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Comparative Study of Structural, Optical, Morphological, and Magnetic Properties of $BiFeO_3$ Nanoparticles Synthesized via Green and Chemical Methods

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Abstract

$BiFeO_3$ nanoparticles were synthesized via a green route using Strychnos nux-vomica *leaf extract and a conventional chemical sol–gel method to study the effect of synthesis routes on their properties. XRD analysis confirmed phase-pure rhombohedral $BiFeO_3$ for both samples. FTIR analysis was carried out to confirm the formation of the perovskite structure and to detect surface functional groups. FESEM analysis indicated a significant effect of phytochemicals in controlling particle growth and morphology. The green-synthesized $BiFeO_3$ nanoparticles showed a reduced band gap (1.98 eV) as compared to chemically synthesized nanoparticles. Both samples exhibited weak ferromagnetism at room temperature, which may be due to size-induced spin canting. The results demonstrate that green synthesis is an effective method for tailoring the functional properties of $BiFeO_3$ nanoparticles.*

Keywords: Strychnos nux-vomica, green synthesis, bismuth ferrite, optical properties

INTRODUCTION

Multiferroic materials have attracted significant research interest due to their ability to exhibit multiple ferroic orders, such as ferroelectricity and magnetism, within a single phase [1–3]. Among these materials, bismuth ferrite ($BiFeO_3$) has been extensively investigated because it simultaneously exhibits ferroelectric and antiferromagnetic ordering at room temperature [4]. In addition to its multiferroic characteristics, $BiFeO_3$ is a suitable material for data storage, sensors, energy harvesting, spintronics, and environmental remediation applications [5].

Various chemical synthesis methods have been used to prepare $BiFeO_3$ nanoparticles. However, these methods often involve toxic chemicals, which are hazardous to our environment [6]. Recently, green synthesis of nanoparticles using plant extracts has gained significant attention from the scientific community [7–9]. Different Phytochemicals present in plant extracts can act as natural reducing, chelating, and stabilizing agents, without requiring any hazardous chemicals. *Strychnos nux-vomica* is a medicinal plant that contains different bioactive compounds and can be used for the synthesis of $BiFeO_3$ nanoparticles [10, 11]. However, there is limited research on the synthesis of $BiFeO_3$ nanoparticles using plant leaf extract and the comparison of properties with chemically synthesized $BiFeO_3$ nanoparticles.

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In the present work, $BiFeO_3$ nanoparticles were synthesized via a conventional chemical route and an eco-friendly green route using *Strychnos nux-vomica* leaf extract. A comparative study was carried out to investigate the influence of synthesis routes on the structural, morphological, optical, and magnetic properties of $BiFeO_3$ nanoparticles.

EXPERIMENTAL SECTION

Green Synthesis of $BiFeO_3$ Nanoparticles

To prepare the plant extract, fresh Strychnos nux-vomica leaves were first cleaned using DI water to eliminate any surface contaminants. Following this, 40 g of the dried leaf material was finely cut and boiled for 15 mins in 200 mL of DI water. Then, the extract was filtered using a filter paper to obtain a reddish–pink solution.

In a typical green synthesis procedure, $BiFeO_3$ nanoparticles were fabricated using bismuth nitrate pentahydrate and iron nitrate nonahydrate as the starting materials. Equimolar solutions (0.05 M) were achieved by integrating 1.21 g of the bismuth precursor and 1.01 g of the iron precursor into a solvent system consisting of 45 mL deionized water and 5 mL of 10% nitric acid. Once fully dissolved, 50 mL of the prepared plant extract was introduced to the mixture under constant stirring at 70°C for 2 hours. The solution was then dehydrated overnight at 80°C. The resulting solid sample was annealed at 550°C for a duration of 4 hours to produce phase-pure $BiFeO_3$ nanoparticles [12].

Chemical Synthesis of $BiFeO_3$ Nanoparticles

The synthesis of $BiFeO_3$ nanoparticles was carried out via a tartaric acid-assisted sol–gel route. Bismuth and iron precursors (nitrate-based) were dissolved in a dilute (10%) nitric acid medium. A 2:1 molar ratio of tartaric acid to metal ions was maintained to facilitate chelation. The resulting solution was stirred at 50°C for 2 hours until a homogeneous sol formed. Following oven-drying and grinding, the material was annealed at 500°C for 4 hours to obtain the crystallized nanoparticles [13].

