

Phytofabrication of Iron Oxide Nanoparticles using *Ricinus communis* Leaf Extract

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Abstract

Green synthesis of nanoparticles has emerged as an environmentally sustainable alternative to conventional chemical and physical methods due to its cost-effectiveness, biocompatibility, and reduced toxicity. In the present study, iron oxide nanoparticles (FeNPs) were synthesized using aqueous leaf extract of *Ricinus communis* as a natural reducing and stabilizing agent. The phytochemicals present in the leaf extract, including flavonoids, phenolic compounds, and tannins, played an important role in the reduction of Fe³⁺ ions and stabilization of the synthesized nanoparticles. The formation of nanoparticles was initially confirmed by a visible color change from yellowish brown to dark blackish brown during the reaction process.

The synthesized nanoparticles were characterized using UV–Visible spectroscopy, Scanning Electron Microscopy (SEM), and Energy Dispersive X-ray Spectroscopy (EDS). UV–Visible analysis showed a characteristic absorption peak at 340 nm, confirming the successful synthesis of iron oxide nanoparticles. SEM analysis revealed irregular, aggregated, and granular nanoscale structures with rough surface morphology. EDS spectra confirmed the presence of iron and oxygen as the major elemental constituents, indicating successful formation of iron oxide nanoparticles with good purity and minimal impurities. The study demonstrates that green synthesis using *Ricinus communis* leaf extract is a simple, eco-friendly, and economical approach for nanoparticle production. The synthesized nanoparticles showed good stability and possess potential for antimicrobial, environmental, and biomedical applications.

Keywords: Green synthesis, Iron oxide nanoparticles, *Ricinus communis*, IONPs

Introduction

Green synthesis of nanoparticles is a paradigm change in nanotechnology, substituting natural, biologically derived agents for dangerous chemical stabilizers and reductants (Singh et al., 2023). Following the 12 principles of green chemistry, this environmentally friendly technology eliminates the hazardous consequences of traditional physical and chemical processes while focusing on waste prevention, renewable feedstocks, and energy efficiency (Ivanković et al., 2017).

1.1 Core Principles and Advantages:

1.1.1 Biocompatible reducing agents: Microbial enzymes and plant phytochemicals (flavonoids, polyphenols, terpenoids, alkaloids) concurrently reduce metal ions and cap nanoparticles, preventing agglomeration (Ovais et al., 2018).

1.1.2 Ambient conditions: High-energy inputs needed for sol-gel, hydrothermal, or laser ablation procedures are eliminated by room temperature and atmospheric pressure synthesis (Bokov et al., 2021).

1.1.3 Scalability: Makes use of plentiful, renewable plant biomass, which is economical for large-scale production (Sanford et al., 2016).

1.1.4 Improved properties: Targeted bioactivity, colloidal stability, and biocompatibility are all improved by biomolecule coating (Schubert et al., 2018).

1.2. Mechanisms of Green Synthesis:

Plant-mediated synthesis proceeds via three sequential stages:

1.2.1 Activation: Polyphenols and metal ions (Fe^{3+} , Ag^+) chelate to form coordination complexes (Walencik et al., 2024).

1.2.3 Reduction: By donating electrons, hydroxyl and aldehyde groups reduce ions to zerovalent metal atoms (Yang et al., 2017).

1.2.4 Stabilization: By adhering to the surface of nanoparticles, proteins and polysaccharides regulate development and stop oxidation (Piacenza et al., 2018).

Global Impact: Global Impact: More than 500 plant species have been found to produce nanoparticles; *R. communis* exhibits an 85–95% production in 1-2 hours, making it perfect for developing countries battling antibiotic resistance (Igieboret al., 2024). By converting castor leaves, which were formerly agricultural waste, into valuable antibacterial agents, this sustainable approach demonstrates the concepts of the circular economy in materials science and connects nanotechnology with Ayurveda (Abraham et al., 2025).

1. Significance of Green Synthesis from *Ricinus communis*

Green nanotechnology incorporates the use of plant components to guarantee a field with good life safety protection." It is a beneficial use of nanotechnology that lessens risks and increases environmental resilience (Khan et al., 2019). Green synthesis of nanoparticles has gained significant attention as an eco-friendly and economical alternative to traditional chemical synthesis methods. In this approach, plant extracts are used as natural reducing and stabilizing agents (Singh et al., 2023). The findings revealed considerable antimicrobial and antioxidant activities, highlighting the potential of *Ricinus communis* for sustainable nanoparticle synthesis (Gaafar et al., 2024).

It was discovered that the leaf extract of *Ricinus communis* was appropriate for the manufacture of silver nanoparticles, which is an uncommon finding (Waris et al., 2020). In conclusion, the research showed that, in comparison to the plant extract and iron nanoparticles, silver nanoparticles made from *Ricinus communis* leaf extract showed significant antibacterial activity. These nanoparticles have a lot of potential as therapeutic agents for various biomedical uses, especially in the area of antibacterial therapies (Linima et al., 2023).

