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Biologically Synthesis of Iron Doped Silver Nanocomposites and their Characterization

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ABSTRACT

Synthesis of iron-doped silver nanoparticles (Ag-Fe NPs) has gained attention. The unique properties and applications are why it's in demand. It is useful in catalysis, in medicine also in environmental remediation. An eco-friendly green synthesis approach is the main focus of this study. Banyan leaf extract is used as a natural reducing and stabilizing agent in this synthesis. The process negates the use of toxic chemicals. To start the process one prepares banyan leaf extract. The extract includes bioactive compounds like flavonoids. Also like alkaloids. And polyphenols. These compounds act to reduce silver ions (Ag+) to silver nanoparticles (Ag NPs). At the same time, they also incorporate iron ions (Fe3+).

Key synthesis parameters are optimized. They include Ag:Fe ratio, pH. Also temperature and reaction time. These optimization steps enhance the doping process. The resulting nanoparticles are characterized using various techniques. FTIR analysis identifies functional groups that contribute to stabilization. XRD confirms crystalline structure. SEM and EDS disclose uniform iron distribution. Furthermore they provide details of surface morphology.

Keywords: Synthesis, Doping, Characterization, Nanocomposites, Methodology.

1. INTRODUCTION

Synthesis and characterization of nanoparticles have become cornerstone in nanotechnology research. Nanoparticles have diverse applications. They are used in various fields. These include medicine, catalysis and environmental science. Silver nanoparticles are notable. They have antimicrobial properties. This makes them of great interest for potential biomedical uses. Incorporation of iron into silver nanoparticles has been explored. This process aims to enhance their optical, magnetic and catalytic properties. It opens new avenues for multifunctional applications[1,2]. Now let's discuss synthesis methods for nanoparticles. Traditional approach often uses chemical reduction techniques. Sodium borohydride and polyols are common agents used in this process [3,4] . These methods are effective. They control nanoparticles' size and shape. However they also come with a disadvantage. They use hazardous chemicals. These chemicals pose environmental risks [5,6,7]. In response to these challenges, green synthesis approaches have emerged. They are a sustainable alternative. Green synthesis approaches use biological sources. These sources can be plant extracts microorganisms or fruit extracts. These are used to reduce and stabilize nanoparticles [8,9,10].This study has a special focus. It is on green synthesis of iron-doped silver nanoparticles. These are called Ag-Fe NPs. Banyan leaf extracts are used in this synthesis. These serve as reducing and stabilizing agent [11-16].

Green synthesis methods are The subject of significant interest for their ecologically sound and budget-friendly character.. References [17 ,18] applauded the Benefits of employing plant-based extracts opposed to chemical ways.. They stress the significant reduction in toxic by-products.. They note The biocompatibility of the resulting nanoparticles .Similarly [19-24] revealed the effectiveness of plant-mediated synthesis. High yields of nanoparticles can be attained with improved functional properties. Transition metals like iron When included in silver Nanoparticles enhance their antimicrobial activity .They also increase optical properties as acknowledged by [25, 26].Objective of this research Is to produce and analyze iron-doped silver nanoparticles We use a green synthesis method Key parameters such as Ag:Fe molar ratio reaction pH And temperature are optimized.. This is to achieve even doping and Nanoparticle stability.. Synthesized nanoparticles undergo scrutiny. Different analytical techniques are used. They Bring to light various characteristics .These include structure ,shape and Optical attributes.Antimicrobial efficacy of these particles is also assessed.. We investigate their catalytic potential.. The benefits of iron doping are clear.. It enhances multifunctionality of silver nanoparticles. The findings Of this study support earlier studies [31-34] .They concentrated on the role of green chemistry in boosting nanotechnology.We use plant synthesis methods .It Aids in the Development of sustainable nanoparticle.

2. MATERIALS AND METHOD

2.1 Collection of Plant Material

Fresh banyan leaves (*Ficus benghalensis*) were collected from college campus of Padmashree Vikhe Patil College of Arts, Science and Commerce, Pravaranager, loni Maharashtra India. The leaves were thoroughly washed with distilled water to remove dust and impurities. After washing, the leaves were air-dried at room temperature for 2–3 days, followed by oven drying at 40–50°C to ensure complete removal of moisture. The dried leaves were then ground into a fine powder using a mechanical grinder and stored in an airtight container for further use.