RESULTS AND DISCUSSION

Structural Analysis

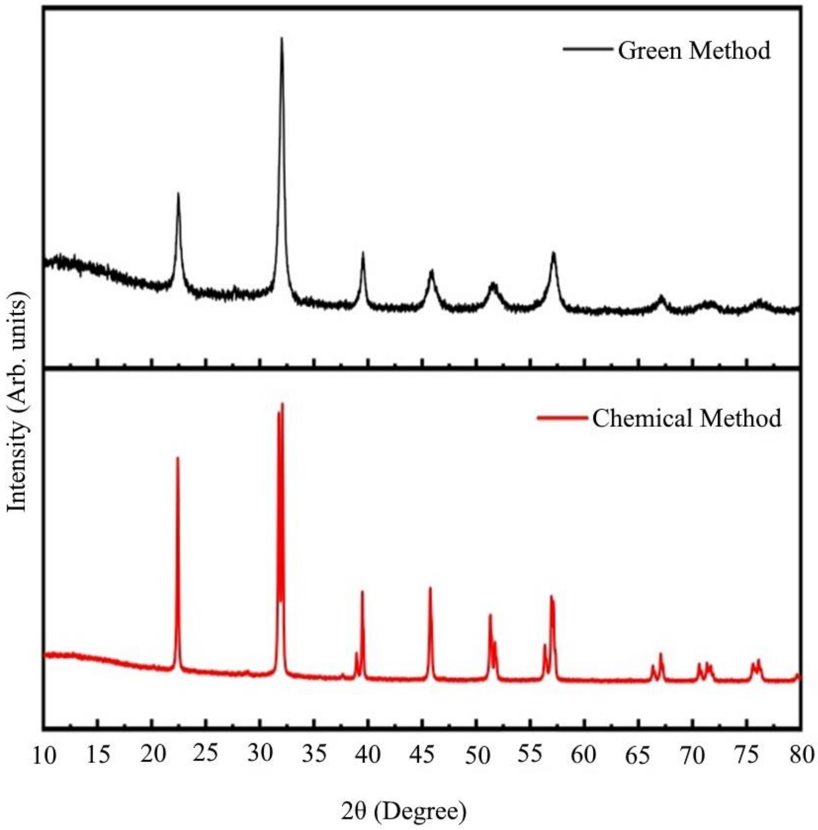
The XRD patterns of prepared $BiFeO_3$ nanoparticles are shown in Figure 1(a). Structural analysis confirms that all diffraction peaks are indexed to the R3c space group, characteristic of a rhombohedral perovskite $BiFeO_3$ lattice, which matches the standard data provided in JCPDS card No. 86-1518 [14]. The average crystallite size estimated using the Debye–Scherrer equation was found to be 16 nm for the green-synthesized $BiFeO_3$ and 28 nm for the chemically synthesized sample.