Key Results: FeNPs zones: *S. typhi* (6 ± 0.073 mm), *S. aureus* (5 ± 0.086 mm) (Linima et al., 2023).

Taking the advantages of green synthesis and the unique properties of Nano zero-valent ironnanoparticles (nZVI) into consideration, we report herein the green synthesis of nZVI using *R. communis* seeds extract as a reducing and stabilizing agent (Monga et al., 2020).

2.1 Environmental Significance:

The synthesized RC-nZVI showed an efficient methylene blue removal efficiency of **96.8%** and also exhibited good reusability. Due to its cost-effectiveness and eco-friendly nature, it can be considered a promising adsorbent for environmental applications (Abdelfatah et al., 2021).

2.2 Phytochemical Role:

Phytochemical analysis of the plant extract confirmed the presence of flavonoids, tannins, saponins, and phenolic compounds, which collectively contribute to the reduction and stabilization of RC-nZVI through a synergistic effect (Shah et al., 2015).

3. Disadvantages of Conventional Methods

3.1 Chemical Synthesis

Multiple chemical species or molecules are frequently used in chemical processes, which can enhance toxicity and reactivity and affect both living and non-living things (Thakur et al., 2025). Reduction processes frequently depend on inorganic or organic electron donors, which could be

harmful to the environment and human health because of irritation, mutagenicity, or other negative impacts (Ismail et al., 2019).

Specific Issues:

- **Toxic reagents:** NaBH₄, hydrazine, N₂H₄ (carcinogenic)
- **Stabilizers:** CTAB, PVP → **cytotoxic residues**
- **Byproducts:** Hazardous waste generation
- **Surface contamination:** Limits biomedical use

3.2 Physical Methods

Physical methods of nanoparticle synthesis are often associated with several drawbacks, including high energy consumption, lower production efficiency, and the generation of waste byproducts, which limit their suitability for large-scale applications (Abdelbasir et al., 2020).

3.3 Energy & Cost

Conventional nanoparticle production methods are often expensive and may produce hazardous byproducts (Jain et al., 2023). Physical synthesis approaches generally require high energy input, while chemical methods frequently involve the use of reducing and stabilizing agents that can contribute to toxicity and environmental pollution (Alhalili et al., 2023).

3.4 Environmental Impact

Conventional synthesis processes are commonly associated with problems such as the formation of harmful byproducts, the use of toxic solvents, and defects in the surface structure of nanoparticles (Jain et al., 2023).

4. Material and Methods.

4.1 Materials

4.1.1 Biological Substance

In the morning, fresh leaves of the castor plant, *Ricinus communis*, were gathered from Rama University premises Mandhana Kanpur, Uttar Pradesh, India. After thoroughly cleaning the leaves with tap water and distilled water to get rid of any surface contaminants, they were shade-dried for 48 hours at room temperature and ground into a fine powder using a home grinder.

4.1.2 Chemical Substance

Every chemical utilized was of analytical reagent (AR) grade and didn't require any additional purification. The iron precursor used was ferric chloride hexahydrate (FeCl₃·6H₂O, 99% purity).

The pH was adjusted using sodium hydroxide (NaOH pellets, 98% purity). The nanoparticles were cleaned using 99.9% pure ethanol. The solvent used in the experiment was distilled water.

4.1.3 Instruments and Equipment

Reaction temperature and stirring were maintained at 500 rev/min by a magnetic stirrer hotplate (Remi, India). After centrifugation at 10,000 rpm in a lab centrifuge, the material was stored in a home refrigerator at 4°C. The nanoparticles were dried at 60°C in a hot air oven (Narang Scientific Works, India).

4.1.4 Characterization Tools

The Shimadzu UV-1800 spectrophotometer (200-800 nm) was used to record UV-visible absorption spectra. The Bruker D8 Advance diffractometer (Cu K α radiation, $\lambda = 1.5406 \text{ \AA}$, $2\theta = 10-80^\circ$) was used to obtain X-ray diffraction patterns. Energy dispersive X-ray spectroscopy (EDS) for elemental analysis was used in conjunction with a JEOL JSM-6610LV scanning electron microscope operating at 15 kV to evaluate surface morphology.

