

One-Pot Facile Green Synthesis of Iron Oxide Nanoparticles Using Aqueous Stem Extract of *Amaranthus Campestris* and Comparison of its Characteristics with Chemically Synthesized Iron Oxide Nanoparticles

D Hazel

Anna University, Chennai

N Gobi (✉ gobsnn@gmail.com)

Anna University, Chennai

Research Article

Keywords: Nanoparticles, non toxicity, plant extract, cost effective, microorganism

Posted Date: November 2nd, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-2213450/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Nanomaterial is defined as a material with the size range of 1 nm to 100 nm. Nanomaterials have landed in many sectors due to its enormous characteristics features. Nanoparticles are synthesized by chemical, physical and biological method in general. The chemical synthesis process comprises limitations like high production cost, usage of toxic chemicals, toxic by-product emission etc., Green synthesized iron oxide nanoparticle (IONPs) are preferred due to higher biocompatibility, non toxicity, cost effective, high yield, less energy consumption, environment friendly by products, less usage of chemicals and eco friendly nature. Green synthesis uses plant extracts (roots, leaves, stem, flowers and fruits) and microorganism (bacteria, fungus and algae) for the iron oxide nanoparticle (IONPs) development. Synthesis of plant mediated nanoparticles has obtained more notice in recent times. In this research, synthesis of iron oxide nanoparticles with desired properties has done by green synthesis method using *Amaranthus Campestris* plant stem extract and chemical method. This article summarizes the synthesis process and characterizations of obtained iron oxide nanoparticle (IONPs) through chemical and biological route. The comparisons between chemically and green synthesized magnetic iron oxide nanoparticle have done using various characterization methods such as FTIR, FE-SEM, XRD, VSM, UV visible Spectroscopy and antimicrobial activity.

Introduction

In recent times, nanoparticles have gained attention and interest by researchers due to its characteristics such as physical properties (size, shape, crystal structure, surface characteristics etc.), physiochemical properties (large surface area, strength, magnetic and optical property), mechanical properties (elastic modulus, hardness, friction and adhesion), thermal properties (thermal conductivity, thermal stability and heat transfer nature) [1] and biological properties (antimicrobial, anticancer and drug delivery system) [2]. It is reported that important properties of nanoparticles are high surface area over volume ratio [3], reduced imperfection, high percentage of atoms on the surface and high surface energy. Nanoparticles are classified into six major categories based on their physical and chemical nature. It includes carbon – based, Metal based, ceramic, semi – conductor based, polymeric and lipid based NPs. In metal based NPs production, metal precursors are used in the synthesise process. Several metal-based nanoparticles have been synthesized and characterized such as Au, Ag, Cu, Fe, Zn etc., [4]. The applications of metal based nanoparticles have vast potential in many sectors. Nano scale structures are synthesized by two major approach i.e. bottom-up and Top-down. Bottom-up synthesis approach is a method in which metal atoms combines to form clusters in nano scale level. It includes atom by atom, molecule by molecule and cluster by cluster. Under bottom-up synthesis, there are several methods to synthesis nanoparticles such as spinning, template support, plasma/flame spraying, laser pyrolysis, CVD, atomic or molecular condensation and biological synthesis [5, 6]. The size of the nanoparticle plays significant role in many end uses. Reducing and capping agents are used to stabilize the nanoparticles at the time of synthesis. The shape and size of the NPs is controlled by involving reducing and capping agent in the process of synthesis [7]. Top-down synthesis method is an approach of forming nanoparticle by breaking down the

bulk material in to small tiny material i.e. converting macro & microscale particle to nanoscale [8, 9]. The disadvantage of top down approach synthesis method is imperfection in NPs surface structure. Top-down synthesis approach includes mechanical milling, mechanical alloying, chemical etching, sputtering, laser ablation, electro explosion etc., Nanoparticles can be synthesized via three different routes: Physical, chemical and biological method. Chemical method for nanoparticle synthesis uses chemicals as a solvent and reducing agent. The process like sono chemical, electro chemical decomposition, thermal decomposition, co-precipitation, hydrothermal and micro emulsion is chemical method. Physical methods for nanoparticle synthesis includes aerosol, gas phase deposition, laser induced pyrolysis, ball milling, electron beam lithography, pulsed laser ablation. Plant, fungi, bacteria and protein mediated synthesis are biological method of nanoparticle preparation [10–12]. Physical method has less possibility to control the size of the NPs in nano range. This is considered as main disadvantage of physical method. Chemical method synthesis is commonly used among these methods due to its characteristics like more yield, efficient, simple methodology and low cost [13]. Now a days, iron oxide nanoparticles have extended its hand in many fields. Iron oxide nanoparticles have attracted many researchers, scientist and industry experts due to its unique characteristics such as superparamagnetism, surface to volume ratio, simple preparation process, low toxicity and easy separation steps. Superparamagnetism characteristics of iron oxide nanoparticle showed colossal potential in biomedical sector [14]. Iron oxide exists in three common form in nature i.e. magnetite (Fe_3O_4), maghemite ($\gamma\text{-Fe}_2\text{O}_3$) and hematite ($\alpha\text{-Fe}_2\text{O}_3$). Iron oxide nanoparticle has wide range of application in the field of biomedical, catalyst, lithium ion battery, magnetic recording media and heavy metal removal. 90% of super paramagnetic iron oxide nanoparticles are synthesized via chemical method [15]. It also shows good results for antimicrobial and anti cancer activity [16]. Iron oxide nanoparticles are prepared using co-precipitation, hydrothermal, thermal decomposition, micro emulsion and sonochemical method [17]. Isobutanol and Iron (II) chloride tetrahydrate along with sodium hydroxide and ammonium hydroxide was used in synthesis of iron nanoparticle [18].

Several plant extract have been used for iron oxide nanoparticle synthesis. Many reports have been published related to plant mediated iron oxide nanoparticles (IONPs) production. Plant extracts acts as a capping and reducing agent. These iron oxide nanoparticles are highly reactive and unstable in nature due to its high surface energy. The capping of nanoparticle is essential to control the agglomeration and over growth. It also stabilizes the nanoparticles during synthesis [19]. Phytochemicals present in the plant extract helps in the formation of nanoparticle. Now a days, plant waste such as peels, seed, hulls bagasse and stem have been used in synthesis of nanoparticle for sustainable production. For some type of vegetable, certain parts are not consumed by consumer such as stem and leaves of cauliflower, broccoli and pumpkin. Vegetable and fruit waste is responsible for green house gas emission. 44% of global food waste comes from vegetable and fruit by products [20]. The plant waste contains valuable phytochemicals which plays vital role in nanoparticle synthesis [21].

Chemically prepared $\text{Fe}_3\text{O}_4/\text{OA}$ magnetic nanoparticle has superhydrophobicity, superparamagnetism, thermal stability and superlipophilicity [22]. Iron oxide nanoparticles have also developed using reverse

co-precipitation method because of its simple nature and high yield value [23] Rapid inducing heating method involved in production of iron nanoparticles. The synthesized iron oxide nanoparticle size ranges from 3 to 11 nm in diameter [24]. *Tridax procumbens* leaf extracts contains carbohydrates, proteins and lipids components which acts as reducing and capping agent in nanoparticle synthesis [25]. The medicinal plant *tridax procumbens* leaf extract mediated IONPs showed good antibacterial activity against E-Coli [26]. Gold and silver nanoparticles were synthesized using aqueous fruit extract of *chaenomeles sinensis* and the developed nanoparticles were characterized for biomedical application [27]. α -Fe₂O₃ nanoparticles were chemically synthesized and modified with leaf extract of *Ocimum Sanctum* to attain enhanced antimicrobial activity [28].