FTIR Analysis

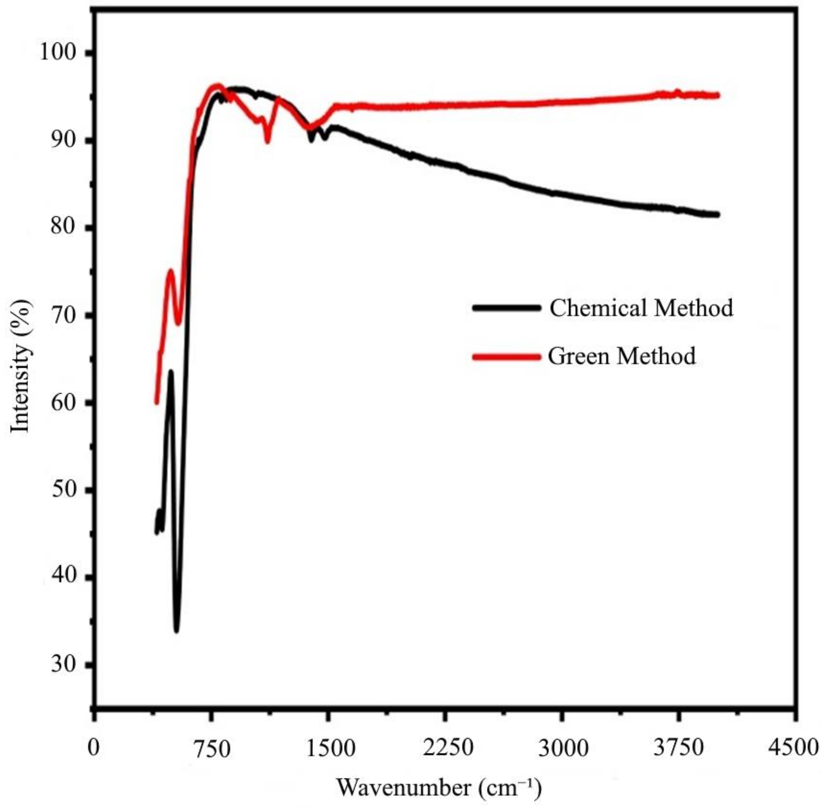
Figure 1(b) shows the FTIR spectra of both samples. FTIR spectra confirm the formation of the perovskite $BiFeO_3$ structure in both samples. The green-synthesized $BiFeO_3$ exhibits characteristic absorption bands at 537 and 429 cm^{-1}, corresponding to Fe–O stretching and bending vibrations of FeO_6 octahedral [15]. Similar bands are observed at 538 and 432 cm^{-1} for the chemically synthesized sample. An additional band at 873 cm^{-1} in the green-synthesized sample is attributed to symmetric O–Bi–O stretching vibrations [16]. Furthermore, in the green synthesized sample, absorption bands at 1043, 1110, and 1373 cm^{-1} indicate the presence of alcohol and carboxylic functional groups originating from phytochemical residues of the plant extract [12]. Similarly, the chemically synthesized $BiFeO_3$ shows bands at 1390 cm^{-1} and 1470 cm^{-1} associated with adsorbed moisture and C–H vibrations, respectively [14].

Morphological Analysis

Figure 2(a) and (b) shows the FESEM images of the prepared samples. The FESEM images reveal that the green-synthesized $BiFeO_3$ nanoparticles consist of nearly spherical and rhombohedral grains, whereas the chemically synthesized $BiFeO_3$ exhibits larger, irregularly shaped particles. EDX analysis confirms the presence of Bi, Fe, and O elements in appropriate stoichiometric proportions in both the samples, as shown in Figure 2(c) and (d).