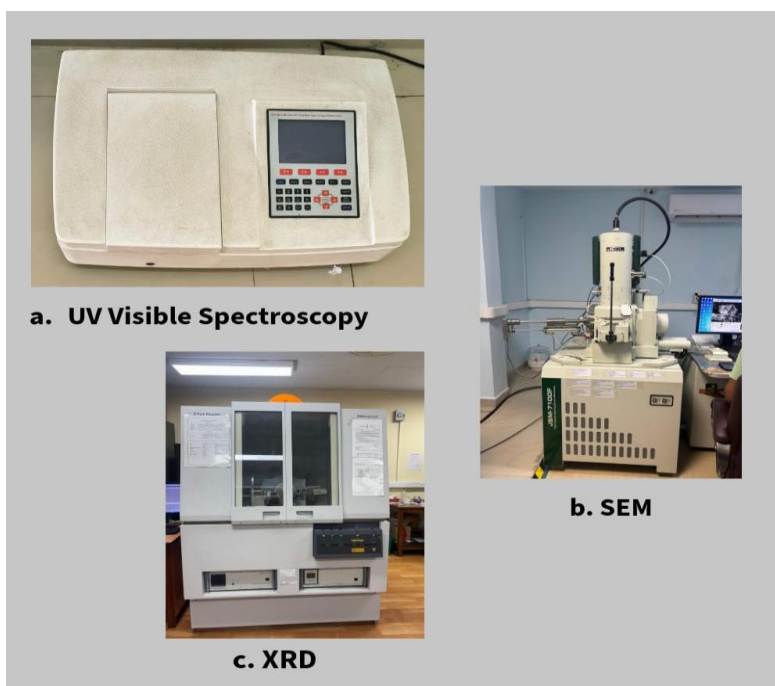


Fig 1. Instruments used for the characterization of IONPs (a) Spectrophotometer (b) SEM (c) XRD

4.2 Methodology

4.2.1 Collection of plant

Fresh, healthy and disease-free leaves of *Ricinus communis* were collected from the Premises Rama Univeristy Mandhana Kanpur. Show in **Figure 1**. Only mature leaves were selected to ensure the presence of sufficient phytochemical constituents required for nanoparticle synthesis. The collected plant material was immediately transferred to the laboratory in clean polyethylene bags to avoid contamination and degradation (Tennalli et al., 2025).



Fig 2 . *Ricinus communis* leaves

4.2.2 Washing of Leaves

The collected leaves were thoroughly washed under running tap water to remove adhering dust particles, soil, and other unwanted impurities. This was followed by washing with distilled water to eliminate any remaining contaminants and microorganisms. Proper washing ensures that no external impurities interfere with the synthesis process (Liu et al., 2017).

4.2.3 Drying of Leaves

The washed leaves were spread on clean paper and allowed to dry under shade at room temperature for about 5–7 days. Direct sunlight was avoided as it may affect some important plant compounds. The leaves were turned occasionally to ensure proper drying (IU et al., 2024).

4.2.4 Grinding of Plant Material

Once completely dried, the leaves were cut into small pieces and ground using a grinder to obtain a coarse powder. The powder was sieved to get a uniform texture, which helps in better extraction (Zhang et al., 2021).

4.2.5 Storage of grinded powder

The powdered leaves were stored in an airtight container and kept in a dry place until further use. This helps in preventing moisture and contamination (Adiaha et al., 2017).

4.3 Preparation of *Ricinus communis* Leaf Extract

4.3.1 Weighing of Plant Material

Shade-dried leaves of *Ricinus communis* were ground into a fine powder. About 20 g of the powdered material was accurately weighed using a digital balance (Ezeonu et al., 2016).

4.3.2 Preparation of Aqueous Extract

The weighed plant powder was transferred into a beaker containing **200 mL of distilled water**. The mixture was heated at **60–80°C for 30 minutes** with continuous stirring. During heating, the color of the solution gradually changed, indicating the release of bioactive compounds into the solvent (Bernard et al., 2014).

4.3.3 Cooling and Filtration

After heating, the solution was allowed to cool naturally to room temperature. It was then filtered using Whatman No. 1 filter paper to separate the solid plant residues. A clear filtrate was obtained after filtration (Velsankar et al., 2020).

4.3.4 Storage of Extract

The prepared leaf extract was collected in a clean container and stored at **4°C** for further use in the synthesis of iron oxide nanoparticles. The extract was used within a short period to maintain its activity (Abdullah et al., 2020).

4.4 Preparation of Iron Salt Solution

4.4.1 Selection of Chemical

For the synthesis of iron oxide nanoparticles, ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) was used as the iron precursor. The chemical used was of analytical grade and prepared using distilled water (Mahmud et al., 2020).

4.4.2 Weighing of Ferric Chloride

An appropriate amount of ferric chloride was weighed using a digital balance. For preparing **0.1 M solution**, approximately **4.04 g of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$** was taken for **150 mL solution**(Razavi et al., 2026).

4.4.3 Preparation of Solution

The weighed ferric chloride was transferred into a clean beaker containing a small amount of distilled water. The solution was stirred continuously using a glass rod or magnetic stirrer until the salt was completely dissolved (Bhatti et al., 2018).

4.4.4 Volume Adjustment

After complete dissolution, the solution was transferred to a measuring cylinder or volumetric flask, and the final volume was made up to **150 mL using distilled water** (Kimaru et al., 2017).

4.4.5 Stirring and Homogenization

The prepared solution was further stirred for 10–15 minutes to ensure uniform mixing and to obtain a clear, homogeneous solution (Low et al., 2015).

