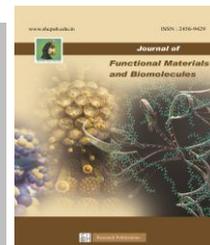




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GREEN SYNTHESIS OF IRON OXIDE AND NICKEL OXIDE USING THE AQUEOUS BARK EXTRACT OF *FICUS RELIGIOSA*

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Abstract

In the present study, α -Fe₂O₃ and NiO nanoparticles were successfully synthesized via a green biogenic route using the aqueous bark extract of *Ficus religiosa*. The prepared bark extract was mixed with iron nitrate and nickel nitrate precursor solutions to yield the respective metal oxide nanoparticles. The synthesized samples were characterized using XRD, FTIR, UV-Visible spectroscopy, SEM-EDAX, and antimicrobial assays. XRD analysis confirmed the rhombohedral phase of α -Fe₂O₃ and the cubic FCC phase of NiO. FTIR spectra revealed characteristic Fe-O and Ni-O vibrational modes at 477, 564, 470, and 568 cm⁻¹. Optical band gaps were calculated as 1.85 eV (Fe₂O₃) and 3.18 eV (NiO). Antimicrobial studies conducted against *Escherichia coli* and *Staphylococcus aureus* showed notable inhibition zones, confirming the biological activity of the synthesized nanoparticles. Overall, this study demonstrates the multifunctional potential of Fe₂O₃ and NiO nanoparticles synthesized via an eco-friendly, biocompatible method suitable for nanoscience-based applications.

1. Introduction

Nanoparticles and nanomaterials have gained substantial attention owing to their wide application in drug delivery, imaging, diagnostics, cosmetics, catalysis, and biosensing, etc. [1-3]. Among these, metal oxide nanoparticles have attracted considerable interest due to their unique physicochemical, magnetic, electrical, optical, and catalytic properties [5-7]. Conventional synthetic routes involve physical and chemical methods, which often require toxic chemicals and generate hazardous waste [8-10]. In contrast, biological synthesis offers a clean, sustainable, and environmentally benign approach to nanoparticle fabrication [11-13].

Plant-mediated nanoparticle synthesis has emerged as a promising green alternative, as plant extracts act as reducing, stabilizing, and capping agents [14-15]. Plants contain phytochemicals such as flavonoids, alkaloids, terpenoids, amino acids, saponins, and tannins, which participate in

Keywords: Nanoparticles, Bark extract, *Ficus religiosa*, Structural, Antimicrobial.

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nanoparticle formation [16-18]. *Ficus religiosa* (peepal tree), a medicinally important species widely used in Ayurveda, contains numerous bioactive compounds with antibacterial, antioxidant, anti-inflammatory, antidiabetic, and wound-healing properties [19-21]. Bark extracts of *F. religiosa* have been reported to contain carbohydrates, flavonoids, amino acids, steroids, saponins, and tannins, which make them suitable for nanoparticle synthesis [22-23]. Biogenic synthesis of metal oxides such as Fe_2O_3 , CuO , ZnO , NiO , Ag_2O , and Co_3O_4 using plant extracts has been widely reported [24-27]. Iron oxide nanoparticles, in particular, are extensively studied due to their variable oxidation states, magnetic behavior, stability, low toxicity, and antimicrobial properties [28-30]. Nickel oxide nanoparticles also exhibit excellent catalytic, optical, and antimicrobial characteristics [31-33]. Given these advantages, the present study aims to synthesize Fe_2O_3 and NiO nanoparticles using aqueous bark extract of *Ficus religiosa*, and evaluate their structural, optical, morphological, and antimicrobial properties.

2. Experimental Procedure

2.1 Preparation of *Ficus religiosa* Bark Extract

Fresh bark of *Ficus religiosa* was collected from Ponneri village near Yelagiri Hills, Tamil Nadu, India. The bark was washed thoroughly with running water to remove dust and impurities, cut into small pieces, and dried under sunlight for one week. The dried bark was ground into fine powder and stored in airtight containers [34].

Thirty grams of bark powder was mixed with 150 mL of distilled water and heated at 100 °C. During heating, the phytochemicals were extracted into the solution. The mixture was allowed to cool and kept undisturbed for 24 hours. The filtered extract was used for nanoparticle synthesis [35].



Fig1. Preparation of *Ficus religiosa* bark extract.

2.2 Synthesis of Iron Oxide and Nickel Oxide Nanoparticles



Fig 2. Experimental images of Fe_2O_3 (a-d) and NiO (e-h) nanoparticle synthesis.

