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RESEARCH ARTICLE OPEN ACCESS

PRODUCTION OF COBALT FERRITE NANOPARTICLES VIA GREEN SYNTHESIS USING ALOE VERA

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ABSTRACT

In view of the increasing prominence of environmental issues on the global agenda, the pursuit of sustainable practices has intensified. In the midst of this, green chemistry has emerged as a relevant approach to address the challenges of chemical pollution and promote sustainable practices in industry and research, paving the way for the development of more efficient and eco-friendly technologies in the field of nanomedicine. The present study aimed to explore the fundamentals of green chemistry in the synthesis of cobalt ferrite nanoparticles, which have been studied for various applications, such as medicine. In addition to cobalt nitrate and iron nitrate, we used *Aloe vera* mucilage to synthesize cobalt ferrite nanoparticles. The choice of *Aloe vera* was based on its rich composition of polysaccharides and phytochemicals, which offers stabilizing properties for nanoparticles. The synthesis was performed in a microwave reactor. Analysis of zeta potential and particle size by dynamic light scattering (DLS) revealed variations in sample stability and yielded particle sizes. Scanning electron microscopy (SEM) confirmed the formation of nanoparticles, although differences in morphology and agglomeration were observed among the samples. The results demonstrate that the adopted green synthesis approach shows promising potential for the production of nanoparticles with possible therapeutic applications.

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INTRODUCTION

In recent decades, the intersection of science, sustainability, and innovation has driven the development of new approaches in the search for more ecological and efficient alternatives (Barbieri *et al*., 2010). Green chemistry has emerged as an essential paradigm for promoting the sustainable synthesis of materials, while plant biodiversity offers a rich source of bioactive compounds with broad application potential capable of replacing synthetic agents in industry and research (Lenardão *et al*., 2003). In this context, this study aims to apply green chemistry to the synthesis of cobalt ferrite nanoparticles using *Aloe vera* mucilage as a synthesis agent. Ferrites comprise a class of magnetic materials based on iron oxide (Fe_2O_3) and one or more transition metals. They are widely used in industry because of their ferrimagnetic and insulating properties, which are characteristics that few other materials possess simultaneously (Ristic *et al*., 2017). Like other ferrites in general, $CoFe_2O_4$ offers high stability, both chemically and thermally. Furthermore, cobalt ferrite exhibits unique characteristics compared to other ferrites: Unlike common ferrites, cobalt ferrite exhibits an intense magnetic field and strong magnetocrystalline anisotropy, making it an excellent material for use in permanent magnets, recording media, and magnetic fluids (Ristic *et al*., 2017). *Aloe vera* is an herbaceous plant that grows in any type of soil, requires little water, and is resistant to dry periods. It is heavily exploited by the industry because of its diverse medicinal, pharmacological, and cosmetic applications (Maan *et al*., 2018). *Aloe vera* gel possesses various pharmacological properties such as anti-inflammatory and antimicrobial properties (Choi & Chung, 2003). Its components, especially its polysaccharides and anthraquinones, are molecules that make up plant mucilage and hold important properties, making *Aloe vera* a plant of interest for the synthesis of cobalt ferrites. Aloin is an abundant anthraquinone in *Aloe vera* (Surjushe, Vasani, Saple, 2008) and a natural phenolic compound that acts as a reducer and stabilizer in nanoparticle synthesis, contributing to size control in cobalt ferrite synthesis. In addition, polysaccharides present in *Aloe vera* gel, such as acemannan and glucomannans, can coat synthesized nanoparticles, forming a protective layer on their surface and preventing particle agglomeration (Rashid *et al*., 2024). In recent decades, green chemistry has emerged as an innovative and increasingly essential alternative to environmental and global health challenges faced (Lenardão *et al*., 2003). Given the growing prominence of environmental issues on the global agenda, the search for sustainable practices in industry and research has intensified. Green chemistry thus represents a revolutionary paradigm based on pollution prevention and reducing the environmental impact throughout the life cycle of chemical products (Clark, 1999). This study explores the fundamentals of green chemistry and its application in the green synthesis of cobalt ferrite nanoparticles using *Aloe vera* mucilage as a synthesis agent instead of synthetic agents from non-renewable sources.

MATERIALS AND METHODS

Reagent Preparation: For the synthesis, solutions were prepared with 2.424 g of iron nitrate in 25 mL of Milli-Q water and 0.8734 g of cobalt nitrate in 2 mL of Milli-Q water.