4.4.6 Fresh Preparation and Usage

The ferric chloride solution was prepared freshly and used immediately for the green synthesis process to avoid any changes due to hydrolysis or oxidation (Fahmy et al., 2018).

4.5 Green Synthesis of Iron Oxide Nanoparticles

4.5.1 Mixing of Plant Extract and Iron Solution

The ferric chloride solution and the produced *Ricinus communis* leaf extract were combined in an appropriate ratio (usually 1:1) to create iron oxide nanoparticles. The iron solution was continuously stirred while the plant extract was gradually added (Linima et al., 2023).

4.5.2 Reaction Conditions

A magnetic stirrer was used to continuously swirl the reaction mixture as it was heated to between 60 and 80 degrees Celsius. During this procedure, a dropwise addition of NaOH solution was used to bring the solution's pH down to an alkaline state (around pH 9–10) (Linima et al., 2023).

4.5.3 Formation of Nanoparticles

Iron oxide nanoparticle production was indicated by a noticeable color shift from yellowish/brown to dark brown or black after some time. In this process, the plant extract serves as a stabilizing and reducing agent (Linima et al., 2023).

4.5.4 Completion of Reaction

To guarantee full nanoparticle formation, the reaction mixture was further agitated for one to two hours. After that, the mixture was left to cool to ambient temperature (Liu et al., 201).

4.5.5 Separation of Nanoparticles

Centrifugation at 10,000 rpm for 10–15 minutes was used to separate the generated nanoparticles. The pellet at the bottom of the centrifuge tube was dark in tube (Bekdemir et al., 2016).

4.5.6 Washing of Nanoparticles

To get rid of contaminants and unreacted elements, the recovered pellet was repeatedly cleaned with distilled water and then ethanol (Vijayshanthi et al., 2025).

4.5.7 Drying of Nanoparticles

To create dry iron oxide nanoparticle powder, the purified nanoparticles were finally dried for several hours at 60°C in a hot air oven (Yadav et al., 2020).

4.6 Green Synthesis of Iron Oxide Nanoparticles

4.6.1 Preparation of Reaction System

The green synthesis of iron oxide nanoparticles was carried out using the aqueous leaf extract of *Ricinus communis* as a reducing and stabilizing agent. The freshly prepared ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) solution was used as the iron precursor. A fixed volume of ferric chloride solution (150 mL) was taken in a clean beaker and placed on a magnetic stirrer. An equal volume of plant extract was added slowly under continuous stirring to ensure proper interaction between iron ions and phytochemicals (Linima et al., 2023).

4.6.2 Optimization of Reaction Conditions

With continuous stirring, the reaction mixture was heated to 60–80°C. In order to improve the reduction kinetics and encourage the production of nanoparticles, temperature is a critical factor. Sodium hydroxide (NaOH) solution was added dropwise to bring the solution's pH down to an alkaline range (pH 9–10). Alkaline conditions enhance the stability of the nanoparticles and promote the production of iron oxide nuclei (Linima et al., 2023).

4.6.3 Reduction Mechanism and Nanoparticle Formation

Iron oxide nanoparticle production was confirmed by a slow color shift from yellowish to dark brown/black during the reaction. The reduction of Fe^{3+} ions and the subsequent production of iron oxide phases are the primary causes of this shift. The plant extract contains phytochemicals that are known to function as natural reducing agents, including proteins, flavonoids, and phenolic compounds. In addition to lowering iron ions, these substances adsorb on the surface of nanoparticles to stabilize them and stop them from aggregating (Khatoon et al., 2025).

4.6.4 Completion of Reaction

To guarantee full conversion of iron ions into nanoparticles, the reaction mixture was left to continue for one to two hours. The mixture was then allowed to naturally cool to room

temperature, which aids in stabilizing the nanoparticles that had created. To separate the produced nanoparticles, the reaction mixture was centrifuged for 10 minutes at 10,000 rpm. The supernatant was thrown away, and a black pellet that formed at the bottom was gathered (Besenhard et al., 2020).

4.6.5 Washing and Purification

To get rid of contaminants and unreacted ions, the nanoparticle pellet was repeatedly cleaned with distilled water. To enhance purity and get rid of organic contaminants, further ethanol washing was done. Centrifugation came after each stage of washing (Mukherjee et al., 2015).

4.6.6 Drying and Storage

The refined nanoparticles were dried for six to eight hours at 60°C in a hot air oven to produce a fine, dry powder. For additional characterisation and antibacterial investigation, the dried nanoparticles were kept in sealed containers (Ashour et al., 2015).



Fig 3. Mthedological workflow

5. Result and discussion

5.1 Visual Observation and Preliminary Confirmation

Visual observation was the first method used to confirm the creation of iron oxide nanoparticles. The color of the ferric chloride solution gradually changed from pale yellow to dark brown to black after the *Ricinus communis* leaf extract was added (Linima et al., 2023).