Iron nitrate and nickel nitrate (AR grade) were used as precursors. For Fe_2O_3 synthesis, 1 M iron nitrate solution was prepared, and 100 mL of bark extract was added. The mixture was stirred at 6000 rpm for 3 hours, then left undisturbed for 24 hours for sedimentation. The precipitate was collected, dried at 110 °C for 4 hours, and calcined at 800 °C in a muffle furnace. The obtained powder was used

for further characterization [36]. A similar procedure was followed to prepare NiO nanoparticles using nickel nitrate precursor [37].

3. Results and Discussion

3.1 Powder X-ray Diffraction (XRD) Analysis

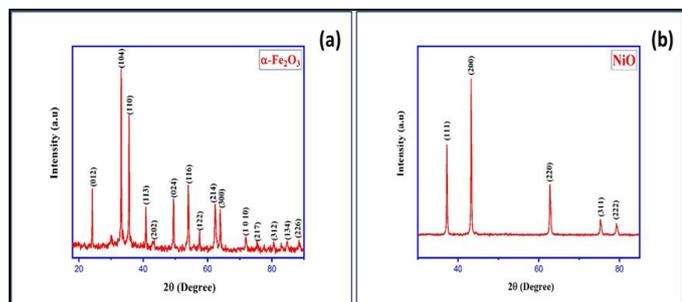


Fig 3. XRD pattern of Fe_2O_3 and NiO nanoparticles.

XRD patterns were recorded in the 2θ range of 20° – 90° . The diffraction peaks of Fe_2O_3 corresponded to the planes (012), (104), (110), (113), (202), (024), (116), (122), (214), (300), (1010), (17), (312), (134), and (226). These matched standard JCPDS card No. 87-1164, confirming the rhombohedral phase of $\alpha\text{-Fe}_2\text{O}_3$ [38-39]. The average crystallite size calculated using the Debye–Scherrer equation was 27.67 nm. NiO nanoparticles exhibited diffraction peaks corresponding to (111), (200), (220), (311), and (222) planes, matching JCPDS card No. 65-5745. The structure was identified as a cubic (FCC) structure [40]. The average crystallite size of 28.86 nm.

3.2 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR spectra were recorded in the range of 500 – 4000 cm^{-1} . For Fe_2O_3 , characteristic Fe–O stretching bands were observed at 477 and 564 cm^{-1} . Additional peaks at 1063 , 2342 , and 2394 cm^{-1} corresponded to C–O–C, CH_2 , and C–N vibrations, respectively [30-31]. Bands at 1624 and

1380 cm^{-1} indicated H–O–H and H–C–H bending, while a broad peak at 3240 cm^{-1} indicated O–H stretching [32].

NiO nanoparticles exhibited Ni–O vibrational modes at 470 and 568 cm^{-1} . Peaks at 1038 , 1098 , 2346 , 2942 , 1394 , and 1608 cm^{-1} corresponded to C–O, CH_2 , C–N, C=C, and H–O–H vibrations, respectively. These functional groups originate from the phytochemicals in the bark extract [33-34].

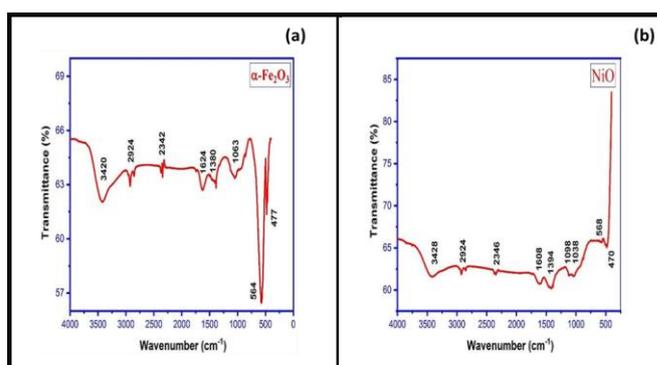


Fig 4. FTIR spectra of (a) Fe_2O_3 and (b) NiO nanoparticles.

