*Article*

# Iron Oxide Nanoparticles from Ocimum basilicum Leaf Extract: A Green route to Synthesis, characterization and Applications

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Citation:
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Iron Oxide Nanoparticles from Ocimum basilicum Leaf Extract: A Green route to Synthesis, characterization and Applications,

J.Adv.Sci.Eng&Tech, 1,1,2025, 10-18

*Received on 12th July 2024*

*Revised on 17th September 2024*

*Accepted on 23rd December 2024*



**Abstract**

In this study, iron oxide nanoparticles (IONPs) were synthesized through an environmentally friendly method utilizing an aqueous extract derived from *Ocimum basilicum* leaves. Various analytical techniques, including UV–Vis spectroscopy, Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), scanning electron microscopy (SEM), and transmission electron microscopy (TEM), were employed to characterize the nanoparticles. The resulting IONPs demonstrated notable antioxidant and antimicrobial properties, suggesting their usefulness in both biomedical and environmental applications.

*Key words*: Iron oxide nanoparticles, Green synthesis, FTIR, SEM , TEM and antibacterial activities

## 1. Introduction

Nanotechnology has significantly transformed multiple scientific fields, with nanoparticles emerging as critical components due to their distinctive physicochemical characteristics. Among them, iron oxide nanoparticles (IONPs) have attracted considerable interest because of their magnetic behavior, biocompatibility, and catalytic potential, making them highly suitable for diverse applications such as drug delivery, medical imaging, and environmental cleanup**.**

Of the eight known forms of iron oxides, hematite, magnetite, and maghemite are especially noteworthy due to their wide-ranging industrial and biomedical applications. Hematite ($\alpha$-$Fe_2O_3$), the most thermodynamically stable form, is commonly utilized in gas sensors, pigments, and catalysts, thanks to its resistance to corrosion and cost-effectiveness. Additionally, hematite can serve as a precursor for synthesizing magnetite and maghemite.

Magnetite ($Fe_3O_4$) possesses an inverse spinel crystal structure with a face-centered cubic lattice. In this arrangement, $Fe^{2+}$ ions occupy half of the octahedral sites, while $Fe^{3+}$ ions are equally distributed between the remaining octahedral and tetrahedral positions.

Maghemite ($\gamma$-$Fe_2O_3$), often regarded as the fully oxidized form of magnetite, consists of 32 oxide ions ($O^{2-}$), 21⅓ $Fe^{3+}$ ions, and 2⅓ vacancies per unit cell. These ions form a closely packed cubic structure in which ferric ions are spread across both tetrahedral and octahedral sites.

Iron oxide nanoparticles are gaining increasing attention for their roles in various advanced technologies, including ferrofluids, magnetic data storage, targeted drug delivery, tissue engineering, cancer therapy, sensors, antibacterial treatments, magnetic resonance imaging (MRI), and environmental remediation.

Traditionally, iron oxide nanoparticles have been synthesized using physical and chemical methods. However, these techniques often involve high temperatures, elevated pressures, and hazardous chemicals, which pose environmental and safety concerns. To address these limitations, green synthesis approaches have been developed.

Biosynthesis methods offer a more sustainable and eco-friendly alternative by utilizing natural, non-toxic materials. These methods have successfully employed plant extracts, fruits, and naturally derived polymers for the synthesis of iron oxide nanoparticles, providing a safer and more environmentally conscious route to nanoparticle production.

Conventional approaches for synthesizing iron oxide nanoparticles (IONPs) typically require hazardous chemicals and consume large amounts of energy. In contrast, green synthesis provides an environmentally friendly and sustainable alternative by employing biological materials, such as plant extracts, which function as both reducing and stabilizing agents.

*Ocimum basilicum*, commonly known for its abundant phytochemicals—including flavonoids, phenolic compounds, and alkaloids—has the potential to assist in the reduction of metal ions and the stabilization of the formed nanoparticles. This research focuses on the green synthesis of IONPs using *Ocimum basilicum* leaf extract and investigates their structural, morphological, and biological characteristics.

