RESEARCH ARTICLE

Green Synthesis of Fe_2O_3 Nanoparticles Utilizing Guava Leaf Extract

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Abstract

This study focuses on the green synthesis of iron oxide (Fe_2O_3) nanoparticles using guava leaf extract as a reducing agent. The methodology involves the extraction of guava leaves to create an aqueous reagent solution, followed by the synthesis of Fe_2O_3 nanoparticles through a series of processes including centrifugation and annealing. The synthesis procedure involved mixing the guava extract with an iron nitrate solution, stirring, and allowing the formation of nanoparticles, which were subsequently annealed at 600°C. Characterization of the resulting nanoparticles was carried out using X-ray diffraction (XRD), revealing a rhombohedral structure with an average crystallite size of approximately 40-45 nm. Ultraviolet-visible (UV-Vis) spectroscopy indicated strong absorption in the 500-800 nm wavelength range, with the calculated optical bandgap of the synthesized nanoparticles being 2.08 eV. Transmission electron microscopy (TEM) analysis showed that the nanoparticles predominantly exhibited irregular, quasispherical shapes with a tendency for slight agglomeration. The findings demonstrate the efficacy of the green synthesis approach not only as a sustainable method for producing Fe_2O_3 nanoparticles but also highlight their potential applications in fields such as environmental remediation, biomedicine, and catalysis.

Keywords: metal oxides, UV-Vis, tauc plot, green synthesis, nanoparticles.

1 Introduction

Nanomaterials, particularly nanoparticles, are at the forefront of the contemporary advancement in nanotechnology [1]. Each nanoparticle production method has pros and cons, but they are constantly improved [2–4]. The production of nanomaterial's mediated by leaf extracts has been the subject of much research in the past few years [5]. Nanomaterial production mediated by leaf extracts is less expensive and less harmful to the environment than traditional synthesis methods including chemical reduction and physical procedures [6, 7]. The manufacture of inorganic materials, especially metal nanoparticles, by the use of microorganisms and plants has garnered significant attention. Recently, magnetic nanoparticles have been recognized as a significant class of nanocatalysts. Their separation process is efficient and economical, reducing catalyst loss and enhancing reusability [8]. Furthermore, magnetic nanoparticles demonstrate significant catalytic efficiency attributed

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to their large surface area, and they are also cost-effective and non-toxic in their production process. Furthermore, magnetic nanoparticles demonstrate significant catalytic efficiency attributed to their large surface area, and they can be produced at a relatively low cost while maintaining non-toxic properties.

Heavy metal ions (HMIs) represent significant micro pollutants and exert a profound influence on environmental systems [9, 10]. The discharge of hazardous materials from agricultural or industrial processes into the environment is leading to contamination and degradation, thereby presenting significant risks to human health [11, 12]. The extraction of heavy metals and inorganic substances from wastewater and industrial effluents via chemical processes demonstrates effectiveness; however, it frequently lacks economic feasibility [13, 14]. Nanomaterials based on iron oxide present significant advantages for the removal of HMI, attributed to their diminutive dimensions, extensive surface area, and inherent magnetic characteristics [15]. According to the existing literature, a variety of iron-based nanocomposites have been documented, including GO-$CuFe_2O_4$ [16], Fe_3O_4@SiO_2@Mel–Rh–Cu [17], $NiFe_2O_4$@SiO_2@aminoglucose [18], MSrFeGO [19], $NiFe_2O_4$ [20], γ–Fe_2O_3 [21], and Fe_3O_4@SiO_2–XO [22].

This report presents the use of recyclable iron oxide (Fe_2O_3) nanoparticles, synthesized through a green method employing Guava Leaf Extract. This approach offers notable surface area, enhances reaction efficiency, and facilitates straightforward preparation.

2 Methodology

Extraction (guava leaf), creation of an aqueous reagent solution, synthesis of reagent and extract, centrifugation, drying, powdering and other processes or steps were used in this study.

2.1 Extraction process

Guava leaves required for the study were taken from the tree. Then, the guava leaves were weighed and were carefully cut into pieces and washed with distilled water. The dried leaves were powdered into fine particles using a mixer grinder. For the preparation of aqueous leaf extract, 10 g of guava leaf powder was dissolved in 100 mL of deionized water, followed by boiling for 4 hours. Leaf extract was then left at room temperature until further use. Finally, it was filtered through filter paper to obtain the pure leaf sample extract. The filtrate thus obtained was used as a plant extract.