***Aloe vera* Gel Extraction:** *Aloe vera* was obtained from a local vendor. For synthesis B1, an *Aloe vera* leaf was cut in half and the halves were scraped to extract the gel, resulting in 14.205 g of the material. Pure gel with no dilution in water was used for synthesis B1. For syntheses B2 and B3, another leaf was cut in half and scraping was performed in the same way, resulting in 16 g of gel, which were mixed with 5 mL of Milli-Q water, forming an organic *Aloe vera* solution.

Microwave-Assisted Synthesis: Three syntheses were performed in an Anton Paar Monowave 200 microwave reactor for 20 min at 110 °C. The following were used in each synthesis: 2 mL of cobalt nitrate solution, 2 mL of iron nitrate solution, 2 mL of gel/organic *Aloe vera* solution.

Sample Purification: Subsequently, the samples were washed twice with Milli-Q water in a centrifuge and finally once in 70% alcohol. Each centrifugation lasted 10 min at 1200 RPM. The precipitates were collected and left in an oven for 48 h to dry at 80 °C. The samples were subjected to a muffle furnace for 2 h at 500 °C and ground before and after the process.

Particle Size and Zeta Potential Analysis: The samples were measured using an Anton Paar Litesizer 500 dynamic light scattering (DLS) instrument in disposable cuvettes for particle size analysis. In addition, the zeta potential was evaluated using a microelectrode flow cell cuvette.

Scanning Transmission Electron Microscopy (STEM): Scanning electron microscopy was performed to study and analyze the size and morphology of the synthesized ferrites. A small amount of sample powder was dispersed in water and the solution was deposited onto a carbon grid fixed to a sample holder, which was inserted into a Tescan VEGA3 scanning electron microscope.

RESULTS AND DISCUSSION

Green chemistry is becoming an increasingly crucial philosophy for addressing environmental issues arising from chemical activity as it aims to prevent negative impacts in contrast to traditional approaches (Lenardão *et al*., 2003). With this in mind, our research sought to adhere to the viable principles of green chemistry by choosing an organic agent over synthetic agents to coat and control the particle size generated in the synthesis (Saratale *et al*., 2018). Metallic nanoparticles show promise in the search for innovative treatments because of their optoelectronic and physicochemical properties, which are related to factors such as size, shape, crystallinity, and structure. Synthesis of metallic nanoparticles such as cobalt ferrites using biological organisms is a clean, economical, and efficient technique (Islan *et al*., 2017). The purpose of the synthesis was to produce nanoparticles with potential therapeutic applications following the principles of green chemistry using *Aloe vera* as an organic source, a plant that is widely exploited by the industry, readily accessible, and cultivable (Kumar & Bhatnagar, 2014). The synthesis occurred in a microwave reactor, with the insertion of reagents and organic molecules from *Aloe vera*, which serve to coat and control the growth of the cobalt ferrites generated, thus providing more precise control over the process, from its polysaccharide gel (Rashid *et al*., 2024).

Table 1. Particle Size Distribution Results

	Peak 1			Peak 2		
Sample	Size (nm)	Area (%)	Standard deviation (nm)	Size (nm)	Area (%)	Standard deviation (nm)
B1	169.75	100	202.2	-	-	-
B2	290.2	74.43	196.07	33.44	25.57	11.17
B3	546.7	65.89	290.7	34.26	34.11	12.55

Table 2. Mean Particle Size and Zeta Potential Results

	B1	B2	B3
Hydrodinamic Diameter (nm)	114.51	186.42	305.3
Polydispersity Index (%)	27.1	24.4	27.6
Transmittance (%)	81.9	83.5	83.4
Mean zeta potencial (mV)	-16.7	-23	-12

