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Research Proposal

on

Tuning the band gap of phyto-mediated Zinc Oxide(ZnO) and Titanium dioxide (TiO_2) nanoparticles to enhance photocatalytic and antimicrobial performances.

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Title

Tuning the band gap of phyto-mediated Zinc Oxide(ZnO) and Titanium dioxide (TiO_2) nanoparticles to enhance photocatalytic and antimicrobial performances.

Introduction

Modern materials science emphasizes nanotechnology for tailoring nanoparticles with unique-size and shape-dependent properties[1]. Biogenic metal oxide nanoparticles, particularly zinc oxide (ZnO) and titanium dioxide (TiO_2), are valued for their antibacterial, optical, and photocatalytic functions, driven by their biocompatibility, Reactive Oxygen Species (ROS) generation, and eco-friendly synthesis. Phytochemical-based synthesis enhances the sustainability of nanoparticles for use in nanomedicine, antimicrobial treatment, and environmental remediation because of its simplicity, affordability, and non-toxicity[2], [3], [4].

ZnO is ideal for UV protection and disinfection[5], [6], while TiO_2 excels in photocatalysis and stability, making them suitable for various sustainable applications[7], [8]. Moreover, when combined with other materials, such as silver (Ag), gold(Au), copper (Cu), magnesium(Mg), and graphene oxide (GO), their strengths are further amplified through synergistic interactions[9], [10]. The biocompatibility and eco-friendly origin of these nanomaterials render them suitable for medical and antimicrobial applications, while their photocatalytic activity enables efficient wastewater purification[11]. Moreover, the nanocomposite of ZnO and TiO_2 can also introduce enhanced sustainable implementations.

This study aims to investigate the size, shape, and structure of green-synthesized ZnO and TiO_2 nanoparticles, as well as their nanocomposites, utilizing eco-friendly plant extracts as reducing and stabilizing agents. The biosynthesized metal oxide nanoparticles will undergo comprehensive structural, morphological, and optical characterization through a suite of advanced techniques, including Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), ultraviolet-visible spectroscopy (UV-Vis), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS). In addition to evaluating the fundamental properties of these materials, this study will explore their multifunctional performances in terms of antimicrobial and photocatalytic efficacy. The findings of this work are expected to contribute to the development of sustainable nanomaterials with broad relevance in biomedical, environmental, and energy-related applications.

Research Questions

- How does phyto-mediated synthesis affect the structural and optical properties of ZnO and TiO_2 nanoparticles?
- Do changes in bandgap enhance the efficiency of nanoparticles in degrading pollutants in water and inhibiting microbial growth?
- What synthesis parameters and modifications ensure optimal multifunctional performance for sustainable applications?

Literature Review

Phytogenic synthesis of nanoparticles has become a promising alternative to conventional methods, providing eco-friendly routes for tailoring their structural and functional properties[1]. Plant metabolites facilitate the reduction and stabilization of precursors while imparting bioactive features that strengthen antimicrobial responses[3]. In the case of ZnO, fruit peel and seed extracts have been shown to adjust the optical band gap, thereby enhancing the bactericidal activity and photocatalytic efficiency[6]. Likewise, green-synthesized TiO_2 demonstrates notable performance in pollutant degradation and microbial inhibition, attributed to biomolecule-mediated surface modifications[7], [8]. Recent advances in TiO_2-based nanocomposites further underline the scope of tuning the electronic structures for synergistic photocatalysis[10]. Collectively, these studies highlight the potential of phyto-mediated ZnO and TiO_2 nanoparticles with tunable band gaps as multifunctional agents for environmental and biomedical applications[11].

Objectives

- Tailoring the size, shape, and bandgap of ZnO and TiO_2 nanomaterials using plant extracts through green, sustainable methods.
- Analyzing their structural, morphological, and optical characteristics using various characterization techniques.
- Investigating the functional performance of the biosynthesized nanomaterials in antimicrobial and photocatalytic applications, aiming to assess their efficacy across diverse environmental and biomedical domains.

Methodology

The proposed research methodology involves both qualitative and quantitative approaches for the completion of the proposal.

Qualitative Phase

After collecting the plant extract, it will be air-dried and processed to obtain a bioactive extract by heating it with DI water, followed by filtration. This plant extract will serve as the natural reducing and stabilizing agent. Then, the filtered extract will be added dropwise to a certain concentration of metallic salt solution under constant stirring at a certain temperature. A visible color change will indicate nanoparticle formation, and the reaction mixture will be left overnight for complete precipitation. The resulting solid will be centrifuged, washed thoroughly, dried, and then calcined to obtain metal oxide nanoparticles. The final product will be stored.

Quantitative Phase

The stored samples will go through further physicochemical characterization and application testing. After characterization and analysis, this procedure is expected to yield environmentally friendly nanoparticles with potential antimicrobial, biomedical, and catalytic utilities.

Expected Outcomes

- This study expects to synthesize phyto-mediated ZnO and TiO_2 nanomaterials successfully, exhibiting desirable structural and optical properties.
- Enhancement of antimicrobial and photocatalytic performances by the synthesized nanoparticles

Socio-Economic Impact

- Promoting low-cost, eco-friendly synthesis methods aligned with national and global green nanotechnology initiatives.
- Supports phyto-based antimicrobial agents to combat antibiotic resistance in resource-limited settings and will offer scalable solutions for industrial wastewater treatment, aiding public health and environmental quality.
- To strengthen national expertise in nanotechnology and sustainable science, equipping students and researchers with skills that align with global technological and economic trends.

Time frame

The total duration of the project is set at nine months. During the initial three months, efforts will focus on a thorough review of existing literature, sample collection, and synthesizing nanoparticles. The following three months are allocated for detailed characterization of the sample as well as comprehensive analysis of the obtained data. The remaining three months will involve evaluating the nanoparticle in targeted applications, followed by a critical review of findings and preparation of the final project report.

Potential Limitations

The phytochemical composition of plant extracts may vary with source and conditions, leading to challenges in reproducibility and precise control over nanoparticle size and morphology. Additionally, while green synthesis is eco-friendly, scaling up the process for consistent large-scale production may be difficult.

Conclusions

This study addresses the current gap in systematic band gap tuning of phyto-mediated ZnO and TiO_2 nanoparticles, aiming to optimize both antimicrobial and photocatalytic efficiency. The findings are expected to contribute novel insights toward sustainable nanomaterial development for real-world biomedical and environmental challenges.

Future Work

Following the completion of this project, the results obtained will be assessed for publishing as a research article, while further study may focus on scaling up the production of nanoparticles and exploring their performance in diverse real-world applications. Moreover, future studies could also examine long-term stability and potential improvements in nanoparticle functionality.

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