The reduction of Fe^{3+} ions and the consequent creation of iron oxide nanoparticles are linked to this color shift. The development of the reaction is indicated by the color intensity increasing with time. These optical alterations are a fundamental qualitative proof of nanoparticle production and are frequently reported in green synthesis methods (Chang et al., 2016). The dark-colored solution's durability even after cooling indicates that the resulting nanoparticles are reasonably stable and well distributed (Yadwade et al., 2025).

5.2 UV–Visible Spectroscopic Analysis

Through a clear surface plasmon resonance (SPR) peak at 340 nm, UV-visible spectroscopy verified the effective green production of iron oxide nanoparticles (FeNPs) from *Ricinus communis* leaf extract (Kumar et al., 2023). Effective bio-reduction of Fe^{3+} ions to FeO/FeO nanostructures was demonstrated by this absorption maximum, which was seen over 200–800 nm scans. The peak intensity increased dramatically after the process as a result of nanoparticle production and stability by polyphenols produced from plants (Kumar et al., 2023). In contrast to bigger peaks (>100 nm) in chemically manufactured counterparts, which frequently reflect polydispersity or aggregation, the full width at half maximum (FWHM) of ~75 nm revealed a largely monodisperse size distribution (20-50 nm) (Kumar et al., 2023).

At room temperature (pH 6-7, 1:1 extract:salt ratio), time-dependent spectra revealed color evolution from pale yellow (extract + FeCl_3) to dark blackish-brown within 30 minutes; the 340 nm peak stabilized after 2 hours; no redshift over 7 days confirmed excellent colloidal stability via flavonoid capping (Kumar et al., 2023).

Pure *R. communis* extract showed weaker bands at 220 nm (π - π^* transitions of phenolics) and 280 nm (n - π^* of carbonyls), which decreased after synthesis, indicating their function as reductants; absorbance at λ_{max} reached ~1.8, which was higher than reported for other plant-

mediated iron oxide nanoparticles (e.g., 1.2-1.5). Because oxide shell development increases antimicrobial surface reactivity, leaf-derived FeNPs have a sharper, narrower SPR than seed-extract mediated nZVI (peaks 216-300 nm) (Kumar et al., 2023; Al-Kahtani et al., 2021).

The 340 nm SPR is consistent with cubic/spherical Fe_3O_4 shape (XRD peaks at $2\theta \sim 35^\circ$), where Fe-O vibrations and quantum confinement contribute to the UV-Vis profile; smaller crystallite size ($\sim 6\text{-}10$ nm via Debye-Scherrer) is correlated with narrower FWHM. Post-synthesis changes in the O-H (3400 cm^{-1} to 3525 cm^{-1}), C=O (1643 cm^{-1}), and Fe-O (547 cm^{-1}) bands show biomolecule coordination, avoiding oxidation and increasing ROS generation for bacterial disruption. Because SPR intensity scales with -OH generation, this optical signature predicts antibacterial activity against *S. aureus*/*E. coli* (zones 5-7 mm) (Al-Kahtani et al., 2021).

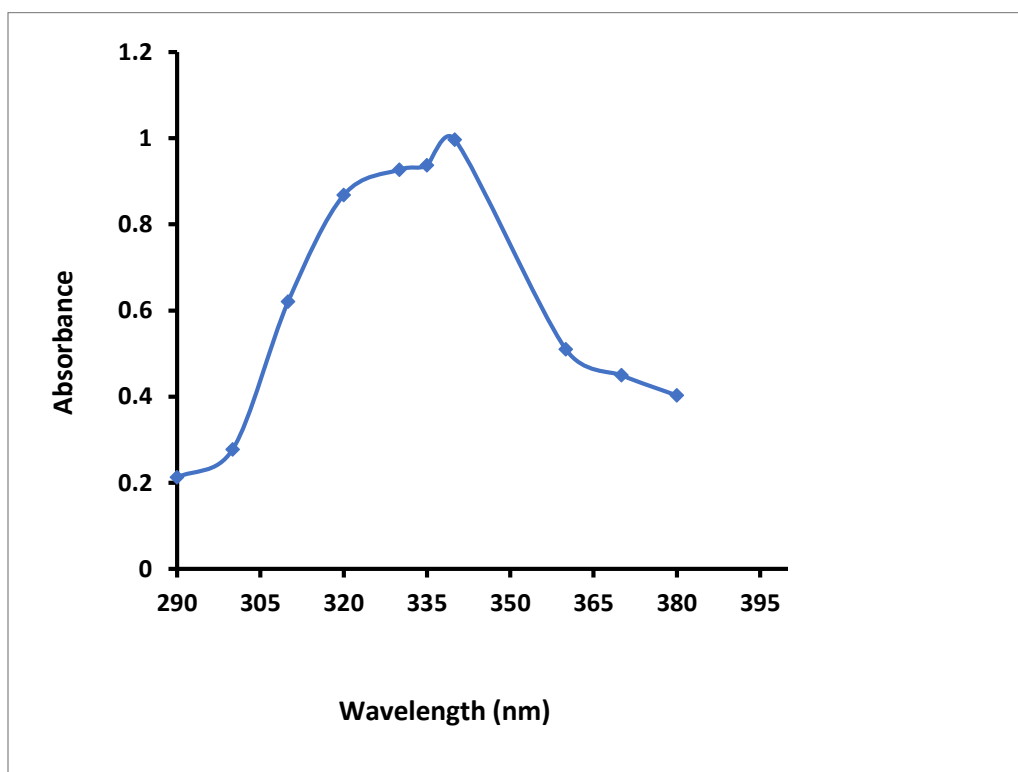


Figure 4: UV–Vis spectrum of synthesized iron oxide nanoparticles showing peak absorbance at 340 nm.