High antibacterial activity has obtained by biologically synthesized iron oxide nanoparticle (*Plectranthus amboinicus* leaf extracts) compared to the chemically synthesized nanoparticle [29]. There are several reports for green synthesis of iron oxide nanoparticle such as *Graptophyllum pictum* [30], *Solanum trilobatum*, *Ziziphora tenuior*, *Persia Americana*, Grape proanthocyanidin, peel extract of plantain *Abutilon indicum*, *Azadirachta indica*, *Camellia sinensis* [31], *Bauhinia tomentosa* leaves [32] and *Carica papaya*. The green synthesized iron oxide nanoparticles using leaf extracts of *carica papaya* were used in photo catalytic degradation of remazol yellow RR dye [33]. Tea extract is most commonly used plant source for iron based nanoparticles [34]. Green route iron oxide nanoparticles have been used as catalyst in degradation of methylene blue and methylene orange dyes [35]. The leaf extract of *Zanthoxylum armatum* mediated iron oxide nanoparticle was used in efficient absorption of methylene blue [36]. Flower petal extract of *Hibiscus Rosa-sinensis* was used to synthesis IONPs for fortifying wheat biscuits [37]. *MyrtuscommunisL.* Leaves extract was used in nanoparticle preparation because of the presence of phytochemicals such as flavonoids, phenolic compounds, terpenoids etc., [38]. *Chlorella K01* extract was taken for the synthesis process to obtain iron oxide nanoparticle for potential enhancement of plant growth stimulating and antifungal activity [39]. Iron oxide nanoparticles have been synthesized by modified polyol method [40]. In this work, iron oxide nanoparticles were synthesized through chemical and green method. The synthesis technique and characteristics features of the prepared nanoparticles were studied, analyzed and characterized. This study also compares the advantage and properties of green synthesized nanoparticle over chemically synthesized nanomaterials.

Experimental

Materials

In general, iron oxide nanoparticles (IONPs) were prepared through co-precipitation method [17]. Ferric Chloride (FeCl₃) and Iron (II) sulfate heptahydrate (FeSO₄ · 7H₂O) were purchased from Sisco Research Laboratories Pvt. Ltd to get Fe²⁺ and Fe³⁺ ions for synthesis. Sodium hydroxide (NaOH) pellets with high purity were purchased from Sisco Research Laboratories Pvt. Ltd. The chemicals required for the synthesis process were used without any purification further. *Amaranthus campestris* stems were collected from market at koyambedu, Chennai. Deionised water was used for synthesis process.

Synthesis Of Iron Oxide Nanoparticle Via Chemical Route

In this process, FeCl_3 and FeSO_4 were used for nanoparticle synthesis. 1g of FeCl_3 and 2g of FeSO_4 were dissolved in 100 ml of deionised water under normal atmospheric condition. The solution was kept under the stirrer for complete dissolution. The dissolution was allowed for 30 minutes at 80°C with continuous stirring to get perfectly dissolved solution. After that, 10 ml of 25% of NaOH was added drop by drop in the solution to attain pH range of 11–12 at constant stirring. The solution starts to precipitate when it reaches the appropriate pH level. Black precipitates were obtained at the end of the synthesis process. After stirring the solution for 1 hour, the black precipitate (Fe_3O_4) was allowed to settle and cool down. Then after, magnet is used to separate the synthesized Fe_3O_4 nanoparticle. The synthesized nanoparticles were washed thoroughly using distilled water until it reach the neutral PH range. The prepared iron oxide nanoparticle were placed in the furnace and dried. The chemical synthesis process of iron oxide nanoparticles were shown in Fig. 1a. Then the annealed nanoparticles were taken for further characterization.

Green Biosynthesis Of Feo Nanoparticle

Preparation of *Amaranthus campestris* stem extract

The fresh stems from the *Amaranthus Campestris* were extracted manually. The collected stems were washed thoroughly twice with water to remove dust and other impurities. After that, the stem was dried under normal sunlight for 5 days. The dried stem was crushed in to fine powder using mixer grinder. The dried *Amaranthus Campestris* stem powder was stored until further processing. Then after, in this study, 5g of *Amaranthus Campestris* stem powder was soaked in beaker containing 50 ml of deionised water and boiled for 30 minutes at 70°C . The beaker was kept on magnetic stirrer with hot plate to obtain better extraction. The resultant extract was allowed to settle and cool down. Then the stem extract was filtered using filter paper and the filtrate was used for the nanoparticle synthesis process.

Synthesis Of Iron Oxide Nanoparticles

Green synthesis of nanoparticle requires plant extracts as capping and reducing agent. In this preparation, 1g of FeCl_3 and 2g of FeSO_4 were added in beaker which contains 100 ml of deionised water to get Fe^{2+} and Fe^{3+} ions. The beaker was kept on magnetic stirrer with hot plate at 80°C for 30 minutes. After getting clear orange color solution, 10 ml of 10% aqueous *Amaranthus Campestris* stem extract was added into the solution. The pH level of the solution was adjusted to 11–12 by adding 2 ml of 25% sodium hydroxide drop wise into the solution. Black precipitates readily formed once the solution reaches the required pH range. In this process, less amount of sodium hydroxide was added to the synthesis process compared to the chemical synthesis of iron oxide nanoparticle. The resultant precipitates in the solution were allowed to settle down. Then after, the solution was centrifuged at 4000 rpm in centrifuge

machine. The collected precipitates were washed twice by deionised water and the extracted Iron Oxide Nanoparticles (IONPs) were dried. The process involved in the preparation of *Amaranthus Campestris* stem extract and green biosynthesis of Fe_3O_4 nanoparticle were displayed in Fig. 1b.

Characterization Of Chemically And Green Synthesized Nanoparticle

The surface characteristics of the synthesized nanoparticles (chemically and green route) were analyzed using Field Emission Scanning Electron Microscope (FESEM) with EDS. The Ultraviolet – Visible spectra for the synthesized nanoparticles were analyzed and recorded in the range of 200–700 nm. Fourier transform infrared (FTIR) spectrum was used to identify the compounds present in the developed nanoparticles. FTIR is used to characterize the chemical composition of the prepared iron oxide nanoparticles. The magnetic susceptibility and strength was characterized using Vibrating–sample magnetometer (VSM) at room temperature. X-Ray Diffraction (XRD) was used to examine the crystal structure and phase of the synthesized Fe_3O_4 nanoparticles. XRD provides valuable information such as crystallite, chemical composition, structure and phase identification of prepared nanoparticles. Iron oxide nanoparticles are widely used in biomedical applications such as tissue engineering, antimicrobial and hyperthermia, targeted drug delivery, Magnetic bioseparation, MRI contrast agent etc. Hence, the antimicrobial activity of the synthesized (chemical and green method) nanoparticle was analysed by standard disc diffusion method using gram negative bacteria i.e *Escherichia coli*.

