RESEARCH PAPER

# Synthesis, Functional Characterization, And Antibacterial Evaluation Of $Sr_{11}O_3/Fe_2O_3$/Zno Nanocomposites Against Oral Pathogens

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**Abstract**

**Aim:** To synthesize $sr_{11}o_3/fe_2o_3$/zno nanocomposites and evaluate their antibacterial activity against selected oral pathogens.

**Background:** Metal oxide nanocomposites have gained increasing attention in biomedical research due to their improved physicochemical stability and enhanced antimicrobial performance resulting from synergistic interactions between different metal oxides. The incorporation of zno and $fe_2o_3$ has been reported to enhance antibacterial activity through mechanisms such as reactive oxygen species (ros) generation, metal ion release, and disruption of microbial cell membranes. In multi metal oxide systems, interfacial charge transfer and increased surface reactivity further contribute to improved antimicrobial efficiency. Therefore, the present study aimed to synthesize $sr_{11}o_3/fe_2o_3$/zno nanocomposites and characterize their structural, morphological, and compositional properties.

**Methodology:** $Sr_{11}o_3/fe_2o_3$/zno nanocomposites were synthesized using a chemical precipitation method followed by calcination. The synthesized materials were characterized using x-ray diffraction (xrd), fourier transform infrared spectroscopy (ftir), scanning electron microscopy (sem), and energy dispersive x-ray spectroscopy (edx). Antibacterial activity was evaluated against streptococcus mutans and enterococcus faecalis using standard microbiological assays.

**Results:** Xrd analysis confirmed the formation of crystalline nanocomposite phases, while ftir spectra indicated the presence of characteristic metal oxygen bonds. Sem analysis revealed agglomerated nanoscale particles with irregular morphology, and edx analysis verified the elemental composition of strontium, iron, zinc, and oxygen. The synthesized nanocomposites exhibited significant antibacterial activity against both streptococcus mutans and enterococcus faecalis strains, with inhibition increasing in a concentration dependent manner.

**Conclusion:** $Sr_{11}o_3/fe_2o_3$/zno nanocomposites demonstrated promising antibacterial activity against oral pathogens, suggesting their potential application in dental materials and other biomedical fields for the management of microbial infections.

**Keywords:** Antibacterial Activity, Nanocomposites, Oral Pathogens, Reactive Oxygen Species.

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## Introduction

In recent years, nanotechnology has significantly influenced advancements in biomedical and material sciences by enabling the development of materials with superior functional properties. Nanomaterials are known for their reduced particle size, increased surface area, and enhanced chemical reactivity, which make them highly effective in biological applications.[1]Among various nanomaterials, metal oxide based systems have gained particular importance due to their stability, ease of synthesis, and strong antimicrobial potential.

Zinc oxide (ZnO) nanoparticles are extensively studied for their ability to inhibit microbial growth through mechanisms such as reactive oxygen species generation and membrane disruption.[2] The production of reactive oxygen species such as hydroxyl radicals, superoxide anions, and hydrogen peroxide induces oxidative stress within microbial cells, leading to damage of proteins, lipids, and nucleic acids. Also ZnO nanoparticles can attach to the bacterial cell surface, causing structural alterations in the cell membrane, increased permeability, and eventual leakage of intracellular components.[3] These nanoparticles may penetrate microbial cells and disrupt metabolic pathways, enzyme activity, and DNA replication. The broad spectrum antimicrobial activity, biocompatibility, and relatively low toxicity, ZnO nanoparticles have gained significant attention for applications in biomedical fields, particularly in dentistry for preventing biofilm formation, controlling oral pathogens, and enhancing the antimicrobial efficacy of dental materials.[4] Iron oxide ($Fe_2O_3$) nanoparticles, on the other hand, are valued for their role in facilitating electron transfer and improving catalytic performance.[5] Strontium containing compounds have also attracted attention due to their bioactive properties and their ability to enhance interactions with biological systems. When these metal oxides are combined to form a nanocomposite, their individual properties can complement each other, resulting in improved overall performance.

Microorganisms such as *Streptococcus mutans* and *Enterococcus faecalis* are commonly associated with oral health issues. *S. mutans* plays a key role in the initiation of dental caries by forming biofilms and producing acids that damage tooth enamel. *E. faecalis* is frequently found in persistent root canal infections and is known for its resistance to conventional treatment methods.[6, 7] The limitations of existing antimicrobial agents, particularly due to increasing resistance, have created a need for alternative approaches to control these pathogens effectively.

Considering these challenges, the present study aims to develop a $Sr_{11}O_3/Fe_2O_3/ZnO$ nanocomposite using a simple chemical synthesis method. The prepared material was further analyzed to understand its structural, chemical, and morphological characteristics using standard techniques such as XRD, FTIR, SEM, and EDX. Additionally, its antibacterial performance was evaluated against selected oral pathogens to determine its suitability for potential applications in dental care and related biomedical fields.