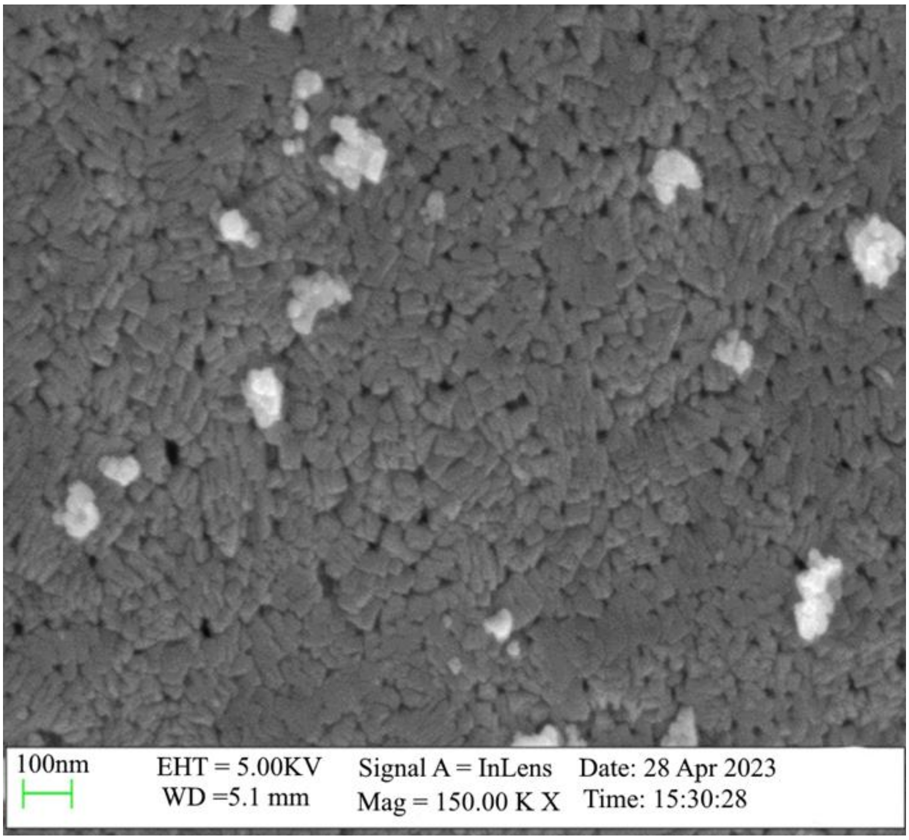


(a)



(b)