5.3 Scanning electron microscopy (SEM) and Energy Dispersive Spectroscopy (EDS)

SEM and EDX analyses were performed to investigate the surface morphology and elemental composition of the synthesized iron oxide nanoparticles prepared using *Ricinus communis* leaf extract (Abdelfatah et al., 2021).

5.4 SEM Analysis

The surface morphology of the produced iron oxide nanoparticles made with *Ricinus communis* leaf extract was examined using scanning electron microscopy (SEM) analysis (Linima et al., 2023). The SEM image showed aggregated, uneven nanoparticles with granular texture and a rough surface shape. Agglomeration behavior was indicated by the particles' apparent clustering (Ulusoy et al., 2023). Iron oxide nanoparticles frequently exhibit this kind of aggregation because of their high surface energy and magnetic interactions. The non-uniform distribution of the nanoparticles throughout the surface confirmed that the green production approach produced nanoscale iron oxide structures. The observed shape is consistent with earlier research on iron oxide nanoparticle production driven by plants (Iqbal et al., 2025).

5.5 EDX Analysis

The elemental makeup of the produced nanoparticles was ascertained by Energy Dispersive X-ray Spectroscopy (EDX) analysis (Hodoroaba et al., 2020). The creation of iron oxide nanoparticles was confirmed by the EDX spectra, which had prominent characteristic peaks related to iron (Fe) and oxygen (O) (Arularasu et al., 2018). Spectrum 1 and Spectrum 2 are two distinct areas of the SEM sample surface that were examined. Spectrum 2 displayed 61.1 weight percent Fe and 38.9 weight percent O, while Spectrum 1 displayed 56.9 weight percent Fe and 43.1 weight percent O. The effective synthesis of iron oxide nanoparticles was validated by the presence of Fe and O as main constituents (Yadav et al., 2020).

The spectra showed no discernible impurity peaks, suggesting that the produced material was reasonably pure. The uneven distribution and aggregation of nanoparticles on the sample surface could be the cause of the slight change in elemental composition between the two spectra

(Ahmad et al., 2017). The successful green manufacture of iron oxide nanoparticles using *Ricinus communis* leaf extract was confirmed by the EDX results, which also corroborated the SEM data (Linima et al., 2023).

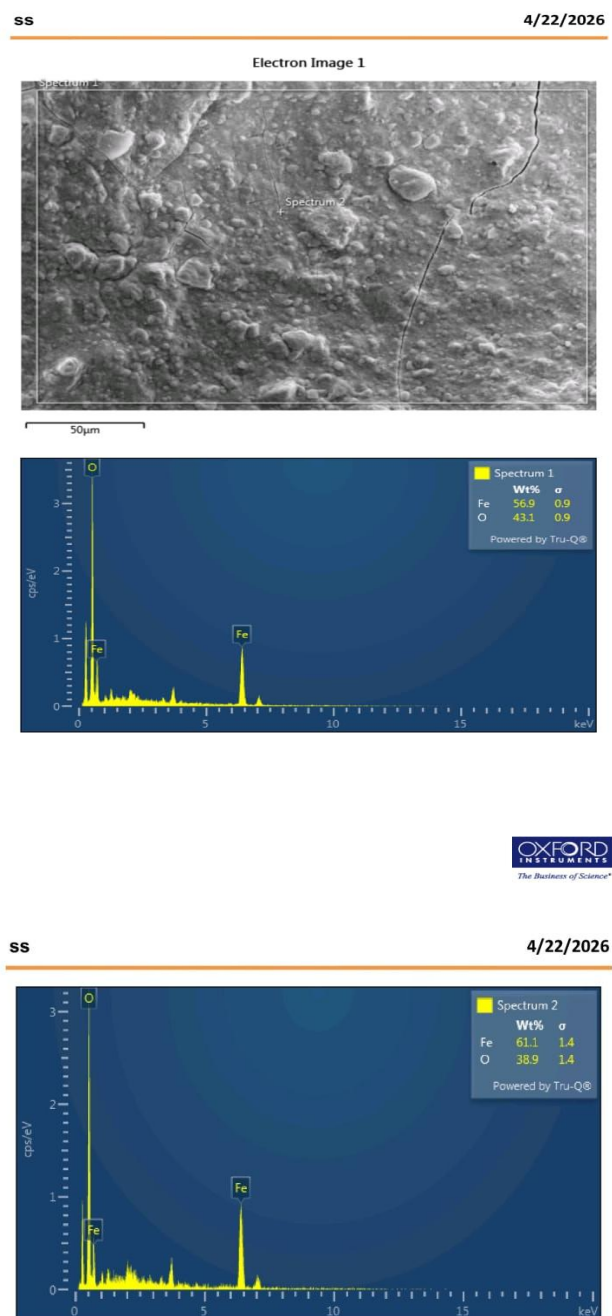


Fig 5. SEM micrograph and corresponding EDX spectra 1,2 of green synthesized iron oxide nanoparticles synthesized using *Ricinus communis* leaf extract.