**Materials and Methods**

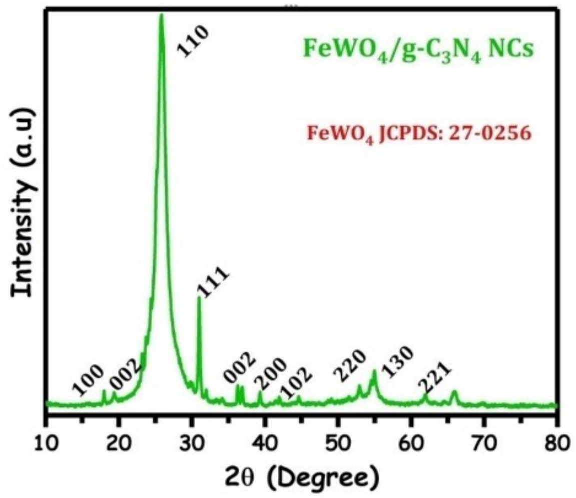
The $Sr_{11}O_3/Fe_2O_3/ZnO$ nanocomposites were synthesized using a chemical precipitation technique due to its simplicity and effectiveness in producing homogeneous nanostructures. The precursors of strontium, iron, and zinc of analytic grade were used without further purification. These salts were individually dissolved in distilled water and then combined under continuous magnetic stirring to obtain a uniform solution. The pH of the reaction mixture was carefully adjusted by adding a suitable base, which facilitated the formation of a precipitate. The solution was stirred for an extended period to ensure complete reaction and uniform particle formation.

The resulting precipitate was separated through filtration and washed multiple times using distilled water followed by ethanol to remove any residual impurities. The cleaned precipitate was then dried at an elevated temperature to eliminate moisture content. Subsequently, the dried material was subjected to calcination at high temperature in a muffle furnace to enhance crystallinity and promote the formation of the final nanocomposite structure.

The structural properties of the synthesized nanocomposites were analyzed using X-ray diffraction (XRD), which provided information on crystalline phases and particle size. Fourier transform infrared spectroscopy (FTIR) was employed to identify functional groups and confirm the presence of metal oxygen bonds. The surface morphology and particle distribution were examined using scanning electron microscopy (SEM), while energy-dispersive X ray spectroscopy (EDX) was used to determine the elemental composition of the nanocomposites.

The anti-biofilm activity was evaluated against *Enterococcus faecalis* and *Streptococcus mutans*, using a 96-well microtiter plate assay at various concentrations of 25 µg, 50 µg, 75 µg, and 100 µg, with untreated biofilms serving as the control. Bacteria were allowed to form biofilms over a 24- 48 hour incubation period at optimal growth conditions, at 37°C. After incubation, the free-floating bacterial cells were carefully washed away with phosphate-buffered saline (PBS). To visualize the biofilm, the wells were stained using crystal violet dye. Once stained, the excess dye was removed, and the wells were rinsed again to remove unbound crystal violet. For quantification, the stained biofilms were solubilized using ethanol. The well plate was allowed for accurate spectrophotometric measurement at a wavelength of 600 nm. The results were compared between the treated groups at different concentrations (25 µg, 50 µg, 75 µg, and 100 µg) and the untreated control group.

**Results**




The X-ray diffraction pattern (Fig. 1) confirms the crystalline structure of the synthesized $Sr_{11}O_3/Fe_2O_3/ZnO$ nanocomposites. Distinct diffraction peaks corresponding to different crystallographic planes indicate the successful formation of a well defined structure. A strong and sharp diffraction peak observed around 25°, which suggests good crystallinity of the $FeWO_4$ phase. The diffraction peaks appearing at approximately 30°, 35°, 40°, 44°, 54°, 58°, and 63° can be indexed to the planes of $FeWO_4$. Furthermore, weak diffraction peaks near 13° and 27° are related to the in plane structural packing and interlayer stacking of the graphitic carbon nitride layers. There was, no additional impurity peaks are observed in the pattern, confirming the high phase purity and successful formation of the $FeWO_4/g\text{-}C_3N_4$ heterostructure nanocomposite**.**

The FTIR spectrum (Fig. 2) reveals the information regarding functional groups and bonding interactions. The absorption band observed at 3781 $cm^{-1}$ attributes to hydroxyl groups. The band at 2684 $cm^{-1}$ associates with C–H bonds. The peak at 2114 $cm^{-1}$ is characteristic of the carbon nitride framework. A prominent peak at 1721 $cm^{-1}$ corresponds to residual oxygen containing functional groups on the surface. The band observed at 1146 $cm^{-1}$ is attributed to heterocyclic aromatic structure of $g\text{-}C_3N_4$**,** confirming the presence of the polymeric carbon nitride network. The peaks at 689 $cm^{-1}$ and 580 $cm^{-1}$ attributes to FeO and metal oxygen confirming the formation of $FeWO_4$ within the composite structure.