Results And Discussion

UV Visible spectrophotometric analysis

The UV Visible spectrum of green and chemically synthesized NPs showed characteristics absorption band at 295 nm which confirms the formation of iron oxide [41] and the spectra of synthesized Fe_3O_4 nanoparticles were shown in Fig. 2. *Amaranthus Campestris* stem contains bioactive compounds like proteins, amino acid, phenolic acid, flavonoids, carbohydrates, tannin, terpenoids and other antioxidants. The phytochemicals available in the plant extracts are responsible for the formation of nanoparticles. A bioactive compound also surrounds the nanoparticle during synthesis process to improve the stability of the obtained nanoparticle. The UV Visible spectrum of *Amaranthus Campestris* stem extract has absorption bands at 206, 221, 235, 254, 273, 290, 299, 301, 311 & 325 nm which indicate the presence of phytochemicals such as flavonoids, phenolic acids, betacarotene, tannins, terpenoids and other components. The absence of *Amaranthus Campestris* stem extract major peaks at 290, 299, 301 and 311 nm in the spectrum of green synthesized nanoparticles specifies that the phytochemicals such as phenolic acid, flavonoids and other biomolecules acts as a bioreducing and capping agent in the synthesis process. The yield comparison between green and chemically synthesized iron oxide nanoparticle showed that the green synthesis attained more yield which is due to the addition of plant

extract at the time of synthesis process. The yield percentage of green synthesized and chemically synthesized IONPs were 48% and 31.6% respectively. The percentage of yield is calculated using the given formula [42].

$$\% \text{ Yield} = \frac{\text{Weight of iron oxide nanoparticles (IONPs)}}{\text{Weight of the iron precursors used}} \times 100$$

Analysis Of X-ray Diffraction (Xrd)

Crystalline structure and phase purity of the synthesized iron oxide nanoparticle was examined via study of XRD pattern. XRD data of prepared *Amaranthus Campestris* mediated IONPs showed Bragg reflection peaks at 2θ values of 30.2, 35.6, 43.2, 57.2 and 62.8 corresponding to the crystal planes of (220), (311), (400), (511) and (440). It has been observed that the synthesized Fe_3O_4 nanoparticles XRD pattern exactly matches with the intense peak of pure Fe_3O_4 NPs XRD data. XRD pattern of chemically and green synthesized Fe_3O_4 NPs were displayed in Fig. 3. From the figure, it was observed that the synthesized nanoparticles are pure form of Fe_3O_4 due to the absence of sharp peaks at the range of 20° - 30° . In this study, the average crystallite size for chemically and green synthesized nanoparticle was calculated using Debye-Scherrer's equation [36].

$$D = k\lambda / \beta_{hkl} \cos\theta_{hkl} \text{ (1)}$$

In Eq. (1), D represents crystallite size, k is a constant i.e shape factor (0.95–0.98), λ indicates X-Ray wavelength (0.154 nm), β_{hkl} is the Half width of the diffraction band (FWHM) and θ is Bragg-diffraction angle (peak position). The average crystallite size of the chemically and green synthesized IONP is 17.22 nm and 19.12 nm respectively.

Field Emission Scanning Electron Microscopy Study (Fesem)

Figure 4 depicts the SEM with EDS spectra of synthesized Fe_3O_4 nanoparticles via chemical and green route. It has been clearly exhibited that the majority of the synthesized nanoparticles were spherical in shape. The average size of the chemically synthesized Fe_3O_4 NP was 72 nm. Nanoparticles synthesized via chemical route were agglomerated in many areas which might be due to high surface energy and absence of capping agent. The tendency of agglomeration leads to microstructure development from nano range structure which influences the properties of obtained nanoparticles. Magnetic nature of Fe_3O_4 may also be another reason behind the agglomeration of nanoparticles. The average size of obtained green synthesized nanoparticle was 38 nm. The size reduction of green synthesized nanoparticle compared to chemically synthesized is due to the presence of reducing and capping agent (plant extract) at the time of synthesis process. Capping agent reduced the agglomeration tendency since it has ability

to cover the nanoparticle and make less possibility for the development of nanoparticle clusters. EDS spectra of synthesized nanoparticles showed elemental composition such as C, Fe, O, Na, Cl etc., The weight percentage of iron is more in green synthesized nanoparticle compared to chemically synthesized nanoparticle because of the phytochemicals involved in the synthesis process. Phytoconstituents improves the reduction of metal ions to zero valent metal atoms. The degradation of phytochemicals present in the plant extract liberates oxygen which helps in metal oxide formation. After that, the phytoactive components surrounds around the nanoparticle to enhance the stability which reduces the agglomeration. Hence the plant extract indicated as bio-reducing and stabilizing agent in the synthesis of nanoparticle.

Analysis Of Vibrating Sample Magnetometer (Vsm)

The developed iron oxide nanoparticles were taken for the analysis of magnetic behavior using VSM at room temperature. The magnetization curve of the chemically and green biosynthesized IONPs were presented in Fig. 5. The samples were measured in the field range of -10,000 to 20,000 at room temperature. The saturated magnetic intensity for the green synthesized and chemically synthesized nanoparticle was 38 and 317 emu/g respectively. The magnetization curve exhibits sigmoidal shape without any hysteresis loop. The magnetization of the chemically synthesized iron oxide nanoparticle is higher than the biologically synthesized nanoparticle. In this curve, no hysteresis loop was displayed for both samples which demonstrate the super paramagnetic nature of the prepared nanoparticle. The developed nanoparticle can be easily separated and concentrated using small piece of magnet. Moreover, plant extracts are used in the synthesis of nanoparticle as a capping and reducing agent. Due to the presence of plant extract as capping agent, the magnetic intensity of biologically synthesized nanoparticles is low compared to chemically synthesized nanoparticles. The plant extract improves the yield during synthesis of nanoparticles due to the presence of phytochemical constituents.

Fourier Transform Infrared Study (Ftir)

The FTIR spectra of synthesized iron oxide nanoparticles were shown in Fig. 6. The FTIR spectrum of chemically synthesized iron oxide nanoparticles showed characteristics peaks at 359, 569, 776, 1194, 1248, 1508, 1718, 2030, 2134 and 3702 cm^{-1} . Due to the flexural vibration of Fe-O in the synthesized nanoparticle the characteristics bands was appeared in the wavenumber of 550–1650 cm^{-1} FTIR spectra (Azizi 2020) [43]. The formation of Fe_3O_4 nanoparticles was confirmed by the peaks present in the range of 400–600 cm^{-1} in the FTIR spectra (Yew et al. 2016) [44]. The peaks found at 1718, 2030, 2134 and 3702 cm^{-1} in the spectra is due to the bending vibration of water molecules and stretching vibration of surface hydroxyl OH group. The FTIR spectrum of green synthesized iron oxide nanoparticles exhibited characteristics peaks at 359, 464, 776, 880, 987, 1094, 1194, 1350, 1455, 1560, 1718, 3232 and 3858. In green synthesized nanoparticle spectrum, the peaks at 1718, 3232 and 3858 cm^{-1} correspond to the stretching of OH group of phenolic compound and other biomolecules. It confirms the phenol compounds

acts as reducing and capping agent in the synthesis process of Fe_3O_4 NPs. The peaks at 569 and 464 cm^{-1} in the FTIR spectrum of chemically and green method respectively confirms the obtained nanoparticles were iron oxide.

