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Green Synthesis, Characterization, and Multifunctional Bioactivity Evaluation of Cymbopogon citratus–Mediated ZnO, CuO, and ZnO–CuO Nanoparticles

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Abstract

Cymbopogon citratus, commonly known as lemongrass, is an aromatic medicinal plant rich in flavonoids, phenolic compounds, essential oils, and other phytochemicals with important pharmacological properties. In this study, zinc oxide, copper oxide, and zinc oxide–copper oxide nanoparticles were synthesized using *Cymbopogon citratus* leaf extract through an eco-friendly green synthesis approach. The aim of this research was to characterize the synthesized nanoparticles and evaluate their antioxidant, antibacterial, antidiabetic, photocatalytic, and cytotoxic activities for potential biomedical and environmental applications. The synthesized nanoparticles were characterized using UV-visible spectroscopy, Fourier transform infrared spectroscopy, dynamic light scattering, scanning electron microscopy, and X-ray diffraction to determine their optical properties, functional groups, particle size, morphology, and crystalline nature. Antioxidant activity was evaluated using the DPPH free radical scavenging assay and reducing power assay, with ascorbic acid as the reference standard. Among the tested nanoparticles, ZnO–CuO nanoparticles showed the highest antioxidant potential. Antibacterial activity was assessed by the agar well diffusion method against *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Staphylococcus epidermidis*, using an antibiotic disc as the positive control. ZnO nanoparticles showed the strongest inhibition against *E. coli*, *K. pneumoniae*, and *P. aeruginosa*, whereas CuO nanoparticles were most effective against *S. aureus*. ZnO–CuO nanoparticles exhibited the highest antibacterial activity against *S. epidermidis*. The antidiabetic activity was investigated using alpha-amylase and alpha-glucosidase inhibition assays, with acarbose as the standard drug. ZnO–CuO nanoparticles demonstrated the highest inhibitory activity in both assays. Photocatalytic activity was evaluated through methylene blue dye degradation, where ZnO nanoparticles showed superior efficiency compared with CuO and ZnO–CuO nanoparticles. Cytotoxicity results indicated promising effects of all nanoparticles against cancer cells. Overall, these findings suggest that *Cymbopogon citratus*–mediated nanoparticles have significant therapeutic, diagnostic, and environmental potential.

Keywords: *Cymbopogon citratus; Green synthesis; Zinc oxide nanoparticles; Copper oxide nanoparticles; Antibacterial activity*