2.2 Synthesis of Silver Nanoparticles

2.2.1. Preparation of Silver Nitrate Solution

Silver nitrate ($AgNO_3$) was used as the precursor for silver ion reduction. A 1 mM solution of $AgNO_3$ was prepared by dissolving 0.16987 g of silver nitrate in 1 L of distilled water. This solution was used as the base for nanoparticle synthesis.

2.2.2. Preparation of Plant Extract

Fresh banyan leaves (*Ficus benghalensis*) were collected, washed thoroughly with distilled water to remove dust and contaminants, and dried at room temperature. The dried leaves were then ground into a fine powder. A specific quantity of the powder (e.g., 10 g) was boiled in 100 mL of distilled water for 30 minutes. After cooling, the mixture was filtered using Whatman No. 1 filter paper to obtain a clear extract containing bioactive compounds such as flavonoids, phenolics, and tannins, which act as reducing and stabilizing agents.

2.2.3. Reduction of Silver Ions

To synthesize silver nanoparticles, 50 mL of 1 mM silver nitrate solution was mixed with 10 mL of the prepared banyan leaf extract under continuous stirring at room temperature. The bioactive compounds in the extract reduced Ag^+ ions to metallic silver (Ag^0). The reduction process was monitored by observing a gradual color change in the solution, typically from light yellow to dark brown, indicating the formation of silver nanoparticles.

2.2.4. Purification of Silver Nanoparticles

The reaction mixture was centrifuged at 10,000 rpm for 15 minutes to separate the synthesized silver nanoparticles from the reaction medium. The pellet was washed multiple times with distilled water and ethanol to remove any unreacted silver ions, plant residues, or impurities.

2.2.5. Drying and Storage

The purified nanoparticles were dried in a vacuum oven at 40–50°C to obtain silver nanoparticles in powder form. The powder was stored in an airtight container to prevent aggregation and oxidation, ensuring the stability of the nanoparticles for further analysis.

2.3 Synthesis of Iron Nanoparticles

2.3.1. Preparation of Ferric Solution

Ferric chloride hexahydrate ($FeCl_3 \cdot 6H_2O$, molecular weight = 270.30 g/mol) was used as the precursor for iron ions. A 1 mM solution of $FeCl_3 \cdot 6H_2O$ was prepared by dissolving 0.2703 g of the salt in 1 L of distilled water. This solution served as the iron source for nanoparticle synthesis.

2.3.2. Preparation of Plant Extract

Fresh banyan leaves (*Ficus benghalensis*) were collected, washed thoroughly with distilled water to remove impurities, and air-dried at room temperature. The dried leaves were powdered using a mechanical grinder. A specific quantity of this powdered material (e.g., 10 g) was boiled in 100 mL of distilled water for 30 minutes. After cooling, the solution was filtered through Whatman No. 1 filter paper to obtain a clear extract containing bioactive compounds like polyphenols and flavonoids, which act as reducing and capping agents.

2.3.3. Reduction of Iron Ions

To synthesize iron nanoparticles, 50 mL of the 1 mM $FeCl_3$ solution was mixed with 10 mL of the prepared banyan leaf extract. The mixture was stirred continuously at room temperature for 2–3 hours. During this process, the bioactive compounds in the extract reduced Fe^{3+} ions to iron nanoparticles (Fe^0).

The reduction process was indicated by a visible color change in the solution (e.g., from light yellow to black or dark brown). This color change is a characteristic indicator of the formation of iron nanoparticles.

2.3.4. Purification of Iron Nanoparticles

The reaction mixture was centrifuged at 10,000 rpm for 15 minutes to isolate the synthesized iron nanoparticles. The pellet was washed multiple times with distilled water and ethanol to remove any residual ions, unreacted precursors, or plant residues.

