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**Research Paper**

# Eco-Friendly Synthesis, and Characterization of Iron Oxide Green Tea Nanoparticles

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***Abstract***
*The green method of producing metal nanoparticles has gained traction since it is easy to use, non-toxic, inexpensive, and environmentally friendly. Iron oxide nanoparticles made from green tea (Fe-GT@NP) were created and described. The zeta analyzer, FTIR, FESEM, and XRD were used to characterize the produced material. Meanwhile, using Fourier transform infrared spectroscopy (FTIR) and X-ray diffraction (XRD), it was shown that iron oxide core-shell nanoparticles were produced with polyphenols serving as a capping/stabilizing agent. FESEM and TEM morphological analysis of the produced NPs revealed a spherical form. The current work appears to be an attempt to evaluate the potential of nanoparticles for a range of industrial and therapeutic applications and to explain a straightforward, efficient, and environmentally friendly technique of producing them.*

***Keywords***: *Green tea; Iron oxide; Nanoparticle.*

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## I. Introduction

The green manufacturing of nanoparticles using living cells through biological processes is more effective and yields a greater mass than other comparable methods. Plants provide a variety of elements and biochemicals that can be used as reducing and stabilizing agents during the manufacture of green nanoparticles. The green synthesis techniques are more stable, non-toxic, cost-effective, and ecologically friendly than traditional biological, physical, and chemical processes [1]. Biosensing platforms, immunotherapy, wound healing, tissue repair, regenerative medicine, and dentistry are some of the biomedical fields that are seeing new applications for green-produced metal and metal-oxide nanoparticles. There was much discussion on biotoxicology's antiviral, antifungal, and antibacterial qualities [2].

Green synthetic metal nanoparticles, which are also affordable, non-toxic, and environmentally safe, are made from various plant parts. When compared to alternative physical and chemical approaches, green produced nanoparticles are more effective at removing metal ions, dyes, and antibiotics [3]. The greatest technique for creating nanoparticles is the green synthesis method, which is also the most economical, environmentally friendly, and helps to decrease toxicity while increasing stability. Plants include a wide variety of phytochemical compounds with oxidation-reduction capabilities, including phenolics, polysaccharides, terpenoids, and flavonoids. They are therefore most effective when employed for the manufacture of ecologically acceptable nanoparticles [4]. The synthesis of phytochemical compounds for nanoparticles is not a generic procedure since the synthesis of stabilized nanoparticles necessitates a precise understanding of the phytochemical components [5]. Most people agree that the secondary metabolites of plants, or polyphenols, are the main elements that are essential to the development of the green synthesis of nanoparticles. The green synthesis approach is safer, more cost-effective, more advanced, stable, and simple to duplicate [6]. One essential tool for preventing hazardous byproducts through environment friendly and sustainable development is a biosynthetic method. A variety of biological entities, including plant extracts, bacteria, yeast, seaweeds, and algae, use the biosynthesis process to create metal and metal oxide nanoparticles [7].

Environmental contaminants can be treated with green generated nanoparticles. According to earlier research, certain nanoparticles catalytic properties can lessen the toxicity of environmental contaminants [8, 9]. Additionally, the pharmaceutical industry is using these green techniques in a big way [10]. The extensive use of

metallic nanoparticles in a variety of industries, including biology, medicine, and others, has increased demand for them and highlighted the need for improved manufacturing techniques. Nanoparticles are appealing in biological domains because of their effectiveness against human pathogenic microorganisms [11-20].

Using iron chloride tetrahydrate as a precursor, we synthesize iron oxide nanoparticles ($Fe_2O_3$ NPs) in this work. For the synthesis of NPs, the several phytochemicals included in green tea extract serve as capping and reducing agents with the addition of iron chloride tetrahydrate and tea extract under certain reaction conditions. Because iron is oxidizable, the phytochemicals in the extract react with the iron ions to produce iron oxide nanoparticles (NPs) rather than reducing $Fe^{2+}$ to $Fe^0$. The interaction between these phytochemicals and metal ions ensured the creation of α-$Fe_2O_3$ nanoparticles, and form the brown color [15]. Hematite ($Fe_2O_3$ NP) iron oxide nanoparticles were chosen above other iron oxide phases due to its stability, anticorrosive qualities, and adjustable magnetic and optical characteristics. They can be produced using the green approach in a wide range of sizes and shapes [16]. To maximize the synthesis of nanoparticles, the volume ratio of precursor to plant extract was adjusted and microwave heating was examined. FTIR, SEM, EDS, TEM, X-ray diffraction, and zeta potential were used to demonstrate the presence of nanoparticles.