## 2. Materials and Methods

### 2.1. Collection and Preparation of Plant Extract

Fresh leaves of OCIMUM BASILIUM were collected from Nanadana Vanam, a visitors park maintained by forest department of Goverrnment of Telangana near Medipally, Hyderabad, authenticated by Department of

 

Botany, Osmania University, and washed thoroughly with distilled water to remove impurities. The cleaned leaves were shade-dried for seven days and ground into a fine powder using a mechanical grinder. To prepare the aqueous extract, 20 g of the powdered leaves were boiled in 200 mL of distilled water at 80°C for 45 minutes. The mixture was cooled to room temperature and filtered using Whatman No. 1 filter paper. The filtrate was stored at 4°C for further use.

### 2.2. Synthesis of Iron Oxide Nanoparticles

A 0.1 M ferric chloride ($FeCl_3 \cdot 6H_2O$) solution was prepared using distilled water. For the synthesis of iron oxide nanoparticles (IONPs), 30 mL of *Ocimum basilicum* leaf extract was gradually introduced into 100 mL of the ferric chloride solution while continuously stirring the mixture at 75°C. A visible color change from yellowish to dark brown signified the formation of IONPs. The reaction was allowed to proceed with continuous stirring for an additional two hours to ensure completion. The synthesized nanoparticles were collected by centrifuging the solution at 10,000 rpm for 30 minutes. The precipitate was then washed three times with distilled water and ethanol to eliminate any residual impurities and unreacted materials. Finally, the purified nanoparticles were dried at 75°C for 18 hours.

### 2.3. Characterization Techniques

#### *2.3.1. UV–Visible Spectroscopy*

The optical properties of the synthesized IONPs were analyzed using a UV–Visible spectrophotometer in the range of 200–800 nm. A characteristic absorption peak at 301 nm confirmed the formation of IONPs.

#### *2.3.2. Fourier-Transform Infrared Spectroscopy (FTIR)*

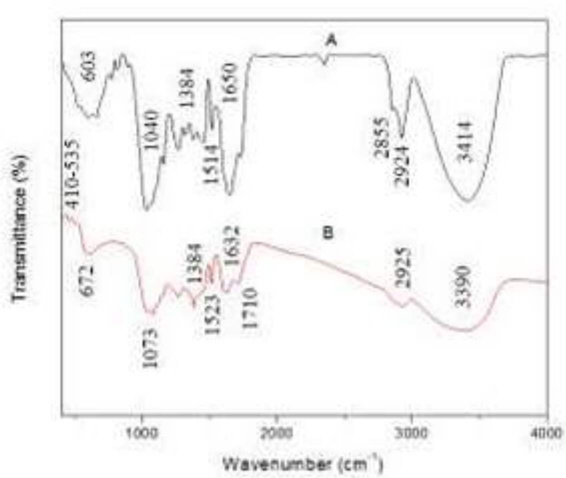


Fig.1. FTIR of a) leaf extract and b) IONPs

Fourier-transform infrared (FTIR) spectroscopy was utilized to identify the functional groups responsible for the reduction and stabilization of iron oxide nanoparticles (IONPs). The FTIR spectrum of the synthesized nanoparticles displayed distinct absorption bands at 3274 $cm^{-1}$, 1688 $cm^{-1}$, and 567 $cm^{-1}$, corresponding to O–H stretching (hydroxyl groups), C=O stretching (carbonyl groups), and Fe–O vibrations, respectively—indicating successful nanoparticle formation and the involvement of these functional groups in the synthesis process.

The FTIR spectrum of the *Ocimum basilicum* leaf extract revealed the presence of various functional groups that may contribute to nanoparticle synthesis. A broad peak at 3416 $cm^{-1}$ was attributed to O–H stretching, while peaks at 2923 $cm^{-1}$ and 2856 $cm^{-1}$ were indicative of asymmetric and symmetric stretching of methylene C–H bonds. A strong absorption at 1727 $cm^{-1}$ suggested the presence of ketones or carboxylic acids. The peak at 1651 $cm^{-1}$ was associated with alkenyl C=C stretching, and a band at 1516 $cm^{-1}$ indicated aromatic C=C–C stretching. The absorption at 1458 $cm^{-1}$ corresponded to methylene C–H bending.