Analysis Of Antimicrobial Activity

The antimicrobial activity of the synthesized Fe_3O_4 nanoparticles against *Escherichia coli* bacteria was analyzed using disc diffusion method as shown in Fig. 7. The antibacterial activity of the green synthesized iron oxide nanoparticle showed appreciable antimicrobial activity against *E.coli* compared to chemically synthesized IONPs due to the presence of phytochemicals on the iron oxide nanoparticles. The plant extract act as a reducing and capping agent in the synthesis process. Many study reported the presence of phytochemicals in the plant extracts helps in the formation of nanoparticle. The plant extract reduces the agglomeration tendency in colloidal synthesis. Addition of plant extract in the synthesis process reduced the size of the developing nanoparticle compared to chemically synthesized iron oxide nanoparticle. During synthesis process, *Amaranthus Campestris* stem extract arrest the over growth of nanoparticle and inhibit the agglomeration to achieve small sized particle. Higher penetration of the nanoparticles into the bacterial cell was attained due to its reduced size compared to chemically synthesized IONPs. Small sized IONPs can have ability to cause high conformational changes in the bacteria due to its high surface area. Moreover, nanoparticles were surrounded by the phytochemicals in the plant extract (as a capping agent and stabilizer) which also assisted in the performance of antimicrobial activity. It was examined the chemically synthesized iron oxide nanoparticle showed 10 mm zone of inhibition. The green synthesized iron oxide nanoparticles showed 18 mm zone of inhibition. In this study, it was observed that plant mediated synthesized nanoparticles showed superior antimicrobial activity than chemically synthesized.

Conclusion

In this study, iron oxide nanoparticles were effectively synthesized via chemical and biological methods and characterization profiles were compared. In biological synthesis process, *Amaranthus Campestris* stem extract was used to synthesize iron oxide nanoparticle. The formation of iron oxide nanoparticles and crystalline structure of synthesized IONPs were confirmed by UV Visible spectra and XRD pattern respectively. Surface morphology and composition of elements in the obtained nanoparticles were analyzed using FESEM with EDS graph. The size of the biologically synthesized iron oxide nanoparticles (38 nm) were small compared to chemically synthesized (72 nm) which exhibited noticeable antimicrobial activity against gram negative bacteria (*E.Coli*). Capping of *Amaranthus Campestris* stem extract on the synthesized iron oxide nanoparticles also aids in antimicrobial performance. Chemically synthesized nanoparticles showed less antimicrobial activity due to its uncapped nature. On the other hand, the magnetic intensity of the chemically synthesized Fe_3O_4 nanoparticles were found to be 317 emu/g and for green synthesized Fe_3O_4 nanoparticles is 38 emu/g. The magnetic intensity of chemically synthesized nanoparticle was superior compared to biologically synthesized due to the absence of

phytochemicals on the nanoparticle surface. This study clearly indicated that the green synthesized nanoparticles are more stable than the chemically synthesized because of the capping of biomolecules. The presence of phytochemicals on Fe₃O₄ nanoparticles increases the anti microbial property and decreases the magnetization nature. The yield of nanoparticle was found to be high in green method. The plant extract (Amaranthus Campestris stem) was responsible for the both synthesis and capping of nanoparticles. The comparison between the chemical and biological route synthesized nanoparticles helped to establish its potential application area. Chemically synthesized iron oxide nanoparticles are used where superparamagnetic behavior is required such as magnetic resonance imaging, magnetic storage area etc. Green synthesized iron oxide nanoparticles have significant characteristics like biocompatibility, antimicrobial, magnetic bioseparation and colloidal stability which can be used in biomedical field.

Declarations

Author Contribution

Hazel D: Conceptualization; Methodology; Writing- original draft; Software

Gobi N: Supervision; Formal analysis

Conflicts of interest/Competing interests

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Funding

No funds, grants, or other support has been received. The authors did not receive fund support from any organization for the submitted work.

Acknowledgement

The authors gratefully acknowledge the support from the Department of Textile Technology, Anna University, Chennai, Tamilnadu, India to carry out this research work successfully.

Data availability

Yes, demonstrating absolute data transparency.

Code availability

Not applicable

Compliance with ethical standards

Ethical approval

Not applicable

Consent to participate

All authors agree with the content and that all have given consent to submit.

Consent for publication

All authors agree for the publication

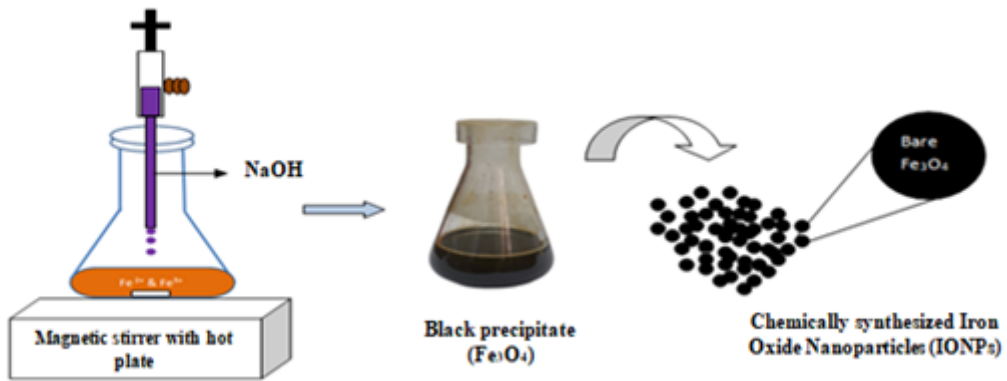
References

1. I. Khan, K. Saeed, I. Khan., Arab. J. Chem. 12, 908 (2019)
<http://dx.doi.org/10.1016/j.arabjc.2017.05.011>
2. V. Kandi, S. Kandi., Epidemiol. health. 37: 1 (2015) <http://dx.doi.org/10.4178/epih/e2015020>
3. P. Christian, F. V. D. Kammer, M. Baalousha, Th. Hofmann., Ecotoxicol. 17, 326 (2008) <http://doi.org/10.1007/s10646-008-0213-1>.
4. J. Jeevanandam, A. Barhoum, Y. S. Chan, A. Dufresne, M. K. Danquah., Beilstein. J. Nanotechnol. 9, 1050 (2018) <http://doi.org/10.3762/bjnano.9.98>
5. N. Abid, A. M. Khan, S. Shujait, K. Chaudhary, M. Ikram, M. Imran, J. Haider, M. Khan, Q. Khan, M. Maqbool., Adv. Colloid Interface Sci. 300, 1 (2022) <https://doi.org/10.1016/j.cis.2021.102597>
6. L. A. Kolahalam, I. V. K. Viswanath, B. S. Diwakar, B. Govindh, V. Reddy, Y. L. N. Murthy., Mater. Today: Proc. 18, 2182 (2019) <https://doi.org/10.1016/j.matpr.2019.07.371>
7. I. Ijaz, E. Gilani, A. Nazir, A. Bukhari., Green Chem Lett Rev. 13, 223 (2020)
<https://doi.org/10.1080/17518253.2020.1802517>
8. A. Escudero, C. Carrión, E. R. Ben, A. Franco, C. R. Barrios, M. C. Castillejos, N. Khair., Inorganics 9, 1 (2021) <https://doi.org/10.3390/inorganics9070058>
9. E. S. López, D. Gomes, G. Esteruelas, L. Bonilla, A. L. L. Machado, R. Galindo, A. Cano, M. Espina, M. Ettcheto, A. Camins, A. M. Silva, A. Durazzo, A. Santini, M. L. Garcia, E. B. Souto., Nanomater. 10, 1 (2020) <https://doi.org/10.3390/nano10020292>
10. T. P. Yadav, R. M. Yadav, D. P. Singh., J. Nanosci. Nanotechnol 2, 22 (2012)
<https://doi.org/10.5923/j.nn.20120203.01>
11. C. C. Koch., Rev. Adv. Mater. Sci. 5:91 (2003)
12. P. Khandel, R. K. Yadaw, D. K. Soni, L. Kanwar, S. K. Shahi., J. Nanostructure Chem. 8, 217 (2018)
13. H. Karami., J. Clust. Sci. 21, 11(2010) <https://doi.org/10.1007/s10876-009-0278-x>
14. Y. P. Yew, K. Shameli, M. Miyake, N. B. Bt. A. Khairudin, S. E. Bt. Mohamad, T. Naiki, K. X. Lee., Arab. J. Chem 13, 2287 (2020) <https://doi.org/10.1016/j.arabjc.2018.04.013>
15. A. Ali, H. Zafar, M. Zia, I. U. Haq, A. R. Phull, J. S. Ali, A. Hussain., Nanotechnol. Sci. Appl. 9, 49 (2016)
<https://doi.org/10.2147/NSA.S99986>