## II. Methodology

The leaves of green tea were gathered. The appropriate tea leaf extract was added to the $FeCl_3$ solution to create iron nanoparticles. Each 20 g of leaves was taken into consideration when preparing the extract. In 500 ml conical flask, fill it with 200 ml of deionized water, and then add 20 g of leaf extract. For 20 minutes, the mixture should be heated to 70°C. The mixture is then allowed to reach room temperature before being strained. This filtrate can be used after being stored at 4 °C [21].

Green tea extract was used to create Fe-nanoparticles by replacing in a solution of $FeCl_3$. In 1000 milliliters of water, dissolve 16 grams of $FeCl_3$ granulate. This should be 1:1 in relation to the amount that is left behind after the tea leaf extract is filtered. At room temperature, the mechanical stirrer should be used to agitate the mixture. The reduction of $Fe^{+2}$ ions is predicted by the rapid appearance of a black precipitate. As a result, the precipitates were centrifuged for 15 minutes at 5,000 rpm. In the end, the Fe-Nanoparticles were dried in a vacuum oven for three hours at 70 °C [21].

The structural, functional, and optical properties of synthesized Fe-Nanoparticles are characterized by employing a field emission scanning electron microscope (FESEM), EDS, TEM, X-Ray diffraction (XRD), FTIR, and Zeta potential.

## III. Result and Discussion

A prominent and powerful peak at 3437$cm^{-1}$ indicates the presence of an O-H bond (hydroxyl group) (Fig. 1). Carbonyl groups C = C are seen as a band at 1633 $cm^{-1}$ (1550-1650 $cm^{-1}$). These functional groups verified that the surface of $Fe_3O_4$ was coated with terpenoids and flavonoids. The asymmetric and symmetric stretching vibration of $COO^-$ were demonstrated by the peaks at 1384 $cm^{-1}$. The presence of an aromatic C-H bending band was confirmed by the absorption peaks at 856 $cm^{-1}$ and 780 $cm^{-1}$. The stretching vibration mode of Fe-O is linked to the absorption peaks detected at 562 $cm^{-1}$. In HI Saleh, the metal-oxygen band at 562 $cm^{-1}$ is associated with intrinsic stretching vibrations of the metal at the tetrahedral site, which is connected to the magnetite phase of magnetite nanoparticles [29].

The XRD pattern of iron green tea nanoparticles (Fe-GT@NPs) displays characteristic diffraction peaks indicating their crystalline nature. Sharp peaks at specific 2θ angles, such as around 31° and 67°, correspond to the planes of iron oxide crystalline structures, confirming successful nanoparticle formation (Fig 2). The broad background suggests the presence of amorphous phases, likely from organic compounds in the green tea extract used during synthesis. The sharp intensity of the primary peaks indicates a high degree of crystallinity, while the absence of additional peaks confirms the purity of the synthesized Fe-GT nanoparticles. This XRD analysis validates the formation of well-crystallized iron oxide nanoparticles through a green synthesis route [22-26]. The soluble biomolecules in green tea extract, including catechin, theanine, and caffeine, were implicated in the creation of nanoparticles, according to Wu et al.'s research [27]. Caffeine was the most significant capping agent among them; it was adsorbed on the surface of the produced nanoparticles and slightly inhibited the oxidation of $Fe^0$ [28].