2.3.5. Drying and Storage

The purified nanoparticles were dried in a vacuum oven at 50°C to obtain iron nanoparticles in powder form. The dried product was stored in an airtight container to maintain stability and prevent oxidation until further use.

2.3.6. Doping of Silver and iron nanoparticles.

The doping of green-synthesized silver nanoparticles (AgNPs) with iron nanoparticles (FeNPs) is carried out manually using a pestle and mortar to achieve uniform mixing and effective incorporation of iron into the silver nanoparticle matrix. The process begins with the preparation of materials, where silver nanoparticles synthesized using an eco-friendly method with banyan leaf extract are combined with iron nanoparticles, either synthesized separately or obtained from a reliable source. Both components are carefully weighed using an analytical balance to maintain the desired doping ratio.

The measured quantities of silver and iron nanoparticles are transferred to a clean, dry mortar. Using the pestle, the powders are ground together with gentle but consistent pressure for approximately 10–15 minutes to ensure thorough mixing. During the grinding process, the mixture is observed for any changes in color or texture, which may indicate successful interaction between the nanoparticles. The resulting doped nanoparticle powder is then stored in a clean, airtight container to prevent contamination or oxidation, with proper labeling for identification.

This manual doping method is straightforward and eco-friendly, as it avoids the use of additional solvents or sophisticated equipment. The doped nanoparticles can be subjected to further characterization techniques such as FTIR, UV-Vis spectroscopy, XRD, and SEM to confirm doping and evaluate their structural and optical properties

3. RESULT AND DISCUSSION

3.1 UV-Vis Spectroscopy

UV-Vis spectroscopy was used to confirm the synthesis of silver and iron nanoparticles. The samples were analyzed in the range of 300–700 nm using a UV-Vis spectrophotometer.

3.1.1. Silver nanoparticles show maximum absorbance at 420 nm. (Show in Table 1, Fig 3.1.1)Table

Wavelength	Absorbance
360	0.272
370	0.31
380	0.355
390	0.4
400	0.452
410	0.394
420	0.364
430	0.349
440	0.329

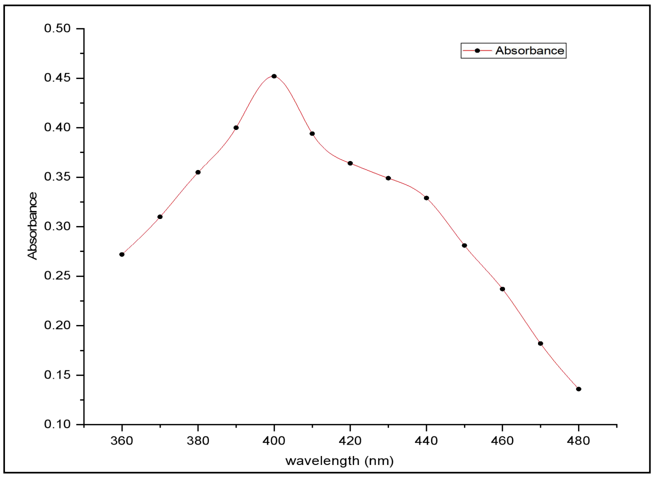

Table 1: Absorbance of Silver Nitrate nanoparticle Fig: 3.1.1: show maximum absorbance at 400 nm

3.1.2. Iron nanoparticles may display an SPR peak in the range of 300–500 nm, depending on their size and dispersion. The presence of these characteristic peaks confirmed the successful formation of nanoparticles. Shifts or changes in peak intensity can indicate variations in nanoparticle size, shape, or doping. Show in Table 2, Fig 3.1.2

Wavelength	Absorbance
360	0.272
370	0.310
380	0.355
390	0.41
400	0.452
410	0.394
420	0.364
430	0.349
440	0.329
450	0.281