2.2 Green synthesis of Fe_2O_3 nanoparticles

Green synthesis was employed for the preparation of Fe_2O_3 nanoparticles. To 50 ml of 0.1M aqueous solution of Iron nitrate hexahydrate taken in a 250 ml beaker was added 10 ml of guava extract and stirred at 60°C for 2 hours and the solution was kept undisturbed. The particles were formed after few hours. The resulting nanoparticles were annealed in a vacuum air oven at 600°C for 3 hours to obtain the Fe_2O_3 nanoparticles. The detail of synthesis of Fe_2O_3 nanoparticles has shown in Figure 1.

3 Discussions and Results

3.1 X-ray Diffraction Analysis

The XRD pattern for the synthesized Fe_2O_3 nanoparticles utilizing Guava Leaf Extract is

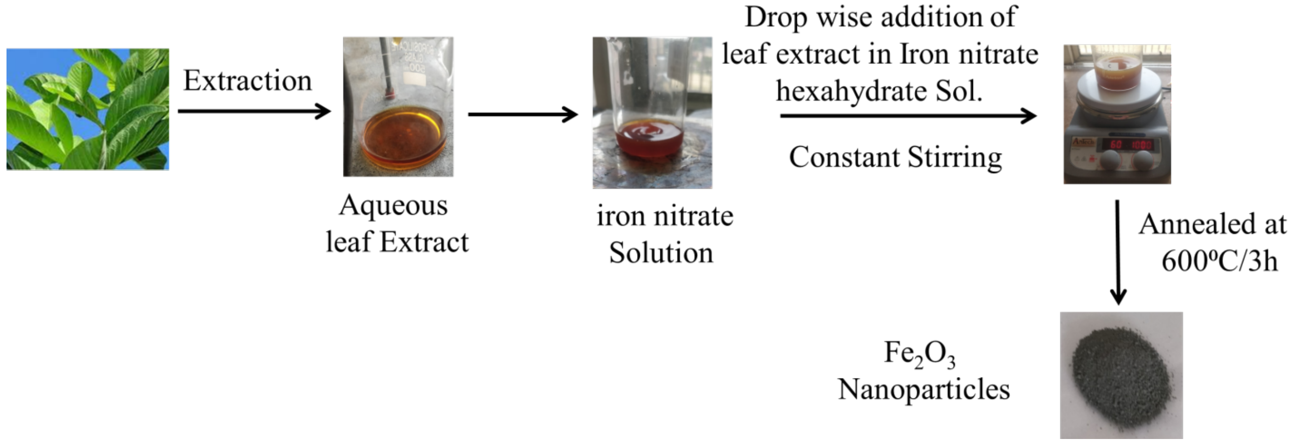

Figure 1. Detailed synthesis of Fe_2O_3 nanoparticles via green synthesis method.

