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Green Synthesis of Zinc Oxide Nanoparticles Using Stingless Bee Honey and Comprehensive Characterization for Antifungal Activity

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ABSTRACT

This study presents a novel approach for the green synthesis of zinc oxide nanoparticles (ZnO NPs) using stingless bee honey (SBH) as a bio-reducing and stabilizing agent. The green synthesis method was employed to reduce environmental impacts compared to conventional chemical methods. The synthesized ZnO NPs were comprehensively characterized using field emission scanning electron microscopy (FESEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR). The FESEM and TEM results confirmed the spherical morphology and uniform distribution of ZnO NPs. The XRD analysis demonstrated the formation of highly crystalline wurtzite-phase ZnO, while FTIR analysis confirmed the presence of functional groups responsible for nanoparticle stabilization. The cytotoxicity assessment using MTT assay revealed moderate toxicity of the ZnO NPs against normal and cancerous cells. The antifungal activity of ZnO NPs was evaluated in vitro against *Aspergillus clavatus*, showing significant inhibitory effects. The findings suggest that SBH-derived ZnO NPs have great potential as eco-friendly antifungal agents for biomedical and food packaging applications.

1 | Introduction

The advancement of nanotechnology has brought zinc oxide (ZnO) to the forefront as a versatile inorganic material with significant potential in various industries, including food processing, packaging, and preservation (Omerović et al. 2021). Among its many benefits, ZnO nanoparticles (NPs) are particularly valued for their robust antimicrobial and antioxidant properties (Abbes et al. 2022), which are crucial for extending shelf life and ensuring the safety of food products. The United States Food and Drug Administration (USFDA) has classified ZnO as generally recognized as safe (GRAS), which further supports its increasing applications in food technology (Mizielińska et al. 2018). Traditional NPs synthesis methods fall into two primary categories: top-down and bottom-up approaches. While the top-down approach involves breaking down larger particles into nanoscale sizes, the bottom-up approach focuses on the assembly of atoms or molecules to form NPs (Agarwal et al. 2017). However, the increasing concern over the environmental and health impacts of chemically synthesized NPs has shifted the focus toward green synthesis. This alternative method utilizes biological substrates, such as