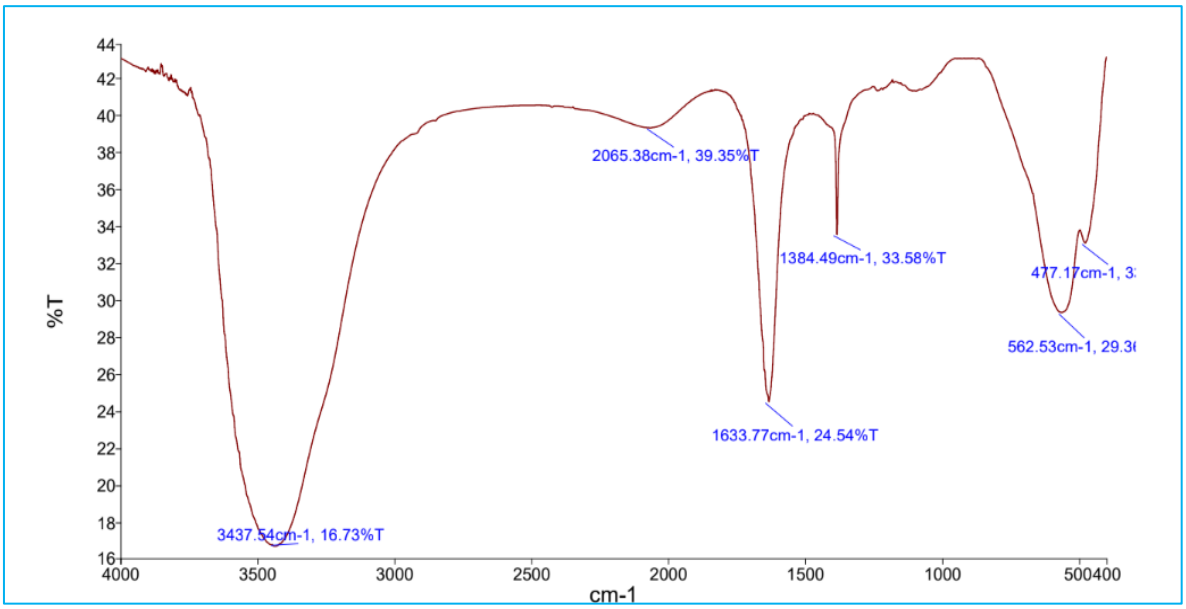


Fig. 1: FTIR spectrum of Fe-GT@NPs.

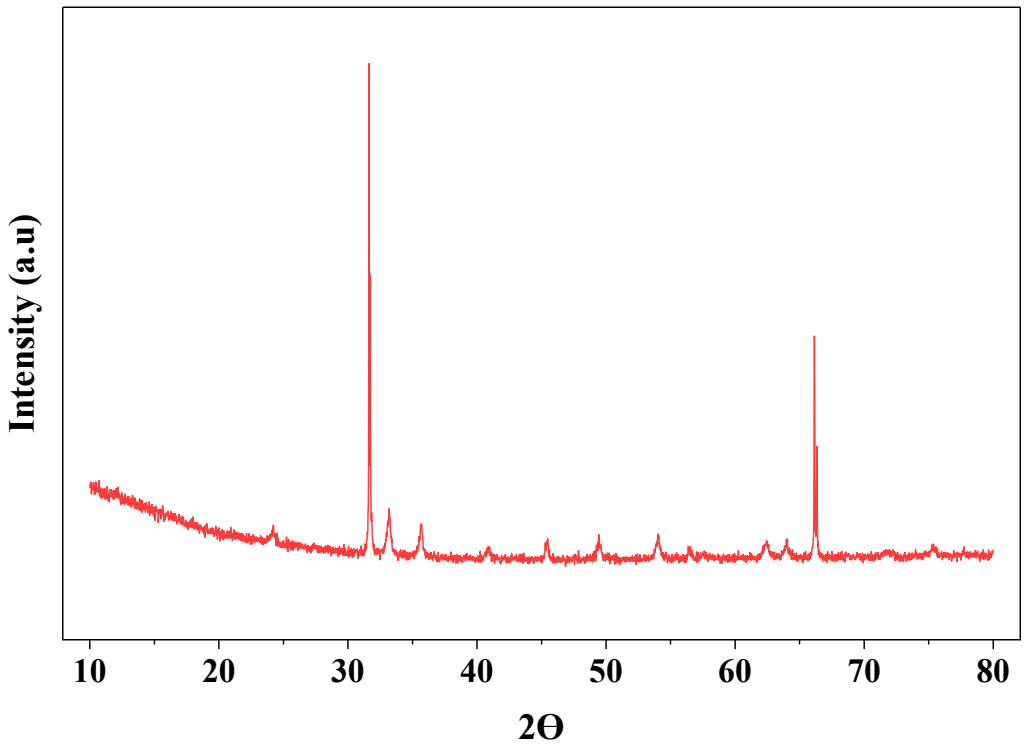


Fig. 2: XRD pattern of Fe-GT@NPs.