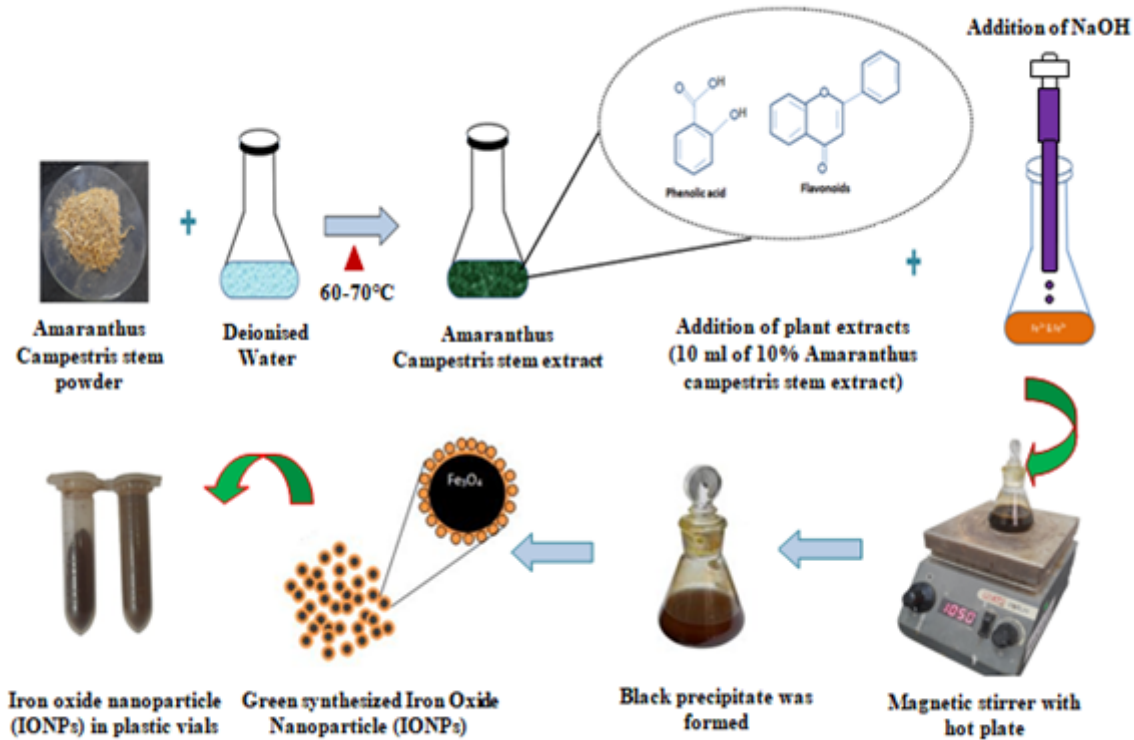
16. A. Alangari, M. S. Alqahtani, A. Mateen, M. A. Kalam, A. Alshememry, R. Ali, M. Kazi, K. M. AlGhamdi, R. Syed., *Adsorpt. Sci. Technol.* 1, 1 (2022) <https://doi.org/10.1155/2022/1562051>
17. W. Wu, Q. He, C. Jiang., *Nanoscale Res Lett* 3, 397 (2008) <https://doi.org/10.1007/s11671-008-9174-9>
18. D. Kostyukova, Y. H. Chung ., *J. Nanomater.* 2016, 1 (2016) <https://doi.org/10.1155/2016/4982675>
19. N. N. Prabhu., *J Bacteriol Mycol.* 6, 260 (2018) <https://doi.org/10.15406/jbmoa.2018.06.00215>
20. K. Q. Lau, M. R. Sabran, S. R. Shafie., *Front. Nutr.* 8, 1 (2021) <https://doi.org/10.3389/fnut.2021.661693>
21. H. Kumar, K. Bhardwaj, R. Sharma, E. Nepovimova , K .Kuca, D. S. Dhanjal, R. Verma, P. Bhardwaj, S. Sharma and D. Kumar., *Molecules* 25, 2 (2020) <https://doi.org/10.3390/molecules25122812>
22. H. Wu, L. Hao, C. Chen, J. Zhou., *ACS Omega.* 5, 27425 (2020) <https://doi.org/10.1021/acsomega.0c03857>
23. A. Nadi, S. J. Sbair, A. Bentiss, M. Belaiche, S. Briche, S. Gmouh., *IOP Conf. Ser.: Mater. Sci. Eng.* 827, 1 (2020) <https://doi.org/10.1088/1757-899X/827/1/012021>
24. P. Sharma, N. Holliger, P. H. Pfromm, B. Liu, V. Chikan., *ACS Omega.* 5, 19853 (2020) <https://doi.org/10.1021/acsomega.0c02793>
25. M. Senthil, C. Ramesh., *Dig. J. Nanomater* 7, 1655 (2012)
26. Y. Y. Patil, V. B. Sutar, A. P. Tiwari., *Int. J. Appl. Pharm.* 12, 34 (2020) <http://dx.doi.org/10.22159/ijap.2020.v12s4.40102>
27. K. H. Oh, V. Soshnikova, J. Markus, Y. J. Kim, S. C. Lee, P. Singh, V. C. Aceituno, S. Ahn, D. H. Kim, Y. J. Shim, Y. J. Kim, D. C. Yang., *Artif. Cells Nanomed. Biotech.* 46, 599 (2017) <https://doi.org/10.1080/21691401.2017.133263>
28. T. Ahmada, R. Phul, N. Khatoon, M. Sardar., *New J. Chem.* 41, 2055 (2017) <https://doi.org/10.1039/C7NJ00103G>
29. P. Mohan, R. Mala., *Mater. Res. Express.* 6, 1(2019) <https://doi.org/10.1088/2053-1591/ab4964>
30. I. P. Sari, Y. Yulizar., *Mater. Sci. Eng.* 191, 1 (2017) <https://doi.org/10.1088/1757-899X/191/1/012014>
31. Priya, Naveen, K. Kaur, A. K. Sidhu., *Front. nanotechnol.* 3, 1 (2021) <https://doi.org/10.3389/fnano.2021.655062>
32. S. Lakshminarayanan, M. F. Shereen, K. L. Niraimathi, P. Brindha, A. Arumugam., *Sci. Rep.* 11, 1 (2021) <https://doi.org/10.1038/s41598-021-87960-y>
33. M. S. H. Bhuiyan, M. Y. Miah, S. C. Paul, T. D. Aka, O. Saha, M. M. Rahaman, M. J. I. Sharif, O. Habiba, M. Ashaduzzaman., *Heliyon* 6, 1 (2020) <https://doi.org/10.1016/j.heliyon.2020.e04603>
34. M. Herlekar, S. Barve, R. Kumar., *J. Nanopart.* 2014, 1 (2014) <https://doi.org/10.1155/2014/140614>
35. L. S. Ardakani, V. Alimardani, A. M. Tamaddon, A. M. Amani, S. Taghizadeh., *Heliyon* 7, 1 (2021) <https://doi.org/10.1016/j.heliyon.2021.e06159>