Scanning electron microscopy (Fig. 3) illustrates the surface morphology of the synthesized nanocomposites. The nanocomposite exhibits a heterogeneous and agglomerated morphology composed of irregular nanoparticles and layered structures. The spectrum confirms the presence of strontium, iron, zinc, and oxygen. The EDS analysis confirms the elemental composition of the synthesized material. The spectrum shows the presence of Fe, W, O, C, and N elements. The uniform distribution of Fe and W elements further suggests that $FeWO_4$ nanoparticles are well dispersed on the $g\text{-}C_3N_4$ matrix, which facilitates efficient charge transfer and suppresses electron hole recombination during photocatalysis.

The antibacterial activity of the synthesized nanocomposites was evaluated against *Streptococcus mutans* and *Enterococcus faecalis*, as shown in Fig. 4. A concentration-dependent decrease in optical density was observed, indicating effective inhibition of bacterial growth. The nanocomposites exhibited strong antibacterial performance compared to the control, demonstrating their potential for biomedical applications.

Figure 1. XRD pattern of Sr11O3/Fe2O3/ZnO nanocomposites showing crystalline phase formation.

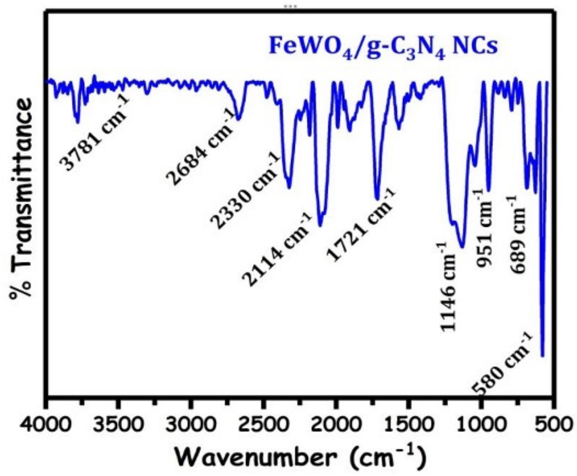



Figure 2. FTIR spectrum showing characteristic functional groups and metal-oxygen bonds.

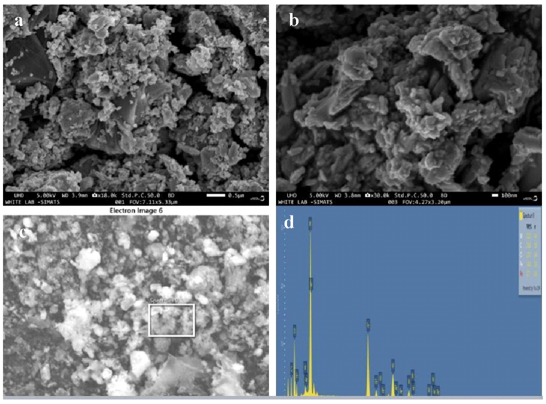



Figure 3(a, b, c): SEM images showing agglomerated nanoscale morphology.(d) EDX spectrum confirming elemental composition of the nanocomposite.

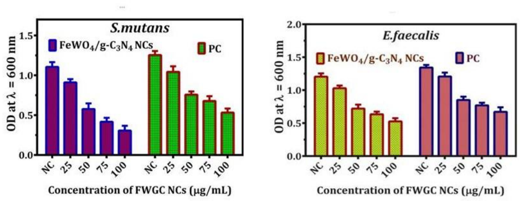



Figure 4. Antibacterial activity of nanocomposites against *S. mutans* and *E. faecalis*.

**Discussion**

The present study confirms the successful synthesis of the nanocomposite and its notable antibacterial efficacy, as evidenced by the antibiofilm results and graphical analysis. The increased antibacterial activity observed across the samples can be attributed to the reduced particle size and increased surface area, which enhance interaction with bacterial cell membranes. The graphical data clearly indicate a concentration-dependent increase in antibacterial performance, suggesting that higher concentrations of the nanocomposite lead to stronger antimicrobial inhibition. This observation is in agreement with earlier studies reporting that nanoscale materials exhibit superior antimicrobial activity due to their enhanced surface reactivity and penetration ability.[8]

The antibacterial mechanism of the synthesized nanocomposite is likely governed by multiple pathways. A key mechanism involves the generation of reactive oxygen species (ROS), which induce oxidative stress within bacterial cells, leading to damage of essential biomolecules such as proteins, lipids, and nucleic acids.[9] Additionally, the nanocomposite may release ions that interfere with intracellular enzymatic activity and disrupt metabolic pathways. The combined effects of oxidative stress and ion mediated toxicity ultimately result in bacterial cell death. The trends observed in the antibacterial graphs strongly support this mechanism, consistent with previously reported findings on metal and metal oxide nanocomposites.[10]