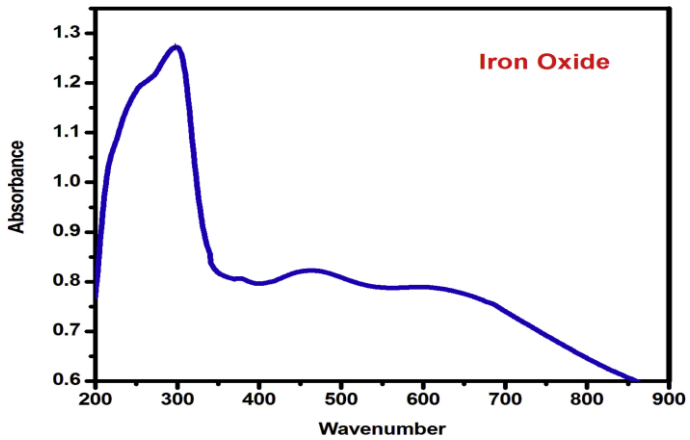


Fig. 3 UV-Vis spectrum of Fe-GT@NPs.

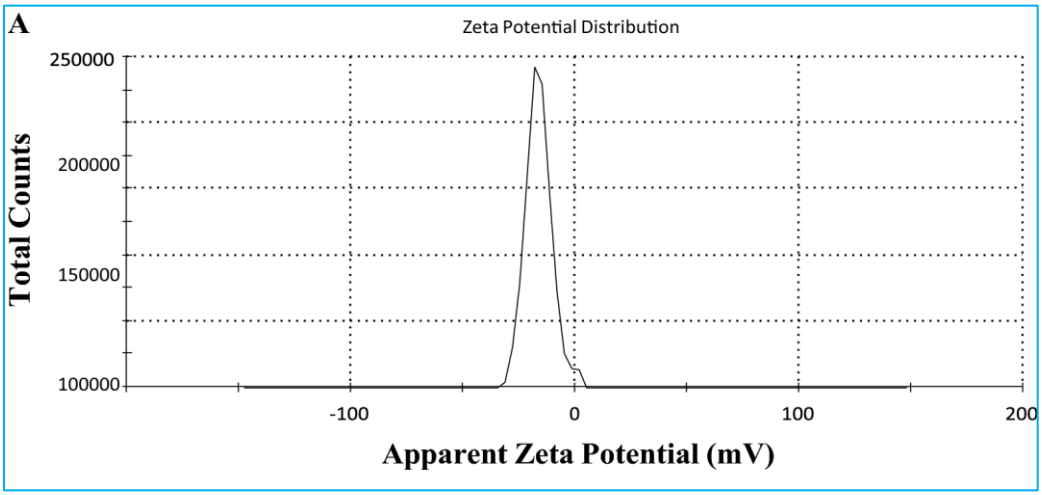


Fig. 4 Zeta potential of synthesized Fe-GT@NPs.