36. A. V. Ramesh, D. R. Devi, S. M. Botsa, K. Basavaiah., J. Asian Ceram. Soc. 6, 145 (2018)
<https://doi.org/10.1080/21870764.2018.1459335>
37. S. A. Razack, A. Suresh, S. Sriram, G. Ramakrishnan, S. Sadanandham, M. Veerasamy, R. B. Nagalamadaka, R. Sahadevan., SN Appl. Sci. 2, 898 (2020) <https://doi.org/10.1007/s42452-020-2477-x>
38. H. I. Saleh., Int. Res. J. Eng. Technol. 4, 6 (2020) <https://doi.org/10.47001/IRJIET/2020.409002>
39. T. T. Win, S. Khan, B. Bo, S. Zada, P. C. Fu., Sci. Rep. 11, 21996 (2021)
<https://doi.org/10.1038/s41598-021-01538-2>
40. S.Palchoudhury,J. R. Lead., Environ. Sci. Technol. 48, 14558 (2014)
<https://doi.org/10.1021/es5037755>
41. P.Karpagavinayagam,C.Vedhi., Vacuum. 160, 286 (2019)
<https://doi.org/10.1016/j.vacuum.2018.11.043>
42. R. Sood, D. S. Chopra., Int. Res. J. Pharm. 8, 100 (2017) <http://dx.doi.org/10.7897/2230-8407.080457>
43. A. Azizi., J. Inorg. Organomet. Polym. Mater. 30, 1 (2020) <http://dx.doi.org/10.1007/s10904-020-01500-1>
44. Y. P. Yew, K. Shameli, M. Miyake, N. Kuwano, N. B. B. A. Khairudin, S. E. B. Mohamad, K. X. Lee., Nanoscale. Res. Lett. 11, 1 (2016) <http://dx.doi.org/10.1186/s11671-016-1498-2>