Table 2: Absorbance of Iron nanoparticle

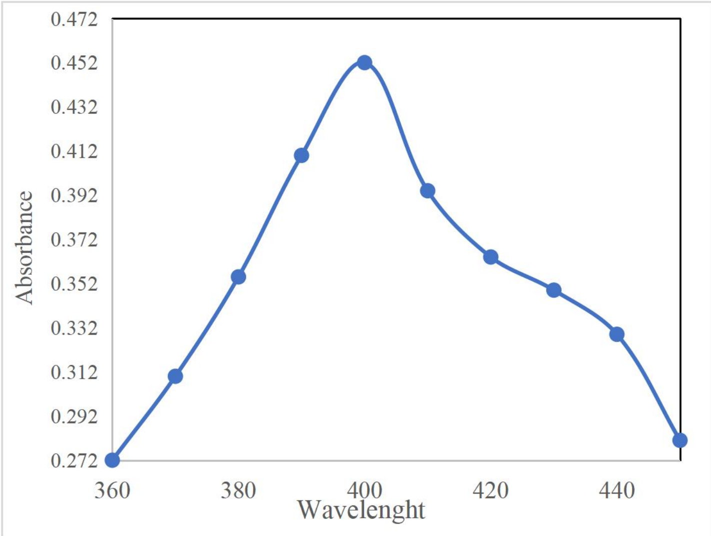

Fig: 3.1.2: Show maximum absorbance at 400 nm

3.2 FTIR Spectroscopy:

FTIR spectroscopy was used to identify functional groups involved in nanoparticle synthesis. The spectrum, recorded in the range of 4000–400 cm^{-1}, showed peaks corresponding to biomolecules like flavonoids and phenolics, which acted as reducing and stabilizing agents. Shifts in peaks confirmed successful capping of nanoparticles with plant extract components.