Additional peaks at 1321 $cm^{-1}$ and 1272 $cm^{-1}$ were characteristic of in-plane O–H bending vibrations. The bands at 1156 $cm^{-1}$ and 1042 $cm^{-1}$ were assigned to skeletal C–C vibrations. Aromatic C–H out-of-plane bending was evidenced by peaks at 825 $cm^{-1}$ and 776 $cm^{-1}$. The signal at 669 $cm^{-1}$ indicated alkyne C–H bending, while the peak at 604 $cm^{-1}$ was associated with S–S stretching.

Similarly, the FTIR spectrum of the synthesized nanoparticles revealed peaks at 3391 $cm^{-1}$ (O–H stretching), 2926 $cm^{-1}$ (methylene C–H asymmetric stretching), and 1712 $cm^{-1}$ (ketone or carboxylic acid). A band at 1630 $cm^{-1}$ corresponded to alkenyl C=C stretching, while 1524 $cm^{-1}$ was attributed to aromatic C=C–C stretching. The peak at 1386 $cm^{-1}$ reflected C–H bending, and the signal at 1276 $cm^{-1}$ indicated in-plane O–H bending. Skeletal C–C vibrations were observed at 1074 $cm^{-1}$ and 1042 $cm^{-1}$. Alkyne C–H bending was seen at 673 $cm^{-1}$, and a range of peaks from 412 $cm^{-1}$ to 536 $cm^{-1}$ confirmed the presence of Fe–O bonds, characteristic of $Fe_3O_4$ nanoparticles.

### *2.3.3. X-ray Diffraction (XRD)*

XRD patterns were recorded using Cu Kα radiation (λ = 1.5406 Å) in the 2θ range of 20°–90°.

The XRD analysis exhibited peaks at; 30.22$^o$, 35.58$^o$, 43.27$^o$, 53.28$^o$, 57.27$^o$, 62.61$^o$, 68.29$^o$ and 74.47$^o$ corresponding to 220, 331, 400, 422, 551, 440, 533 and 553 respectively which indicates the inverse spinel structure of Fe3O4 shows the crystalinity and high purity of synthesized Fe3O4 nanoparticles. The iron oxide nanoparticles were in the size range of 36nm to 48nm.

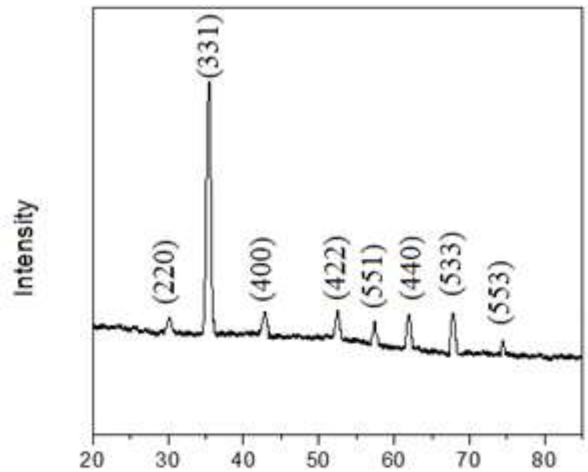


Fig.2. XRD pattern of the synthesized IONPs

### *2.3.4. Scanning Electron Microscopy (SEM)*

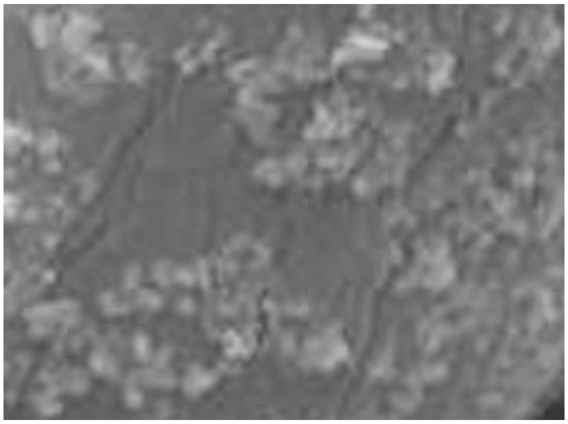

Fig.3. SEM images of the synthesized IONPs.

