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Ultrasonic-Assisted Synthesis of Zinc Oxide Nanocomposites with Substituted Thiosemicarbazide Ligands

•Ekhlakh Veg[1,2], Nashra fatima[1], Tahmeena Khan[1*]

[1]*Department of Chemistry, Integral University, Lucknow-226026, U.P., India*

[2]*Department of Chemistry, Isabella Thoburn College, Lucknow-226007, U.P., India*

**Corresponding email: tahminakhan30@yahoo.com*

ABSTRACT

In recent years, much attention has been paid to synthesising metal oxide nanocomposites because of their distinctive physicochemical characteristics, which have uses in biomedicine, environmental remediation, sensing, and catalysis. Various metal oxide nanoparticles, including FeO, ZnO, TiO_2, In_2O_3, SnO_2, SiO_2, NiO, CeO_2, and CuO nanoparticles are used for the synthesis of nanocomposites. Among these, zinc oxide (ZnO) nanoparticles have attracted a lot of interest due to their unique characteristics. Adding organic ligands, especially thiosemicarbazides and their derivatives, improves its stability, chemical reactivity, biocompatibility, solubility, etc. Ultrasonic-assisted methods have become a viable, environmentally friendly, and effective way for producing nanocomposites with unique characteristics among a variety of synthesis approaches. This process uses ultrasonic cavitation to facilitate the efficient coordination of thiosemicarbazide derivatives while enabling fast nucleation, uniform dispersion, and fine particle size control of metal oxides. Various characterisation methods, including Fourier transform Infra-Red (FT-IR), X-ray diffraction (XRD), Scanning Electron Microscopy (SEM), Energy Dispersive X-ray spectroscopy (EDX), and Ultraviolet-visible (UV-Vis), have been used to confirm the synthesis of metal oxide nanocomposites functionalized with ligands that exhibit promising physicochemical and biological properties. This review focuses on the synthesis processes, characterization, and their uses in environmental remediation, catalysis, and antimicrobial therapy.

INTRODUCTION

- Metal oxide nanocomposites have attracted significant attention owing to their unique physicochemical properties and wide applications in catalysis, sensing, environmental remediation, and biomedicine. Among various oxides, zinc oxide (ZnO) nanoparticles are of particular interest due to their distinct optical, electronic, and chemical features, along with their abundance, low cost, and biocompatibility [1].
- Surface modification with organic ligands such as thiosemicarbazides and their derivatives further enhances the stability, solubility, and functional versatility of ZnO, making them suitable for advanced applications. Recently, ultrasonic-assisted synthesis has emerged as an eco-friendly and efficient route for preparing ZnO–ZnO-thiosemicarbazide nanocomposites. Ultrasonic cavitation enables rapid nucleation, uniform dispersion, and effective ligand coordination, thereby offering superior control over particle size and morphology compared to conventional methods [2].
- This review summarizes recent advances in the synthesis, functionalization, and applications of ZnO-thiosemicarbazide nanocomposites, with emphasis on ultrasonic-assisted strategies and their advantages over traditional approaches.

METHODOLOGY

In preparing this review, relevant literature was collected from databases such as ScienceDirect, Scopus, Web of Science, SpringerLink, and PubMed covering publications from 2015 to 2025. Keywords including "metal oxide nanocomposites," "ZnO nanoparticles," "thiosemicarbazide conjugates," "sonochemical synthesis," "ultrasonication-assisted synthesis" and "biomedical applications" were used for the search. Articles were screened to include original research papers, review articles, and recent advances focusing on the synthesis, functionalization, and applications of ZnO-based nanocomposites with thiosemicarbazide derivatives.

RESULTS AND DISCUSSION

Some of the following recent studies have been reviewed from literature.

- ZnO@Gln-TSC NPs were synthesized by using ZnO NPs , Glutamic acide and finally conjugated with Thiosemicarbazide.ZnO@Gln-TSC nanoparticles with a size range of 20–70 nm (DLS: 374 nm; zeta potential: –31.7 mV) exhibited strong cytotoxicity against AGS cells with an IC_{50} of 9.8 µg/mL, which was markedly lower than that of ZnO (130 µg/mL), TSC (80.5 µg/mL), and oxaliplatin (67.7 µg/mL), while in HEK293 cells the IC_{50} was 150.5 µg/mL compared to 215 µg/mL for ZnO [3].
- Plant-derived ZnO NPs were conjugated with salicylaldehyde thiosemicarbazone (STSC), vanillin thiosemicarbazone (VTSC), and 3-acetylpyridine thiosemicarbazone (3-APTSC) using an ultrasonication-assisted method, and the resulting nanoconjugates (ZnO/STSC, ZnO/VTSC, ZnO/3-APTSC) were characterized by spectral and surface analyses, including UV–Vis, FT–IR, W–H plots, and BET studies. ZnO/3-APTSC showed an increased surface area (32.188 m^2/g) compared to pure ZnO NPs (26.687 m^2/g) and exhibited the highest antioxidant activity (59.89% scavenging). Antibacterial assays revealed effective inhibition against both Gram-positive and Gram-negative bacteria,while photocatalytic studies demonstrated significant dye degradation efficiencies of 61.6%, 90.6%, and 94% for ZnO/STSC, ZnO/VTSC, and ZnO/3-APTSC, respectively, within 90 minutes, highlighting their potential as effective photocatalysts for environmental remediation [4].
- Nejabatdoust et al. reported the synthesis of ZnO NPs functionalized with glutamic acid and subsequently conjugated with thiosemicarbazide (ZnO@Glu–TSC). The nanoconjugate was tested against multidrug-resistant *Staphylococcus aureus* and demonstrated antibacterial activity that was 2–8 times stronger than that of ciprofloxacin [5].

CONCLUSION

ZnO–thiosemicarbazide nanocomposites represent a promising class of materials with enhanced physicochemical and biological properties compared to bare ZnO nanoparticles. Functionalization with thiosemicarbazide derivatives improves stability, surface activity, and biocompatibility, while ultrasonic-assisted synthesis offers an efficient, eco-friendly route to achieve well-dispersed nanostructures with controlled morphology. Recent studies highlight their strong cytotoxic, antibacterial, antioxidant, and photocatalytic performances, underscoring their potential in biomedical and environmental applications. Continued exploration of ligand design and sonochemical strategies may further expand their practical utility.

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