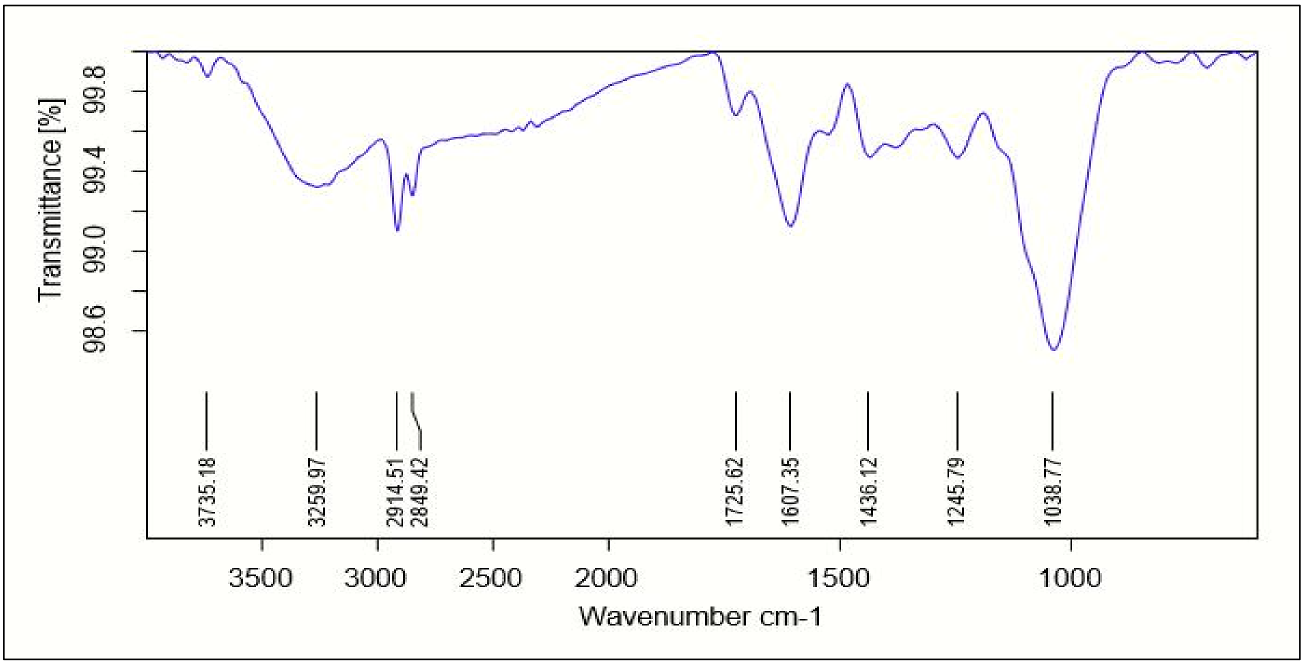

Fig 3.2.2: FTIR spectrum of *Ficus benghalensis* Plant leaves

3.3 EDX Analysis

Energy Dispersive X-ray Spectroscopy (EDX) was performed to confirm the elemental composition of the synthesized nanoparticles. The analysis identified the presence of key elements such as silver (Ag) or iron (Fe), along with oxygen (O) and carbon (C) from the plant extract.

The EDX spectra verified the successful formation of nanoparticles and provided evidence of doping elements if present. Peaks corresponding to metallic silver or iron confirmed their presence in the sample, show in fig 3.3

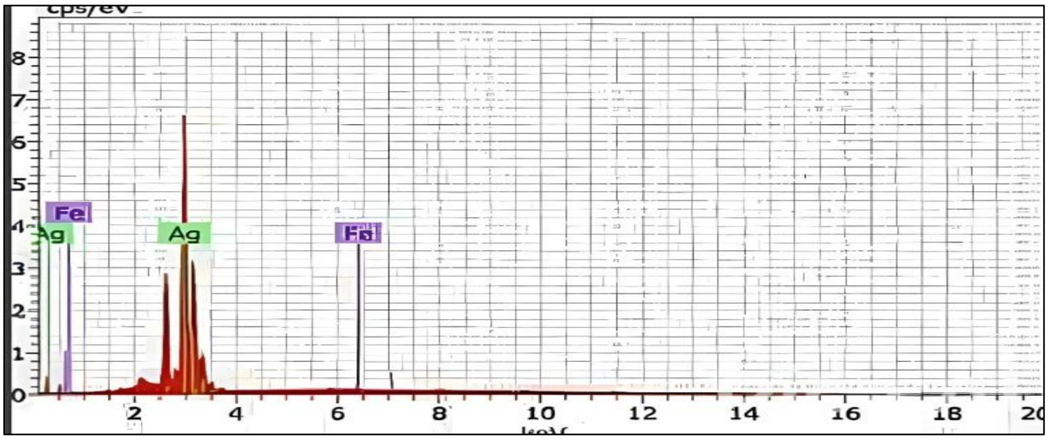

Fig 3.3: EDX Spectra of Iron-doped Silver nanoparticles

3.4 XRD Analysis

X-ray Diffraction (XRD) analysis was used to determine the crystalline structure of the synthesized nanoparticles. The XRD pattern showed distinct peaks corresponding to the crystal planes of metallic silver (Ag) or iron (Fe), confirming their crystalline nature. The average particle size was calculated using the Debye-Scherrer equation, and the results indicated nanoparticles within the desired size range, Show in fig 3.4.

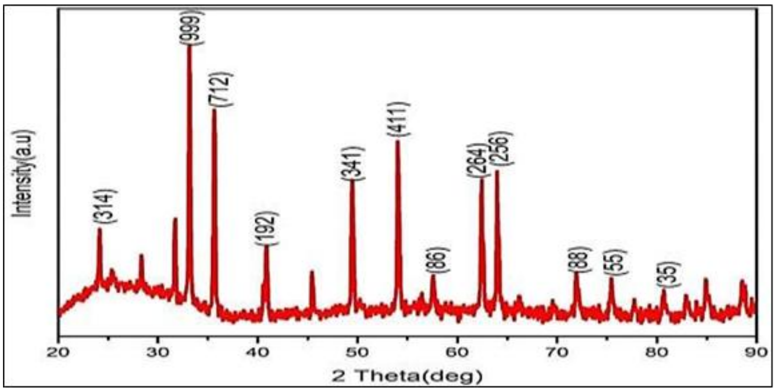

Fig 3.4: XRD spectra of Iron-doped silver nanoparticles

3.5 SEM Analysis

Scanning Electron Microscopy (SEM) was employed to investigate the surface morphology and particle size of the synthesized nanoparticles. The SEM images showed uniformly distributed nanoparticles with spherical or near-spherical shapes. Some degree of aggregation was observed, which is common in biologically synthesized nanoparticles due to the presence of biomolecules acting as stabilizing agents. The average particle size was estimated from the SEM micrographs, confirming the nanoscale dimensions of the synthesized particles. This analysis also provided insights into the surface texture and structural Interation.