SEM analyses revealed that the IONPs were predominantly spherical with slight agglomeration. The average particle size was found to be 24–36 nm, consistent with previous studies .

## 2.4. Biological Activity Assessment

### *2.4.1. Antioxidant Activity*

The antioxidant potential of the IONPs was evaluated using DPPH and ABTS assays. In the DPPH assay, the IONPs exhibited an $IC_{50}$ value of 53.1 µg/mL, while in the ABTS assay, the $IC_{50}$ was 51.3 µg/mL, indicating significant free radical scavenging activity .

#### *2.4.2. Antimicrobial Activity*

The antimicrobial properties of the synthesized iron oxide nanoparticles (IONPs) were evaluated using the disc diffusion technique against selected microbial strains, including *Staphylococcus aureus*, *Escherichia coli*, *Candida albicans*, and *Candida tropicalis*. The nanoparticles exhibited inhibition zones of 13 mm for both *S. aureus* and *E. coli*, while zones of 15 mm and 13 mm were observed for *C. tropicalis* and *C. albicans*, respectively..

## 3. Results and Discussion

### 3.1. Characterization of Synthesized Nanoparticles

UV–Visible spectroscopy validated the successful synthesis of iron oxide nanoparticles (IONPs), displaying a distinct absorption peak at 301 nm. FTIR results suggested that plant-derived phytochemicals played a key role in reducing and stabilizing the nanoparticles. The X-ray diffraction (XRD) pattern corresponded to the standard magnetite phase, confirming the crystalline nature of the particles. Scanning electron microscopy (SEM) revealed that the nanoparticles were predominantly spherical, with an average diameter ranging between 24 and 36 nm..

### 3.2. Biological Activities

The synthesized IONPs demonstrated significant antioxidant activity, comparable to standard antioxidants like ascorbic acid. The antimicrobial studies revealed effective inhibition of both bacterial and fungal pathogens, suggesting potential applications in antimicrobial formulations.

### 3.3. Comparative Analysis

When compared to iron oxide nanoparticles (IONPs) produced through other plant-based methods, those synthesized using *Ocimum basilicum* leaf extract exhibit comparable, and in some cases enhanced, physicochemical traits and biological activities:

- IONPs prepared with *Psidium guajava* leaf extract have been reported to possess strong antimicrobial effects against various pathogenic microbes. Similarly, IONPs derived from *Ocimum basilicum* show equivalent antimicrobial performance, highlighting their promise for biomedical uses and environmental sanitation.
- Nanoparticles synthesized with *Melia azedarach* leaf extract demonstrate similar optical and structural properties, as revealed by UV–Visible absorption and FTIR spectroscopy. The spectral data suggest effective capping and stabilization by phytochemicals, a feature also evident in *Ocimum basilicum*-mediated IONPs, confirming successful surface modification and nanoparticle synthesis.

- Likewise, IONPs fabricated using *Calotropis procera* leaf extract are characterized by uniform particle size and notable antimicrobial activity. The nanoparticles generated from *Ocimum basilicum* exhibit similar size distribution, as confirmed by SEM and TEM imaging, along with comparable antimicrobial efficacy, reinforcing their stability and functional bioactivity.
- These comparative results confirm that *Ocimum basilicum* leaf extract serves as an effective and dependable natural reducing and stabilizing agent for the eco-friendly synthesis of biologically active iron oxide nanoparticles (IONPs). The similar characteristics observed across different plant-mediated methods highlight the promise of *O. basilicum* as a sustainable and readily available resource for producing functional nanoparticles with a wide range of applications.

## 4. Conclusion

This study successfully demonstrates the environmentally friendly synthesis of iron oxide nanoparticles utilizing *Ocimum basilicum* leaf extract. The produced nanoparticles are crystalline and spherical in shape, exhibiting notable antioxidant and antimicrobial properties. This green synthesis method provides a sustainable pathway for generating IONPs, with promising uses in biomedical and environmental fields.

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