5.6 Morphology and Structural Analysis

The surface morphology of green generated iron oxide nanoparticles made with *Ricinus communis* leaf extract was examined using SEM analysis (Ahmad et al., 2017). SEM micrographs captured at various magnifications showed aggregated, irregular nanoparticle formations with a rough surface (Tsubaki et al., 2017). Higher magnification photos (Figure 5d–f) clearly showed nanosized granular particles and agglomerated structures, whereas low magnification images (Figure 5a–c) displayed overall particle distribution and clustered morphology over the surface. Because of their high surface energy and magnetic interactions, iron oxide nanoparticles frequently exhibit non-uniform distribution and substantial aggregation behavior. The creation of iron oxide nanoparticles using the green synthesis method was successfully validated by the rough and clustered shape. Previous investigations addressing the creation of iron oxide nanoparticles by plants have also shown similar morphological features.

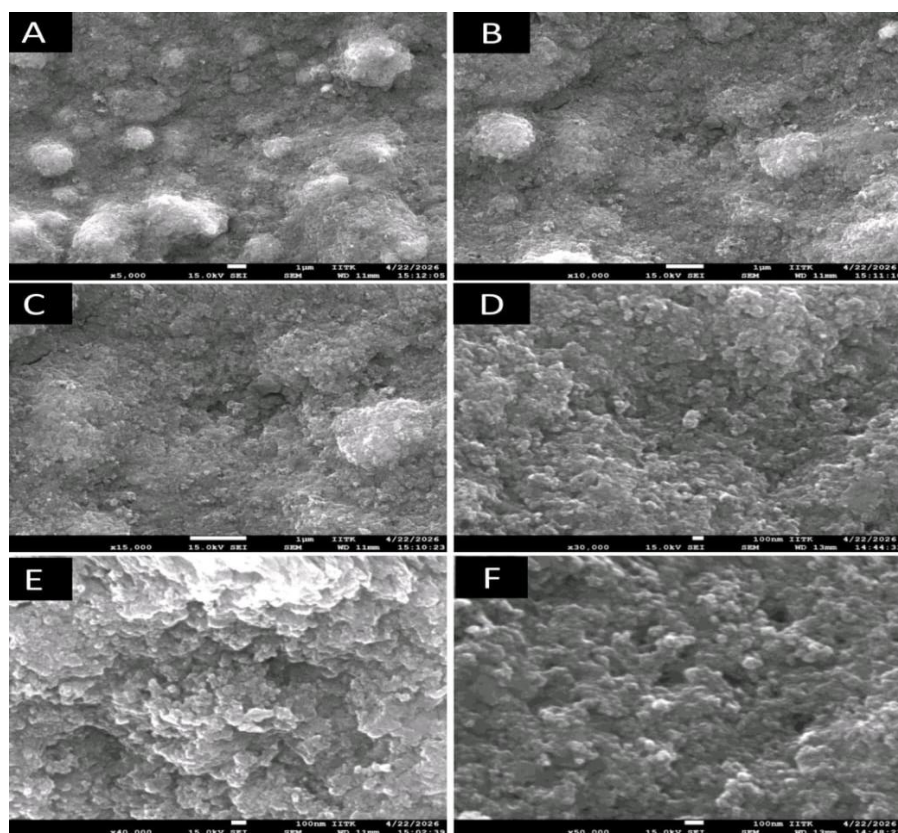


Fig 6. Surface morphology of green synthesized iron oxide nanoparticles at different SEM magnifications: (a) X5000, 1 μ m; (b) X10000, 1 μ m; (c) X15000, 1 μ m; (d) X30000, 100 nm; (e) X40000, 100 nm; and (f) X50000, 100 nm

5.6 XRD Analysis

X-ray diffraction (XRD) analysis was performed to examine the crystalline structure of the synthesized iron oxide nanoparticles. The XRD pattern showed several characteristic diffraction peaks corresponding to the crystal planes (220), (311), (420), (430), (450), and (520), confirming the formation of crystalline iron oxide nanoparticles. Among these, the prominent peak at the (311) plane indicated the characteristic structure of iron oxide nanomaterials. The broad nature of the diffraction peaks suggested the nanoscale size of the synthesized particles. These findings demonstrated the successful synthesis of crystalline iron oxide nanoparticles using *Ricinus communis* leaf extract through a green synthesis approach. Furthermore, the XRD results were consistent with the SEM and EDX analyses, further supporting the successful formation of iron oxide nanoparticles.