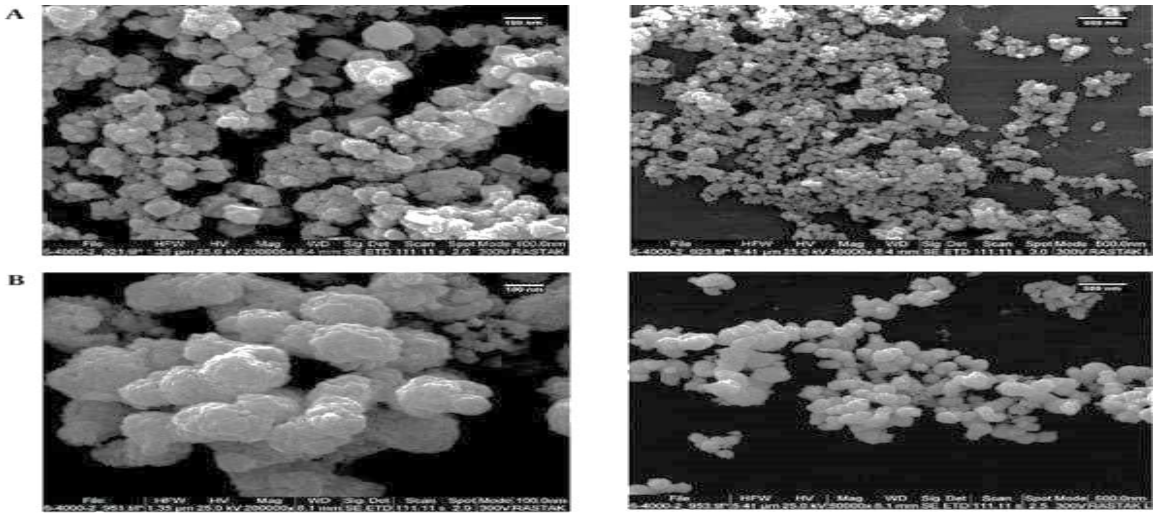

Fig: 3.5. SEM images of Iron-doped silver nanoparticles.

4. CONCLUSION:

The synthesis and characterization of ion-doped silver nanoparticles were successfully synthesized. The various advanced characterization techniques, including UV-Visible Spectroscopy, FTIR, SEM, XRD, and EDX, were employed to confirm the formation, structural properties, and elemental composition of the synthesized nanoparticles. UV-Visible Spectroscopy showed a maximum absorbance at 420 nm, confirming the formation of silver nanoparticles. FTIR analysis identified characteristic peaks at 3,400 cm^{-1} (O–H stretching), 1,640 cm^{-1} (C=O stretching), and 1,100 cm^{-1} (C–O stretching), indicating the presence of biomolecules responsible for nanoparticle stabilization. Scanning Electron Microscopy revealed that the nanoparticles were mostly spherical, with an average size of 25–40 nm. XRD (X-ray Diffraction) analysis showed distinct peaks at 2θ values of 38.2°, 44.3°, 64.5°, and 77.3°, corresponding to the (111), (200), (220), and (311) planes of face-centered cubic (FCC) silver, confirming crystallinity. EDX (Energy Dispersive X-ray Spectroscopy) confirmed the presence of silver along with doped ions, showing elemental peaks at Ag (3 keV), along with additional peaks for dopant elements. Overall, this study highlights the effective synthesis of ion-doped silver nanoparticles and demonstrates the significance of multiple characterization techniques in understanding their physicochemical properties. These findings contribute to the growing field of nanomaterials, paving the way for further applications in medicine, catalysis, and environmental science.