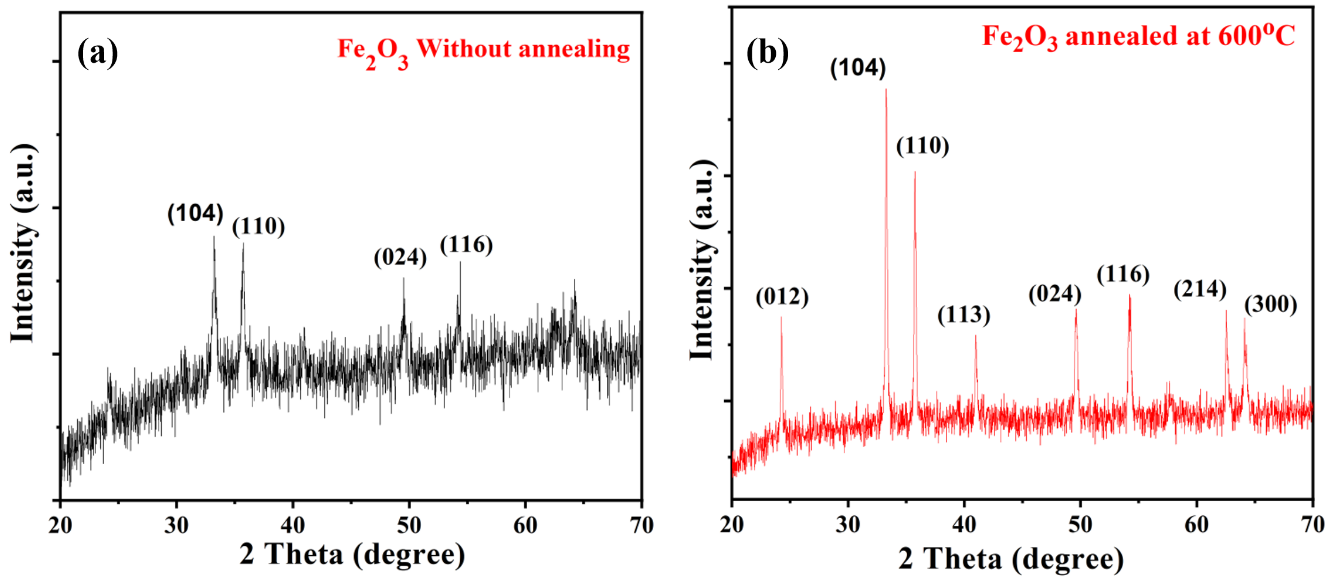

Figure 2. (a) XRD of Fe_2O_3 without annealing (b) XRD of Fe_2O_3 with annealing.

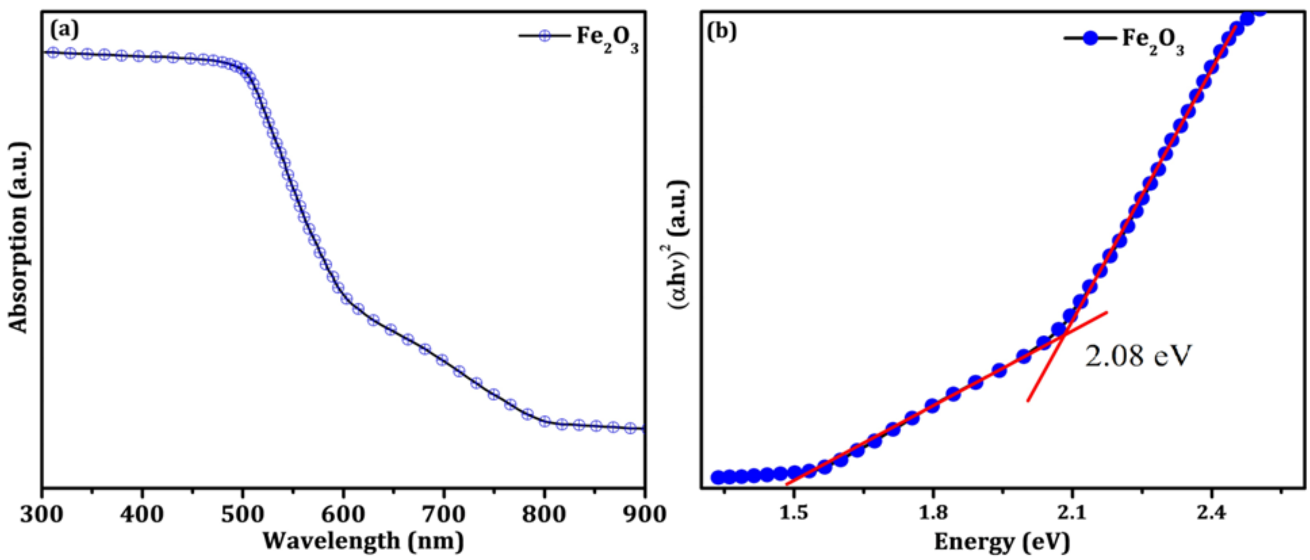

Figure 3. (a) UV-Vis spectra of Fe_2O_3 (b) Tauc plot obtained with UV-Vis spectra.

presented in Figure 2. Figure 2(a) presents the Fe_2O_3 nanoparticles prior to annealing, whereas Figure 2(b) illustrates the Fe_2O_3 nanoparticles subjected to annealing at 600°C for a duration of three hours, with a heating rate of 20°/min. The prominent characteristic peaks of iron oxide particles are identified at 2θ = 24.17, 33.18, 35.62, 40.86, 49.49, 54.08, 62.47, and 63.96, corresponding to the amorphous structures (012), (104), (110), (113), (024), (116), (214), and (300) of Fe_2O_3. All reflection peaks were successfully indexed to the rhombohedral structure of iron oxide (JCPDS NO. 00033-0664). These findings are consistent with the crystalline characteristics observed in iron oxide nanoparticles [23]. The average crystallite size of the rhombohedral nanoparticles was estimated using the Debye-Scherrer equation [24, 25], indicating their nanocrystalline nature.

$$\mathrm{D} = \frac{k\lambda}{\beta \cos f_0(\theta)} \tag{1}$$

where, λ (1.5418 Å) denotes the wavelength of the $Cu - K\alpha$ radiation, B represents the full width at half maximum (FWHM) of the diffraction peak measured in radians, D refers to the crystallite diameter, and θ is the Bragg angle associated with the corresponding peak. The average crystalline size of the nanoparticle is found to be $\sim 40 - 45$ nm.