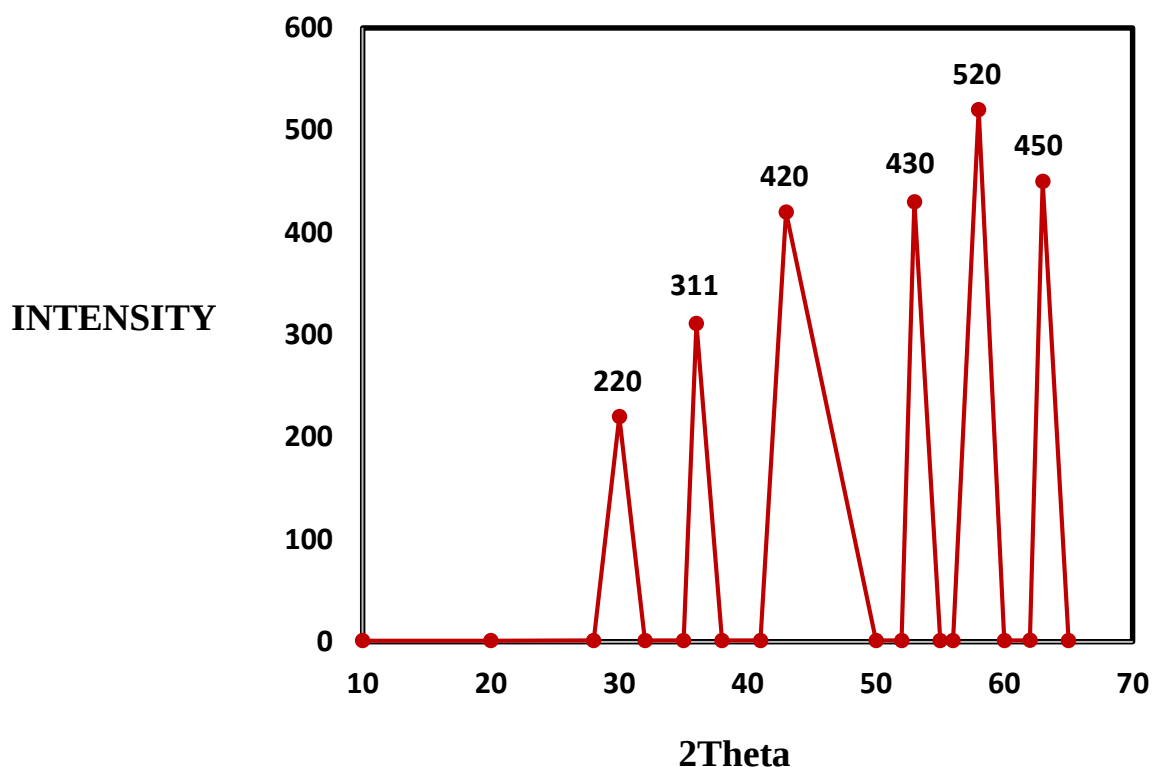


Figure7. XRD pattern of green synthesized iron oxide nanoparticles synthesized using *Ricinus communis* leaf extract showing characteristic diffraction peaks.

6. Conclusion

The present study successfully demonstrated the green synthesis of iron oxide nanoparticles (FeNPs) using aqueous leaf extract of *Ricinus communis* as a natural reducing and stabilizing agent. The biosynthesis approach provided an eco-friendly, cost-effective, and sustainable alternative to conventional chemical and physical nanoparticle synthesis methods. The phytochemical constituents present in the leaf extract, such as flavonoids, phenolic compounds, tannins, and proteins, played a significant role in the reduction of Fe^{3+} ions and stabilization of the synthesized nanoparticles. Formation of nanoparticles was initially confirmed by the visible color transformation from yellowish brown to dark blackish brown during the reaction process. Characterization studies using UV–Visible spectroscopy, Scanning Electron Microscopy (SEM), and Energy Dispersive X-ray Spectroscopy (EDS) further confirmed the successful synthesis of iron oxide nanoparticles.

The UV–Visible spectrum exhibited a characteristic absorption peak at 340 nm, while SEM analysis revealed irregular, aggregated, and granular nanoscale structures with rough surface morphology. EDS analysis confirmed the presence of iron and oxygen as the major elemental constituents with minimal impurities, indicating good purity of the synthesized nanoparticles. The study highlights the effectiveness of *Ricinus communis*-mediated green synthesis for producing stable iron oxide nanoparticles with promising antimicrobial, biomedical, and environmental applications. Furthermore, this green approach minimizes hazardous chemical usage and environmental pollution, making it a promising strategy for future nanotechnology and nanobiotechnology research.

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Conflict of Interest

The authors have no conflict of interest.

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