3.3 UV-Visible Spectroscopy

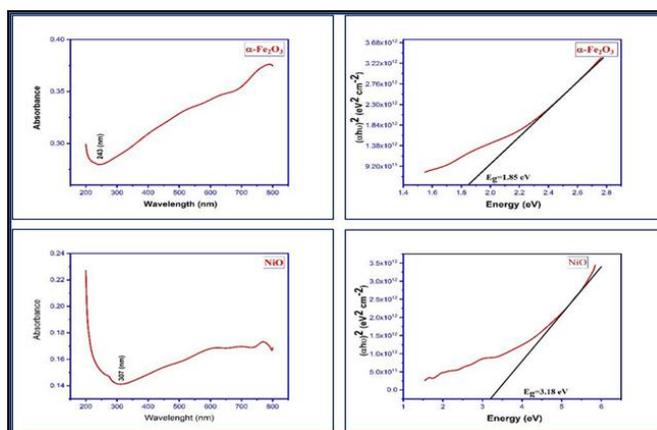


Fig 5. UV-Vis spectra of (a) Fe_2O_3 and (b) NiO nanoparticles.

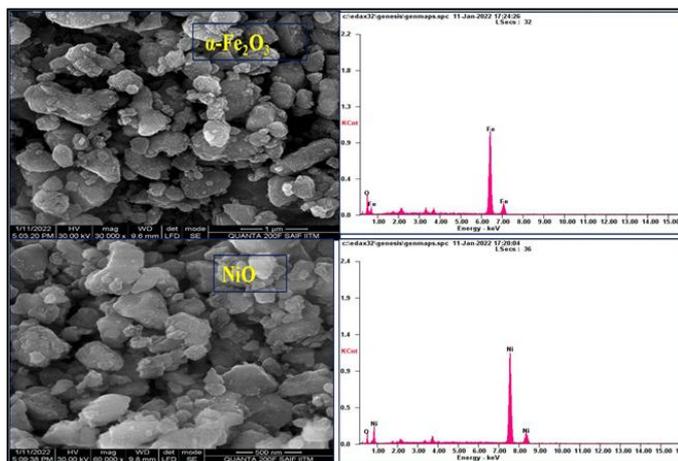
UV-Visible spectra were recorded between 200 – 800 nm . Fe_2O_3 nanoparticles exhibited an absorption peak at 243 nm and a cut-off at 200 nm . The optical band gap, determined using Tauc plot analysis, was 1.85 eV [24-25].

NiO nanoparticles showed a characteristic absorption peak at 307 nm with a cut-off at 198 nm. The calculated band gap was 3.18 eV [26-27].

3.4 Morphological and Elemental Analysis (SEM-EDAX)

SEM images revealed inhomogeneous morphologies with spherical, rod-like, and square-shaped particles, along with some agglomeration. This morphological variation is attributed to the influence of bioactive phytochemicals acting as capping agents [28-29].

The average particle sizes were 93.56 nm (Fe_2O_3) and 98.35 nm (NiO). EDAX spectra confirmed the elemental composition for Fe_2O_3 : Fe (79.40%), O (20.60%), and NiO: Ni (89.46%), O (10.54%) [30].



3.5 Antimicrobial Activity

Antibacterial activity was assessed using the disc diffusion method against *E. coli* (gram-negative) and *S. aureus* (gram-positive). Nanoparticles were dispersed in DMSO and tested on Mueller–Hinton agar plates [31].

Both Fe_2O_3 and NiO nanoparticles exhibited inhibitory zones, indicating effective antimicrobial action [32].

The enhanced activity may be due to the generation of reactive oxygen species (ROS) and interaction of nanoparticles with bacterial cell walls [33].



Sample	Bacterial Strain	Inhibition Zone (mm)
Fe_2O_3	Fe_2O_3	Fe_2O_3
	<i>S. aureus</i>	<i>S. aureus</i>
NiO	<i>E. coli</i>	<i>E. coli</i>
	<i>S. aureus</i>	<i>S. aureus</i>

4. Conclusion

Iron oxide ($\alpha\text{-Fe}_2\text{O}_3$) and nickel oxide (NiO) nanoparticles were successfully synthesized using a green, eco-friendly method employing aqueous bark extract of *Ficus religiosa*. XRD confirmed the rhombohedral and cubic structures of Fe_2O_3 and NiO, respectively. FTIR spectra verified Fe–O and Ni–O bonding, while UV–Visible analysis revealed band gaps of 1.85 eV (Fe_2O_3) and 3.18 eV (NiO). SEM–EDAX confirmed particle morphology and elemental composition. Antimicrobial studies demonstrated significant activity against *E. coli* and *S. aureus*. The results confirm the potential of *Ficus religiosa*–mediated Fe_2O_3 and NiO nanoparticles as multifunctional, biocompatible materials suitable for biomedical and nanotechnological applications.

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