The SEM images included in the study provide direct visual confirmation of the antibacterial activity. In untreated samples, bacterial cells appear intact with smooth and well-defined surfaces. In contrast, treated samples show significant morphological alterations, including membrane rupture, shrinkage, and deformation. These structural damages indicate that the nanocomposite disrupts the integrity of the bacterial cell wall, leading to leakage of intracellular components and eventual cell death. Such SEM based observations are widely recognized as evidence of nanoparticle induced membrane damage and antibacterial action.

Furthermore, the enhanced antibacterial efficiency of the nanocomposite compared to conventional materials can be attributed to the synergistic interaction between its components. The combination of materials within the nanocomposite may improve stability, dispersion, and overall bioactivity, resulting in a more effective antibacterial response. This synergistic effect has been reported in several studies, where composite nanostructures demonstrated improved performance over individual components due to combined physicochemical properties and enhanced interaction with microbial cells.[11, 12]

The antibacterial performance of $Sr_{11}O_3/Fe_2O_3/ZnO$ nanocomposites observed in the present study can be critically interpreted in light of previously reported metal oxide systems, particularly ZnO- and $Fe_2O_3$-based nanostructures. ZnO nanoparticles have consistently demonstrated strong antibacterial activity against oral pathogens such as *Streptococcus mutans*, primarily due to reactive oxygen species (ROS) generation, $Zn^{2+}$ ion release, and disruption of bacterial membranes. However, several studies indicate that combining ZnO with other oxides significantly enhances this activity. For instance, chitosan and $/Fe_2O_3/ZnO$ nanocomposites showed superior antibacterial efficacy compared to individual oxides, attributed to improved dispersion, increased surface area, and synergistic ROS production.[13] Similarly, trimetal oxide systems such as Cu–Zn–Fe nanoparticles exhibited enhanced inhibition of *S. mutans* due to the combined effects of multiple metal ions and improved charge transfer dynamics.[14] These findings align with the current study, where the incorporation of $Sr_{11}O_3$ into the $Fe_2O_3/ZnO$ matrix likely promotes additional ionic interactions and structural modifications, further improving antibacterial efficiency.

Moreover, nanocomposites such as $Fe_2O_3$ , CuO, ZnO have been reported to possess higher antibacterial activity than binary systems, owing to increased catalytic activity and improved electron hole separation, which enhances ROS generation.[15] Reviews on metal oxide nanocomposites also emphasize that ZnO typically serves as the primary antibacterial component, while $Fe_2O_3$ contributes to electron transfer processes and structural stability, thereby amplifying the overall antibacterial response.[16] In dental applications, ZnO containing composites have shown effective inhibition of *S. mutans* biofilms and prevention of enamel demineralization, highlighting their clinical relevance.[17] The enhanced activity observed in nanocomposites compared to single oxides is generally attributed to heterojunction formation, reduced electron hole recombination, and increased availability of reactive sites.[18] Therefore, the improved antibacterial performance of $Sr_{11}O_3/Fe_2O_3/ZnO$ nanocomposites in this study can be reasonably attributed to synergistic interactions among the constituent oxides, enhanced ROS mediated bacterial killing, and possible contributions from Sr ions in modulating surface reactivity and biocompatibility. Notably, the inclusion of strontium based oxides remains relatively underexplored in oral antimicrobial nanomaterials, suggesting that the present system offers a novel and potentially more effective alternative to conventional ZnO based or binary nanocomposites.

Overall, the findings of this study highlight the strong antibacterial potential of the synthesized nanocomposite, supported by both quantitative and qualitative (SEM analysis) evidence. The material shows promising applications in biomedical fields such as antimicrobial coatings, wound dressings, and infection control. However, further studies focusing on cytotoxicity, environmental impact, and long term stability are essential before practical implementation. Similar recommendations have been emphasized in recent literature to ensure the safe and sustainable use of nanomaterials in clinical applications.[12]

**Conclusion**

In conclusion, the present study successfully demonstrated the synthesis and characterization of a nanocomposite with significant antibacterial activity. The results, supported by zone of inhibition data, graphical analysis, and SEM observations, confirm that the nanocomposite effectively inhibits bacterial growth through mechanisms such as membrane disruption and oxidative stress induction. The concentration dependent increase in antibacterial efficacy highlights its potential for controlled and enhanced performance. Overall, the nanocomposite shows promising applicability in biomedical and antimicrobial fields, including coatings and infection control. However, further studies on biocompatibility, toxicity, and long-term stability are necessary to ensure its safe and practical implementation in real-world applications.

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