Figure 1. (a) XRD and (b) FTIR patterns of prepared samples.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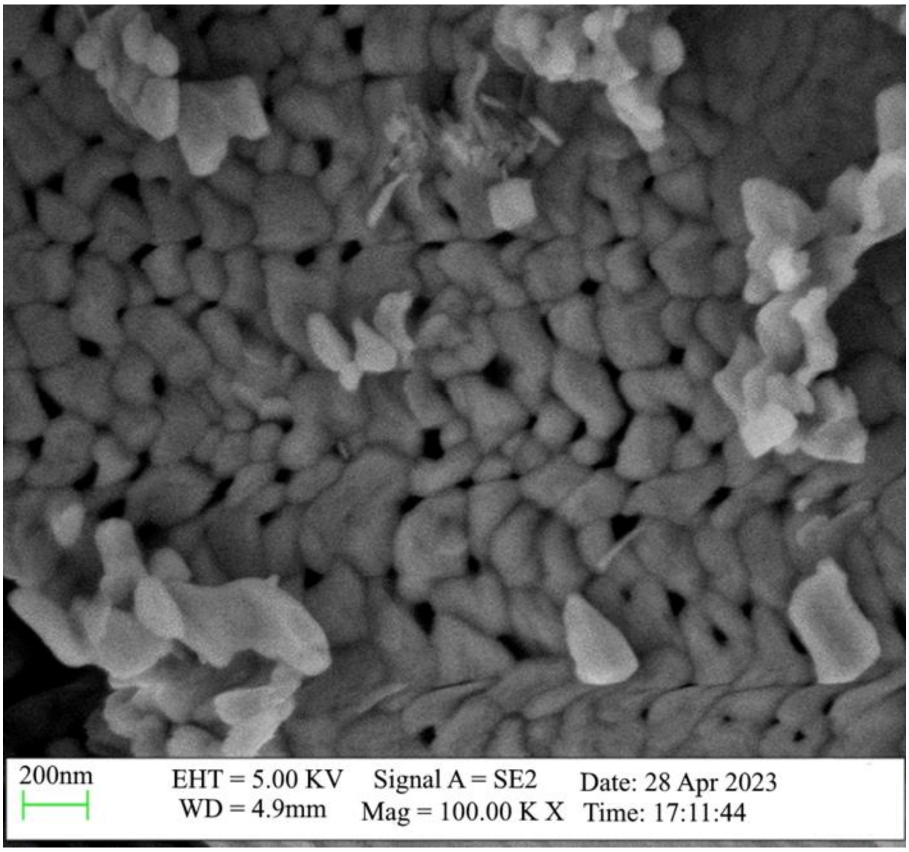
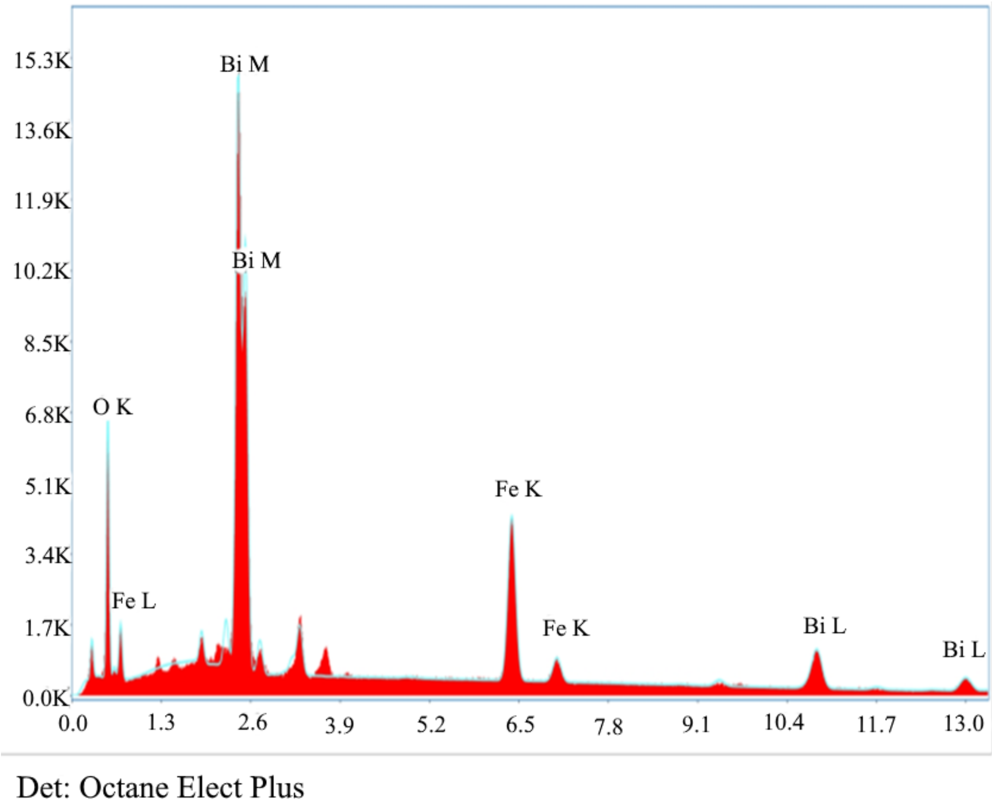
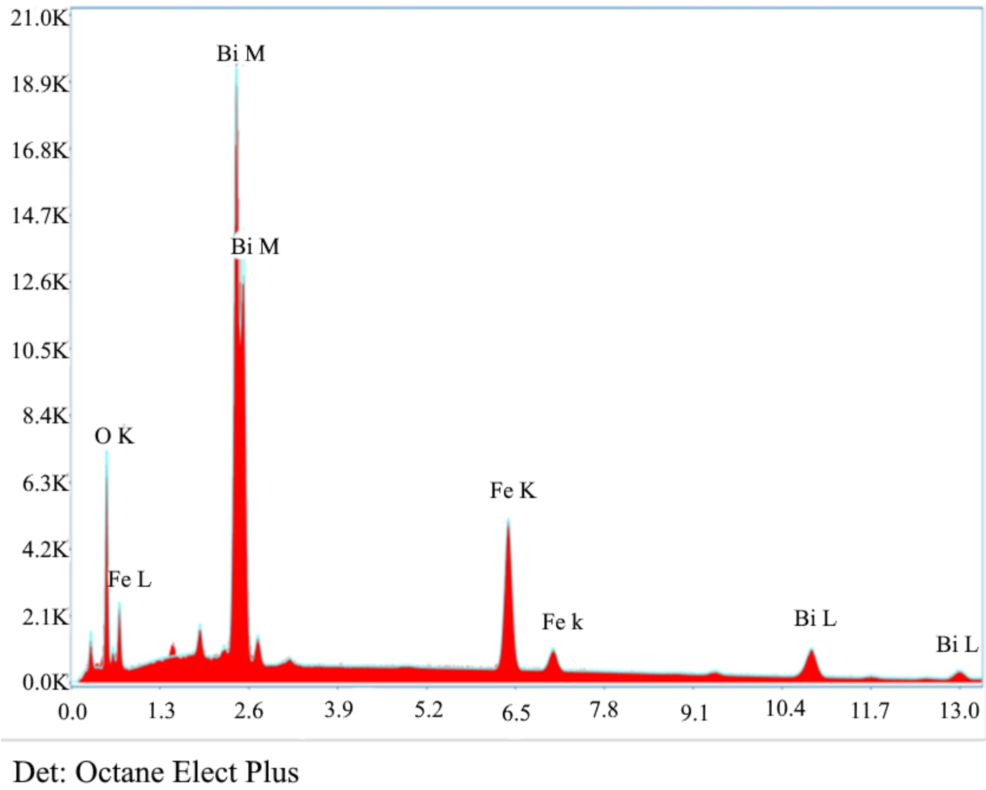
EHT = 5.00KV
WD =5.1 mm
Signal A = InLens
Mag = 150.00 K X
Date: 28 Apr 2023
Time: 15:30:28
(a)