3.2 Uv-Vis analysis

The absorption curves display a strong absorption in the 500-800 nm wavelength regions when analyzed in the UV-Vis range using synthesized Fe_2O_3 nanoparticles precursor prepared by green synthesis (Figure 3(a)). This outcome aligns with results from other investigations [26].The optical bandgap (Eg) for Fe_2O_3 nanoparticles can be ascertained using extrapolation from the absorption edge, as described by the equation (2) [24].

$$(\alpha h\nu)^n = A(h\nu - E_g) \tag{2}$$

where A is a constant, $h\nu$ is the energy of light, n is a constant that depends on the type of electron transfer, and α is the absorption coefficient. The bandgap of Fe_2O_3 is direct ($n = 2$). The graph of $(\alpha h\nu)^2$ against $h\nu$ can be seen in Figure 3(b). The calculated value of bandgap is found to be 2.08 eV for Fe_2O_3 nanoparticles prepared via green synthesis method.

3.3 Morphology analysis

Fe_2O_3 nanoparticles produced via green synthesis are observed in the TEM image (Figure 4) as mostly irregular, quasi-spherical forms that have a propensity to form tiny agglomerates. Successful nanoscale production is indicated by the well-dispersed, sharply defined edges of the nanoparticles, which are mostly less than 100 nm. The reduction of iron salts and stability of the nanoparticles by natural capping agents like proteins and polyphenols are made easier by the green synthesis approach, which usually uses plant extracts or other biological agents. Partial stabilization, which is a frequent feature of biosynthesized nanomaterials, is probably the cause of the observed aggregation. The picture demonstrates how well the green way produces Fe_2O_3 nanoparticles using sustainable and eco-friendly methods, making them appropriate for use in environmental remediation, biomedicine, and catalysis.

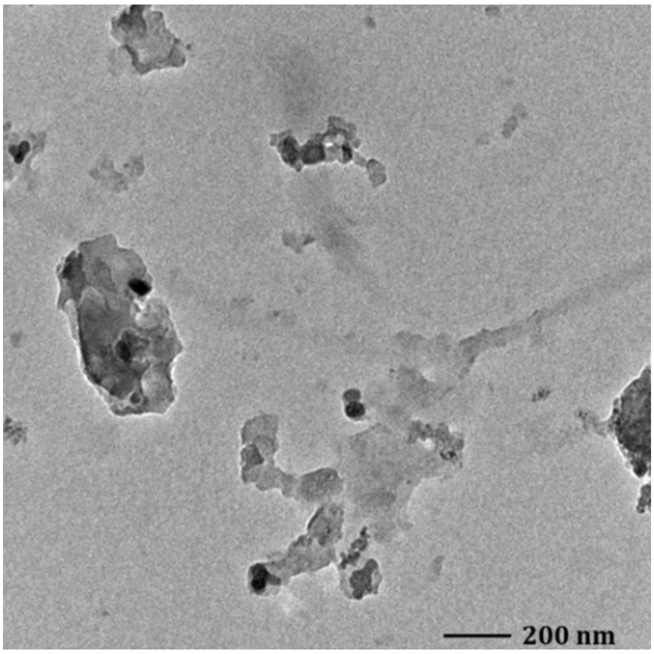

Figure 4. TEM picture of Fe_2O_3 nanoparticles produced by green synthesis and annealed at 600°C, displaying mild agglomeration and irregularly shaped nanoscale particles.

4 Conclusion

This report presents the use of recyclable Fe_2O_3 nanoparticles, synthesized through a green method employing Guava Leaf Extract. The resulting Fe_2O_3 particles were annealed in a vacuum air oven at 600°C for 3 hours to obtain the nanoparticulates. The average crystalline size of the Nanoparticle is found to be 40 - 45 nm. The bandgap value is 2.08 eV, and the average particle size is below 90 nm. The XRD, UV-Vis and TEM analysis demonstrates how well the green synthesis approach produces Fe_2O_3 nanoparticles using sustainable and eco-friendly methods, making them appropriate for use in environmental remediation, biomedicine, and catalysis.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The author declares no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

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