Figures



a) Process of chemical synthesis of Fe_3O_4 iron oxide nanoparticle



b) Process of green synthesis of Fe_3O_4 iron oxide nanoparticle

Figure 1

Synthesis of iron oxide nanoparticle a) Chemical method b) Green method

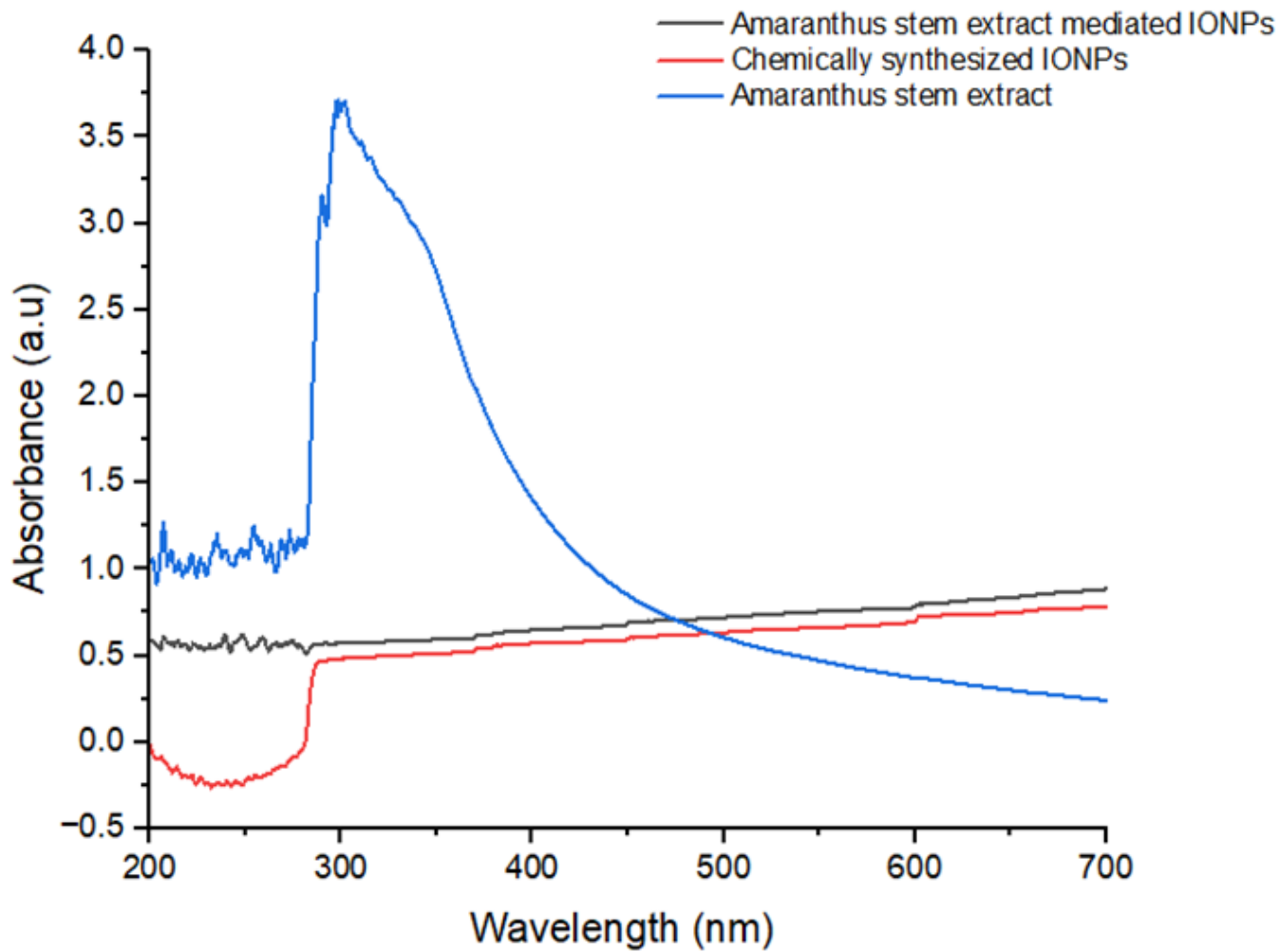


Figure 2

UV Visible absorption spectra of synthesized Fe_3O_4 NPs

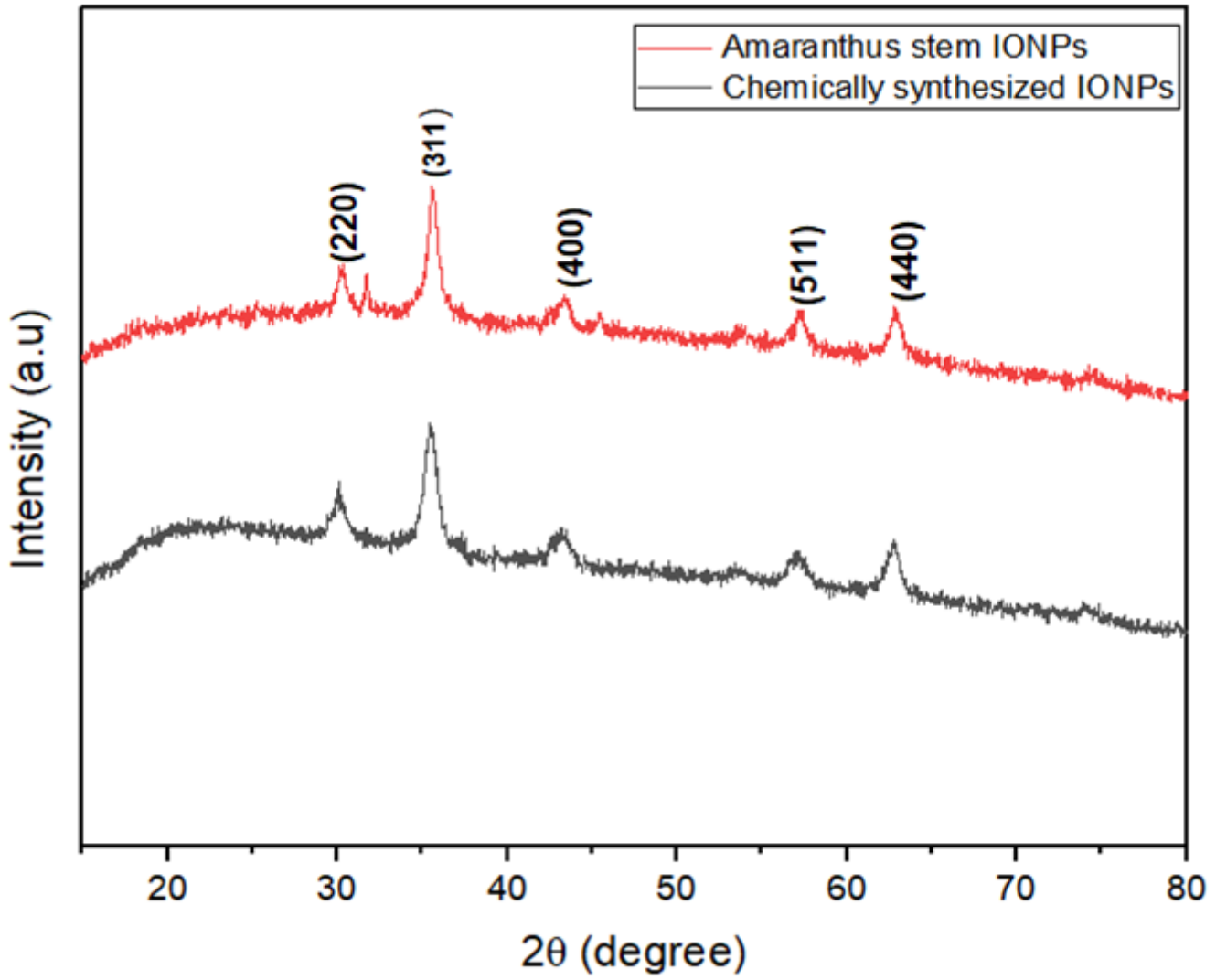
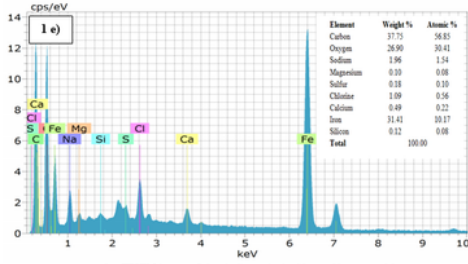
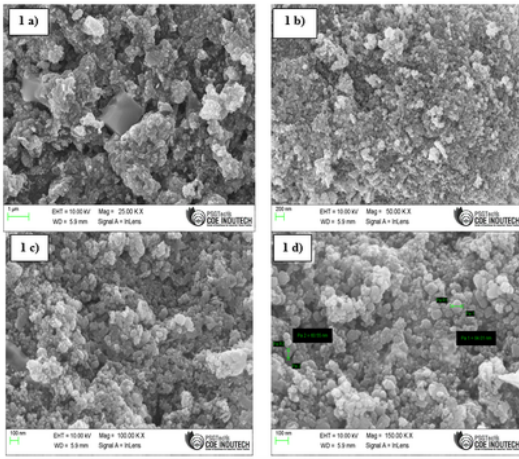
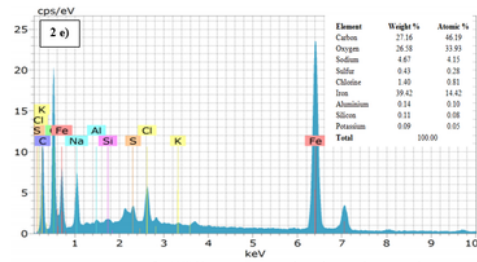
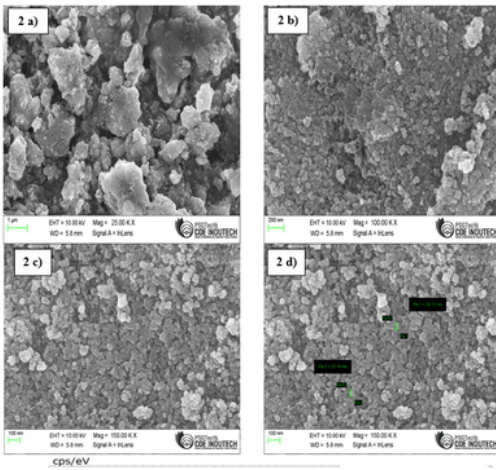


Figure 3

XRD pattern of synthesized Fe_3O_4 NPs via chemical and green method



1. FESEM images of chemically synthesized iron oxide nanoparticles



2. FESEM images of green synthesized iron oxide nanoparticles

Figure 4

FESEM images of synthesized Fe_3O_4 via 1) Chemical method 2) Green method

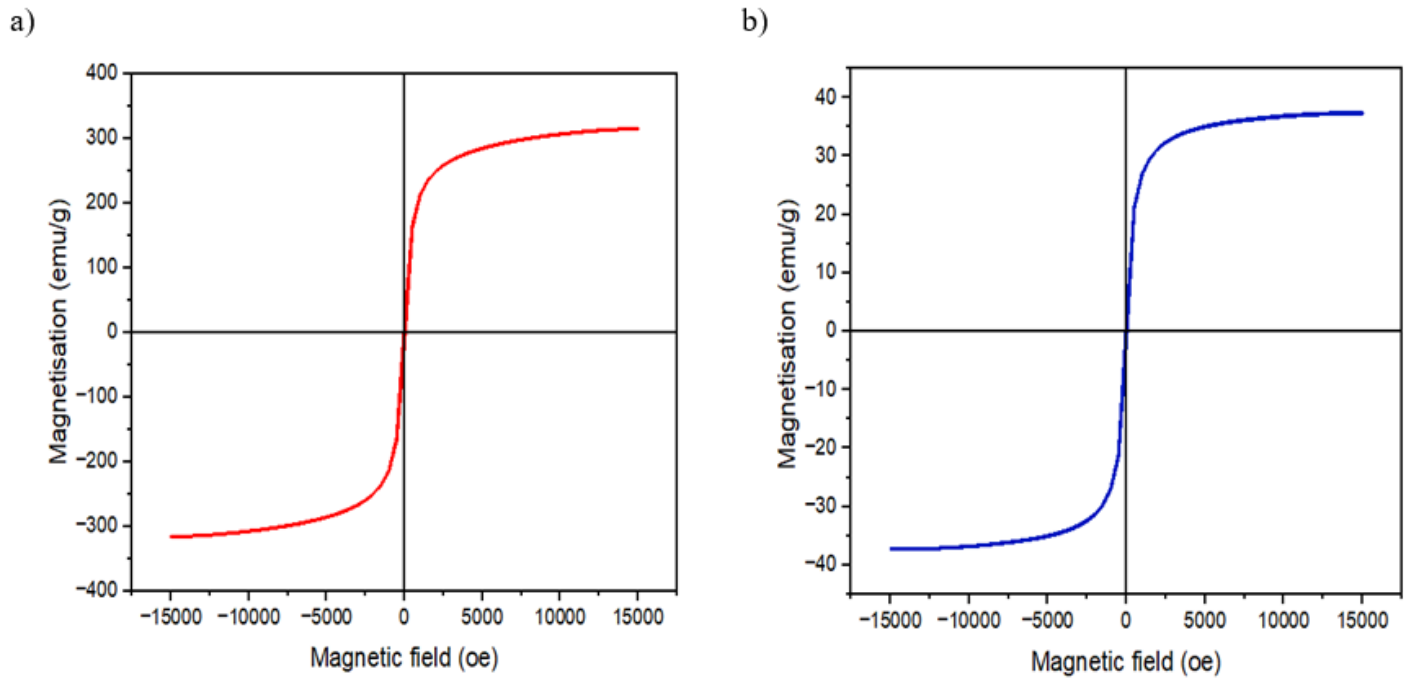


Figure 5

The magnetization curve of synthesized Fe₃O₄ NPs via chemical (a) and green method (b)