200nm
EHT = 5.00 KV
WD = 4.9mm
Signal A = SE2
Mag = 100.00 K X
Date: 28 Apr 2023
Time: 17:11:44
(b)



(c)

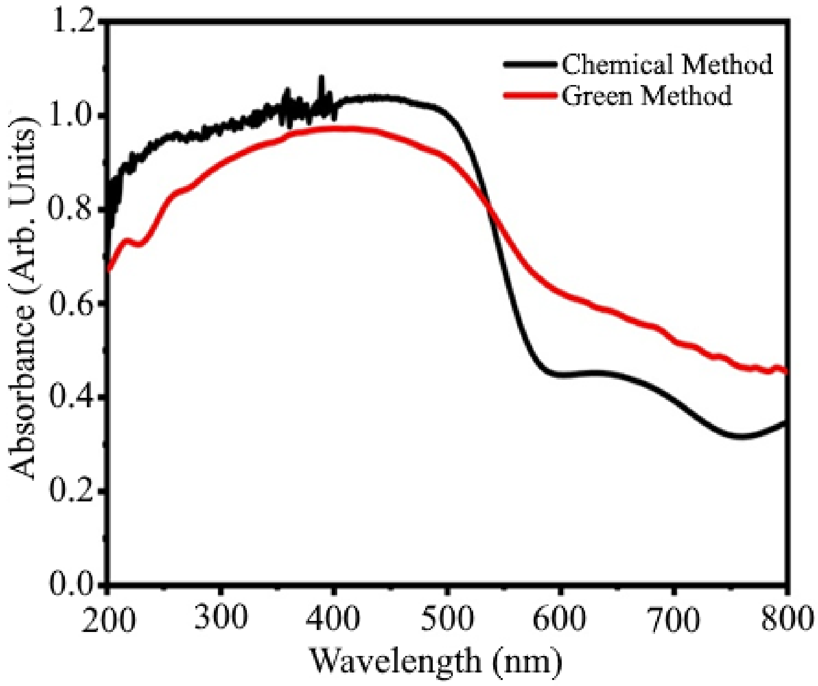


(d)

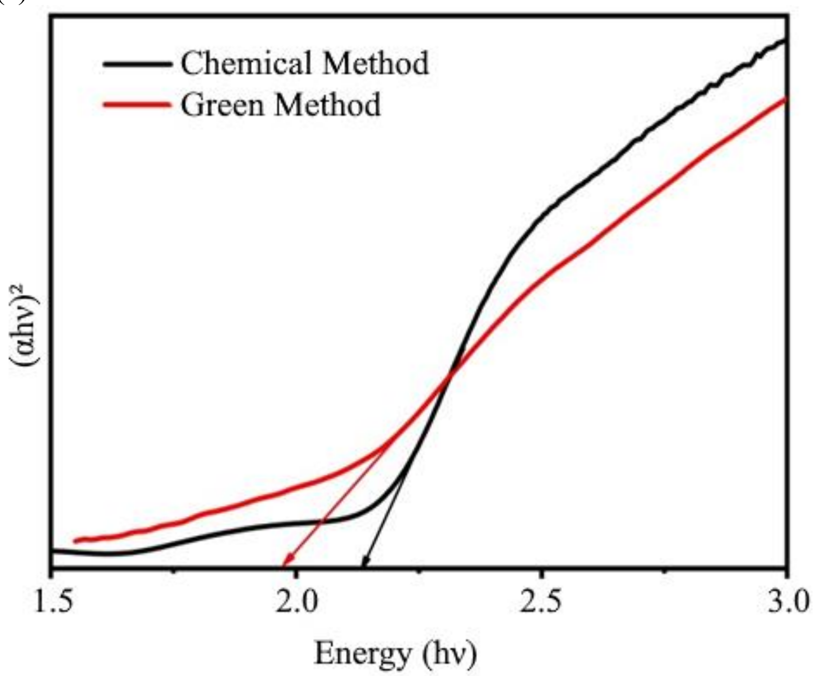
Figure 2. FESEM images of (a) green and (b) chemically synthesized nanoparticles, and EDX spectra of (c) green and (d) chemically synthesized nanoparticles.