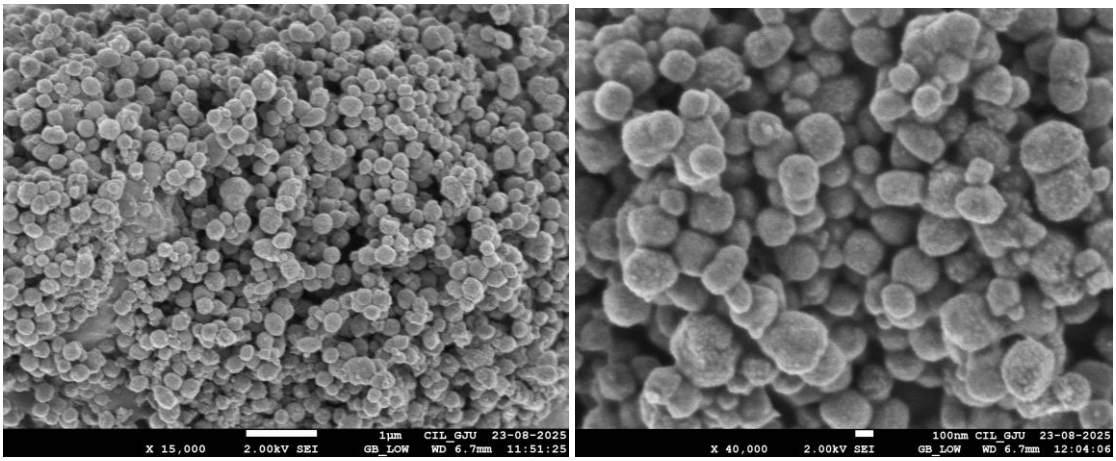


Fig. 5: FESEM of synthesized Fe-GT@NPs.

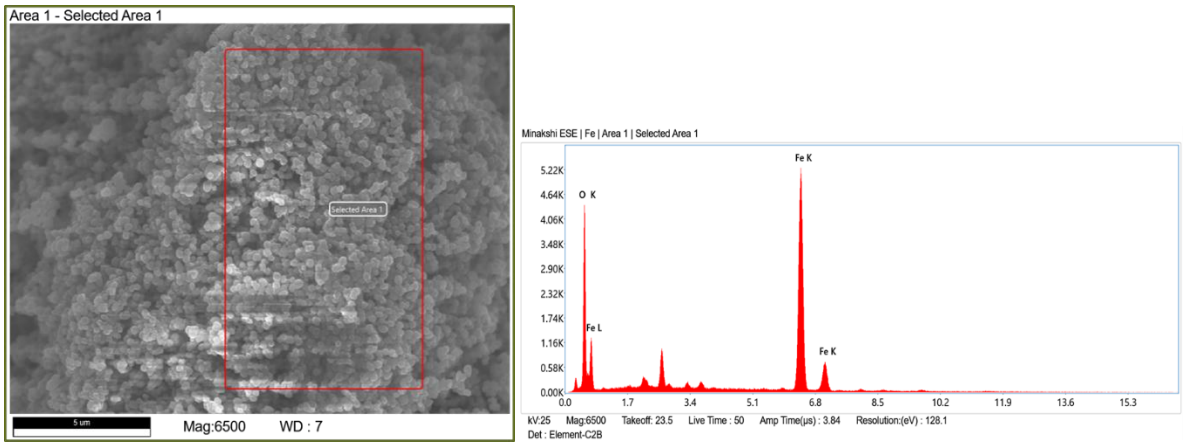


Fig. 6: EDS of synthesized Fe-GT@NPs.

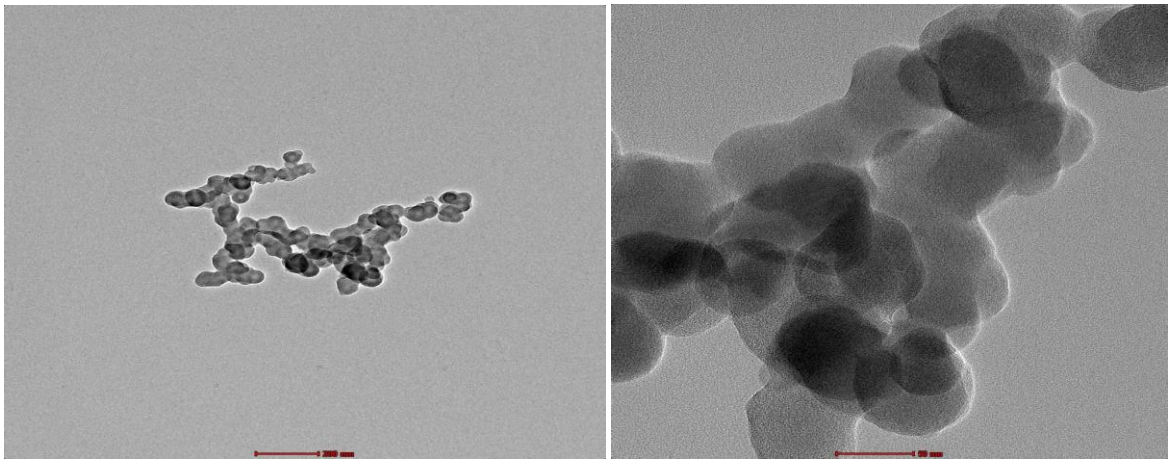

Fig. 7 TEM of synthesized Fe-GT@NPs.