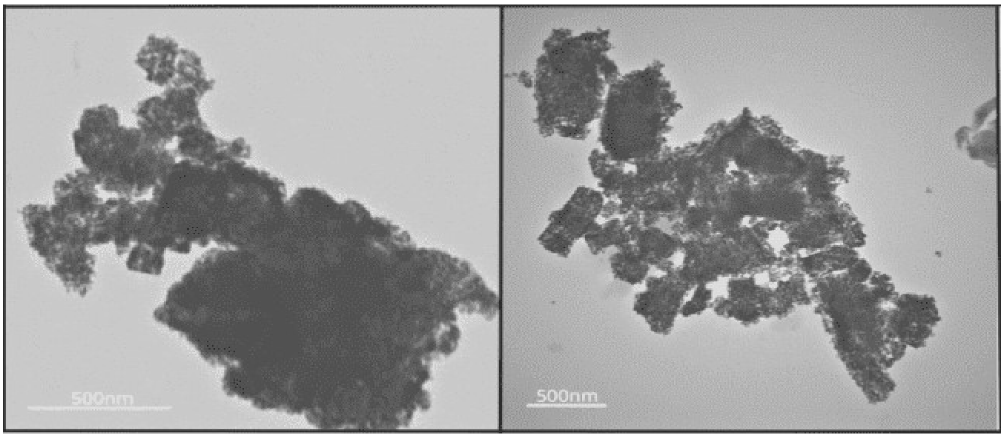

Figure 1. STEM images from sample B1

Dynamic light scattering (DLS) analysis revealed the particle size of each of the synthesized cobalt ferrite groups (Table 1).Additionally, zeta potential analysis of the three samples was performed to assess the tendency of each to aggregate. Table 2 summarizes the zeta potential results obtained alongside the particle size analysis data of the samples. Although the samples exhibited particles larger than 100 nm, all syntheses performed using *Aloe vera* were able to successfully synthesize nanoparticles, as particles up to 100 nm were found in all samples (Murthy, 2007).

The closest similarity in the particle size profile analyzed is noticeable between B2 and B3, as both samples resulted from syntheses with the same parameters, although there are still differences between the samples. In B3, despite a satisfactory nanoparticle range, a wide range of much larger particles was still observed, suggesting that this synthesis resulted in more agglomerations (Walter, 2013), resulting in larger average hydrodynamic diameter. Sample B1 exhibited the smallest average size and a more uniform particle size profile, characterized by a single

Figure 2. STEM images from sample B2

Figure 3. STEM images from sample B3

peak. A possible explanation for such smaller average particle size lies in the use of undiluted *Aloe vera* mucilage, indicating that a more viscous and less diluted gel may offer greater control over particle growth. The viscosity of a fluid is directly related to resistance to movement or flow (Hack, 2018). Therefore, higher viscosity implies greater resistance to particle growth during synthesis. On the other hand, samples B2 and B3 exhibited larger mean particle sizes compared with B1, which may be attributed to less resistance during the particle growth process, as the mucilage used was diluted in water, resulting in a less viscous synthesis environment (Hack, 2018). Images of sample B1 (Figure 1) revealed many aggregates, although the ferrites synthesized showed satisfactory sizes when analyzed by DLS below 100 nm. STEM analysis of sample B2 (Figure 2) showed nanoparticle size variation between 10 and 30 nm with less agglomeration compared with B3 (Figure 3) and the presence of fine elongated structures (Figures 2B and 2C), similar to ferrites previously obtained in syntheses from *Aloe vera* (Manikandan *et al*., 2014). STEM analysis performed on sample B3 revealed the presence of larger hexagonal-shaped structures (Figures 3B, 3C and 3D), approximately 200 nm in size, while sample B2 also exhibited nanoparticles of approximately 40 nm in agglomerates (Figure 2D). The discrepancy between the crystalline structures formed also indicates that the synthesis conditions influence the results so that even small variations in the conditions lead to different structures of the synthesized samples (Hassanien, Akl, Sáaedi, 2018). Although smaller sizes were observed in B1, microscopy results indicate greater agglomeration in the sample, and the zeta potential obtained for it contributes to explaining the presence of aggregates when compared to B2, which had a lower presence of aggregates and a zeta potential closer to 30 in absolute value, indicative of stability and a tendency not to aggregate (Luxbacher, 2014). Indeed, samples that achieved zeta potential values greater than 30 had a higher presence of aggregates when observed by microscopy. Observations of the structures in B2 and B3 revealed that nanoparticles with a crystalline morphology similar to that in previous studies on *Aloe vera* synthesis were generated (Hassanien *et al*., 2018, Rao *et al*., 2015). The presence of nanoparticles with suitable sizes for potential therapeutic applications in all samples synthesized demonstrates the success of the approach adopted (Petros & De Simone, 2010), indicating that the polymers present in *Aloe vera* mucilage are a valid and more sustainable alternative for nanoparticle synthesis, replacing synthetic polymers (Ahmadi, Jafarizadeh-Malmiri, Jodeiri, 2018).

CONCLUSION

The use of *Aloe vera* as an organic source proved to be effective in the production of cobalt ferrite nanoparticles, providing a cleaner, more economical, and efficient means for the synthesis of these materials based on green chemistry principles. Analysis of the results revealed variations in the characteristics of the synthesized nanoparticles, such as size, morphology, and stability, attributed to different synthesis parameters and reagent compositions. Despite the variations observed, the results obtained provide a foundation for future studies in the field of cobalt ferrite nanoparticle synthesis using green methods. The continuation of this research could lead to the development of new materials with optimized properties for therapeutic applications, contributing to advancements in the field of nanotechnology and medicine.

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