Optical Properties

The optical properties of both samples are analysed using UV-Visible spectroscopy as shown in Figure 3(a). UV–visible absorption spectra show enhanced visible-light absorption for the green-synthesized $BiFeO_3$ compared to the chemically synthesized sample. Band gap energies for both samples were estimated using Tauc's relation [17], as shown in Figure 3(b). The green-synthesized $BiFeO_3$ exhibits a bandgap of 1.98 eV, whereas the chemically synthesized sample shows a band gap of 2.2 eV. The decrease in bandgap in the green-synthesized nanoparticles may be due to the presence of oxygen vacancies and defect states introduced during the green synthesis process.



(a)



(b)

Figure 3. (a) Uv-Vis absorption spectra and (b) tauc plot for prepared samples.

Magnetic Properties

Room-temperature magnetic hysteresis (M–H) loops reveal weak ferromagnetic behavior in both green- and chemically synthesized $BiFeO_3$ nanoparticles, as shown in Figure 4. Although bulk $BiFeO_3$ exhibits G-type antiferromagnetism [18], the nanoparticles display non-zero saturation magnetization, remanent magnetization, and coercivity. This behavior arises from the canting of Fe^{3+} spins induced by Dzyaloshinskii–Moriya interactions, which become significant at the nanoscale [19]. The similar magnetic response observed for both samples suggests that weak ferromagnetism is primarily size-dependent rather than synthesis-route-dependent.

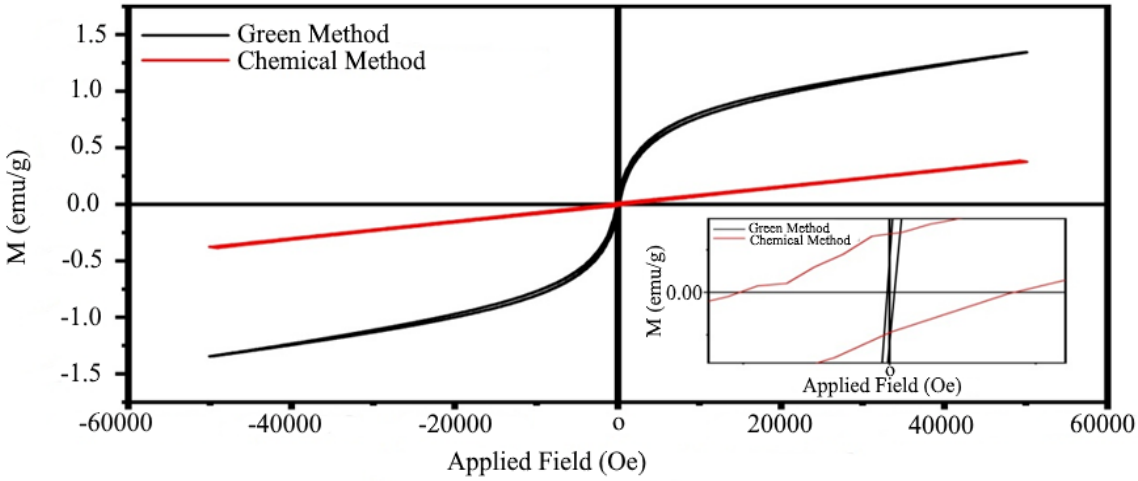


Figure 4. Room temperature M-H plot for prepared samples.

CONCLUSION

$BiFeO_3$ nanoparticles were successfully synthesized using green and chemical methods. The green-synthesized $BiFeO_3$ showed reduced crystallite size, enhanced visible-light absorption, and improved photocatalytic activity compared to the chemically synthesized sample. Weak ferromagnetic behavior was observed in both cases due to nanoscale effects. Overall, the green synthesis route offers a sustainable and efficient approach for enhancing the photocatalytic performance of $BiFeO_3$ nanoparticles.

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