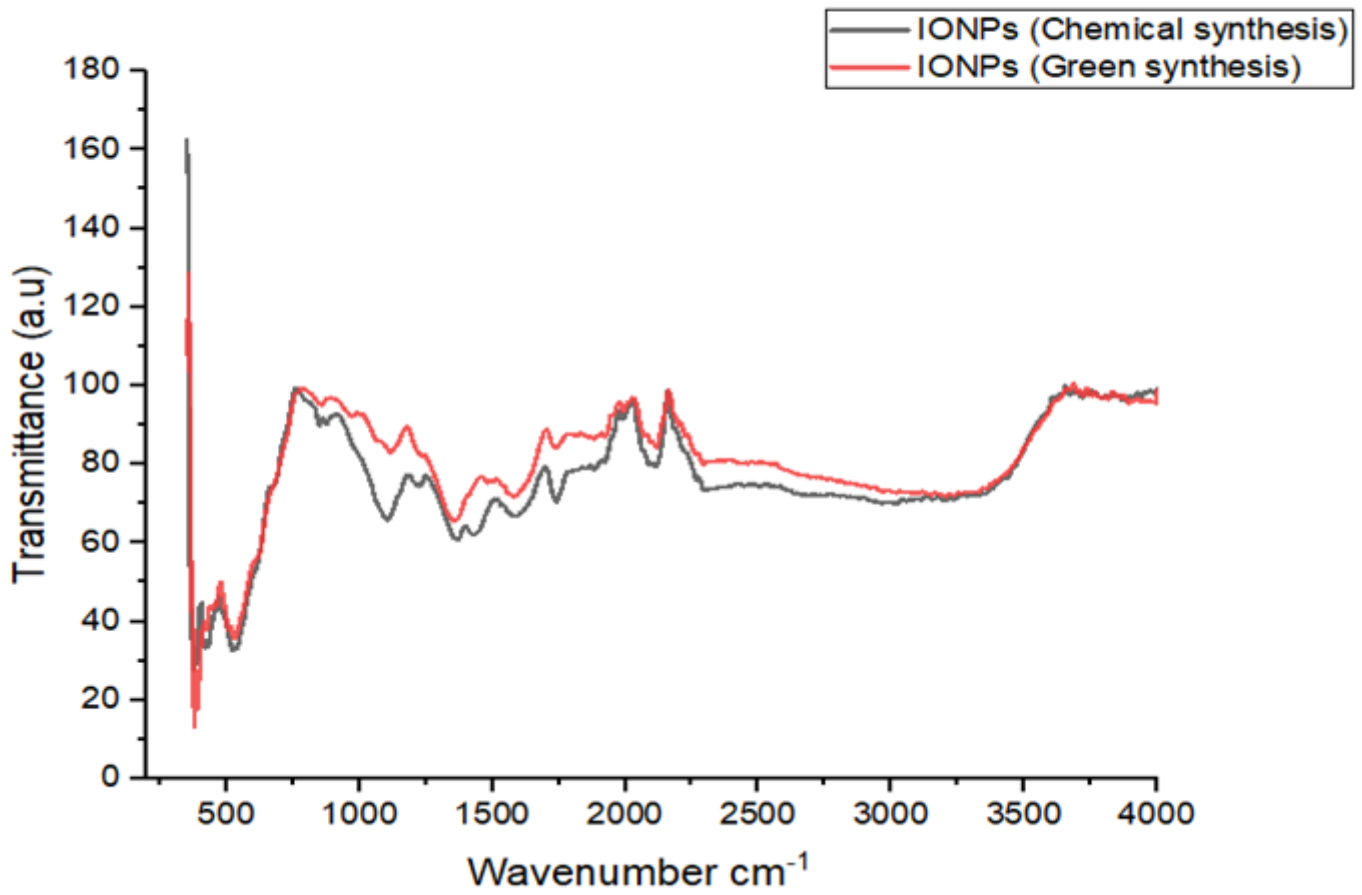


Figure 6

FTIR pattern of synthesized Fe₃O₄ NPs via chemical and green method

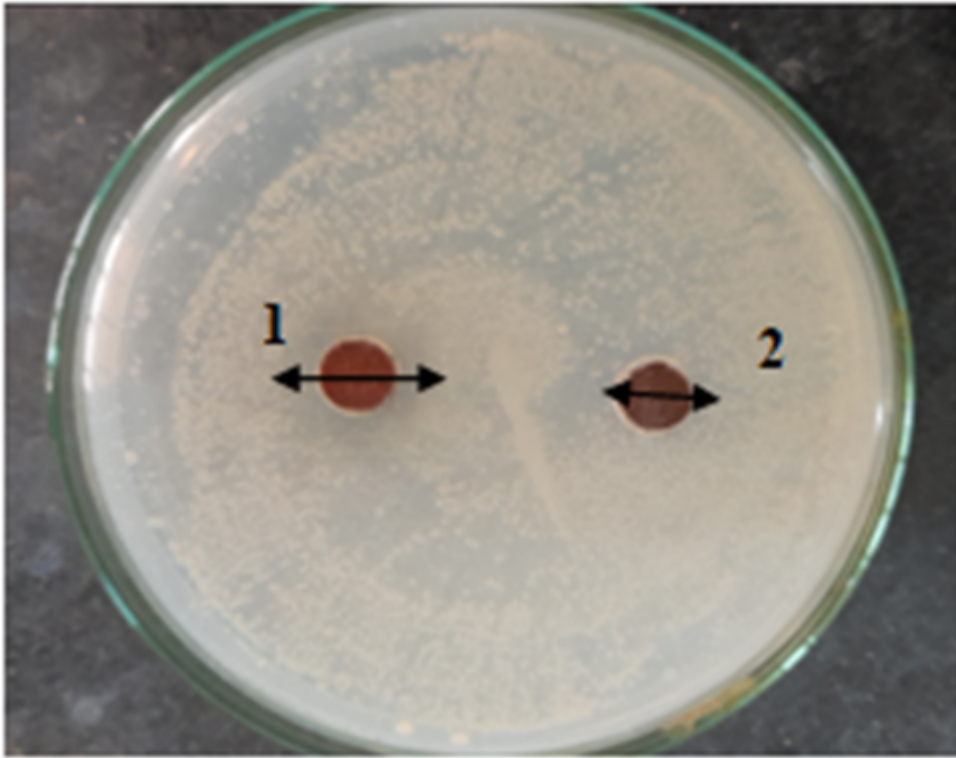


Figure 7

Antibacterial activity of Iron Oxide Nanoparticles (IONPs) 1. Green synthesized

2. Chemically synthesized