UV–Vis spectrum of Fe-NPs was measured at room temperature a by using UV-1800/Shimadzu, (CIL, GJUST, Hisar). The absorption peak at 298–301 nm depicted that iron oxide nanoparticles formed (Fig 3). Figure 4 illustrates the prepared Fe-GT@NP's zeta potential, zeta potential of −16 mV was found which was a good manifestation for nanoparticle formation. The potential difference between the EDL (electric double layer) of electrophoretically mobile particles and the layer of dispersant around them at the slipping plane is reflected by the zeta potential. It is also termed electrokinetic potential, the potential at the slipping/shear plane of a colloid particle moving under the electric field. Therefore, the particle size distribution and magnitude of electric charge at the particle surface are determined. Thus, another important factor to take into account while assessing novel nanomaterials. Initially, a number of scientists demonstrated that protein adsorption reduced as the hydrophobicity of the nanoparticle's surface decreased following the functionalization of the nanomaterial. Furthermore, the attachment of nanoparticles to plasma proteins like albumin can improve biological characteristics that lengthen blood circulation, decrease toxicity, and lessen the activation of the complement system [30].

The FESEM study provides an excellent micrograph of the surface morphology. The FE-SEM images of green-synthesized iron nanoparticles reveal a predominantly spherical morphology with slight aggregation. At 15,000× magnification, the particles appear uniformly distributed, while at 40,000× magnification, the individual nanoparticles are clearly visible, with sizes approximately ranging from 50 to 100 nm. The surface appears rough, suggesting effective capping by green tea phytochemicals, contributing to nanoparticle stability. The Iron Green Tea Nanocomposite's surface morphology is seen in Figure 5, where the uniformly smooth surface indicates that the FeO nanoparticles are dispersed evenly. The nanocomposite has small pores and a uniform dispersion of FeO nanoparticles due to its strong cross-linked structure. The SEM results demonstrated the homogeneous dispersion of nanoparticles and the highly cross-linked structure of the nanocomposite. Because of the high cross-linking, the nanocomposite might have tiny pores. According to the SEM findings, the nanocomposite's surface shows a few wrinkles that might be brought on by the green extract. The EDS spectrum of iron nanoparticles synthesized using green tea extract confirms the presence of iron (Fe) as the major element, indicated by strong Fe peaks (Fig 6). Additionally, oxygen (O) peaks suggest the formation of iron oxides due to oxidation. EDS quantification shows Fe (58.8 wt%) and O (41.2 wt%).

TEM images of iron nanoparticles synthesized using green tea extract reveal spherical to quasi-spherical morphology with agglomeration (Fig 7). The particle size ranges from 50-100 nm, forming clusters due to surface energy and biomolecule capping. The darker regions indicate dense Fe-rich cores, while lighter edges suggest thin organic layers from phytochemicals, confirming successful green synthesis and nanoscale formation [25, 26].

## IV. Conclusion

In conclusion, this study successfully demonstrates the green synthesis of iron oxide nanoparticles (Fe-GT@NPs) using green tea extract as a natural capping and stabilizing agent. Characterization techniques including FTIR, XRD, FESEM, TEM, and zeta potential analysis confirmed the formation of spherical core-shell structured nanoparticles with good stability and crystallinity. The use of polyphenols in the green tea extract facilitated environmentally friendly nanoparticle formation without the need for toxic chemicals. These iron oxide nanoparticles exhibit promising structural and morphological properties, indicating their potential for diverse industrial and therapeutic applications. The findings support the development of a simple, cost-effective, and sustainable approach to nanoparticle synthesis.

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