activity,

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and efficient light absorption). CuO nanoparticles can be synthesized through various methods, encompassing both chemical and biological approaches. For example, chemical precipitation allows for a precise control over particle size and physicochemical characteristics, while green synthesis using plant extracts has been explored in order to reduce copper ion release and mitigate the environmental impact[1]. Due to their nanoscale dimensionality (1–100 nm), CuO nanoparticles exhibit unique structural, optical, electrical, magnetic, and mechanical properties not observed in bulk materials, placing nanotechnology at the forefront of scientific innovation in the twenty-first century[2]. Among the key parameters influencing nanoparticle performance are particle size, morphology, and crystallinity. In order to optimize these attributes, several synthesis methods have been developed, including the sonochemical method, sol-gel processing, laser ablation, electrochemical techniques, chemical precipitation, and surfactant-mediated approaches.

Despite their biomedical potential, CuO nanoparticles pose toxicity concerns. CuO nanoparticles may exhibit cytotoxic effects on mammalian cells and various vertebrate and invertebrate species. Their primary mechanism of toxicity involves the generation of reactive oxygen species (ROS), which induce oxidative stress in human pulmonary epithelial cells, potentially damaging DNA and mitochondria. Transition metal oxide nanoparticles, including CuO nanoparticles, are now widely applied in catalysis, biosensing, cosmetics, pharmacy, food and agriculture, electronics, dentistry, energy, and environmental science; domains where their popularity has markedly grown over the past two decades[3].

Chemical precipitation is commonly employed so as to control particle size and crystallinity, with optimal outcomes achieved at specific calcination temperatures[4]. Green synthesis approaches using natural biopolymers such as chitosan and alginate have also gained traction for their environmental benefits and enhancement of antibacterial properties. Co-precipitation has been used to fabricate Cu-doped nanoparticles exhibiting improved antibacterial and photocatalytic efficacy. CuO nanoparticles have demonstrated utility in antimicrobial, antifungal, anti-inflammatory, anticancer, and antioxidant applications[5]. Their antibacterial mechanism is primarily attributed to the generation of ROS, which induces lipid peroxidation, protein oxidation, and DNA degradation, ultimately leading to cell death[6].

This study aimed at synthesizing CuO nanorods by employing the co-precipitation method and at evaluating their antibacterial efficacy against *Staphylococcus aureus* by determining the inhibition percentage across varying nanoparticle concentrations.

2. Methodology

CuO nanorods were synthesized *via* a co-precipitation method using copper sulfate and sodium hydroxide as precursor compounds. Specifically, copper sulfate (0.5 M) was dissolved in distilled water, and upon complete dissolution, sodium hydroxide solution (1 M) was added dropwise under constant stirring, with drops directed along the vessel walls in order to maintain a pH of 12. The reaction mixture was allowed to proceed for 2 h. The resulting suspension was left to settle overnight; the supernatant was carefully discarded, and the precipitate was thoroughly washed with distilled water. The washed precipitate was dried at 80°C overnight and was subsequently calcined at 200°C for 1 h in order to obtain the final product[7].

The antibacterial activities of the synthesized CuO nanorods against *Staphylococcus aureus* were evaluated *in vitro* by using the total bacterial count method. CuO nanorods (0.1, 0.15, 0.2, 0.25, and 0.3 g) were suspended in 5 ml deionized water and subjected to ultrasonic treatment for 45 min. Subsequently, 100 µl of bacterial suspension was introduced into each nanoparticle solution, which was agitated in a shaking incubator for 1 h. Samples were then cultured on a Mueller-Hinton agar and incubated at 37°C for 24 h.

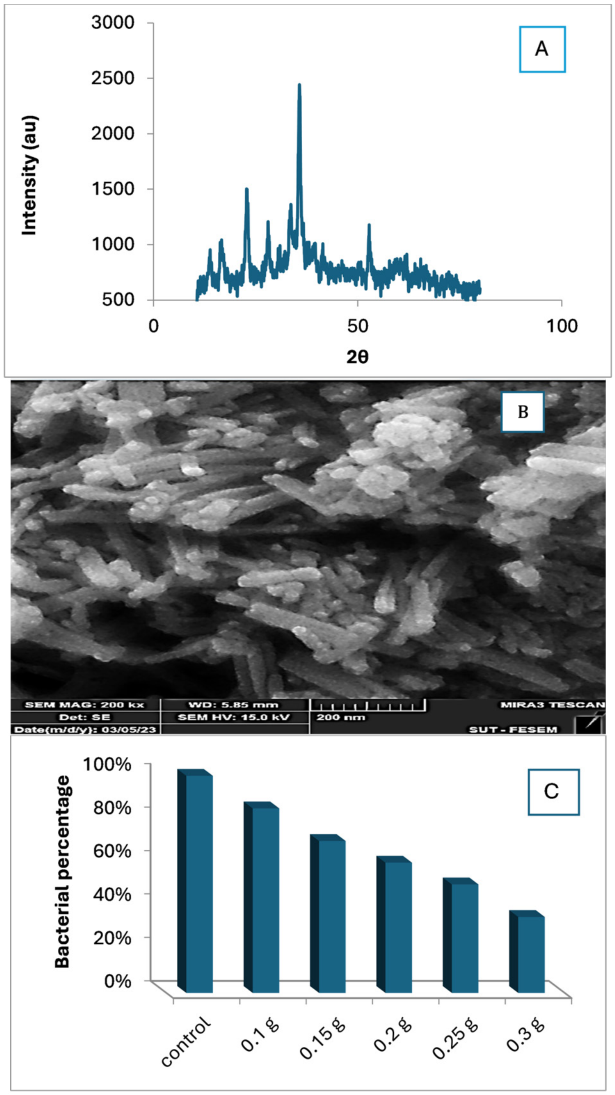

Figure 1. *Instrumental analysis and antibacterial activity of copper oxide (CuO) nanorods (NRs). (A): X-ray diffraction pattern of CuO NRs. (B): Field emission scanning electron microscopy image of CuO NRs. (C): Percentage of Staphylococcus aureus in response to varying concentrations of CuO NRs.*

3. Results and Discussion

X-ray diffraction (XRD) was employed in order to determine the crystal structure and size of the synthesized nanoparticles. XRD analysis provided information on crystalline phase, lattice parameters, and average crystallite size (Figure 1.A). By using the Scherrer's formula, the average crystallite size was calculated as 10.538 nm[8]. Field emission scanning electron microscopy (FE-SEM) has enabled high-resolution morphological analysis, revealing well-defined rod-shaped CuO nanorods with diameters of approximately 25 nm[9], as shown in Figure 1.B. Both particle size and concentration of CuO nanorods were found to be critical determinants of antibacterial activity. As indicated in Figure 1.C, smaller CuO nanorods demonstrated enhanced penetration across bacterial membranes due to their larger surface area and positive surface charge. These properties facilitated interactions with bacterial cell membranes and promoted the disruption of essential cellular components (including lipids, DNA, and proteins), leading to effective bactericidal action against *S. aureus*[10].

4. Conclusion

In conclusion, CuO nanorods possess notable physicochemical properties and promising antibacterial capabilities. Structural characterization *via* XRD confirmed a crystalline architecture with an average crystallite size of approximately 10.538 nm, while FE-SEM analysis validated the rod-like morphology, with diameters near 25 nm. The observed antibacterial potency against *Staphylococcus aureus* is largely attributable to the small size and positive surface charge of CuO nanorods, enabling disruptive interactions with bacterial membranes and internal cellular structures.

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Conflicts of interest

None exist.

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