

Research Article

Green Cobalt Nanoparticle Synthesis, Characterisation, Magnetic Properties, and Phytostimulatory Impacts of *Moringa oleifera* Leaf Extract

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Abstract

The distinctive structural, chemical, magnetic, and biological characteristics of cobalt nanoparticles (CoNPs) have garnered significant interest. In this work, *Moringa oleifera* leaf extract and cobalt nitrate solution were used in an eco-friendly green synthesis method to create cobalt nanoparticles. The crystalline structure, functional groups, and magnetic behavior of the synthesized CoNPs were examined using X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FT-IR), and vibrating sample magnetometry (VSM). Characteristic diffraction peaks were identified by XRD analysis with 2θ values of 36.2° , 43.1° , 50.4° , and 73.9° , corresponding to the (311), (400), (422), and (533) planes. The diffraction pattern matched JCPDS card No. 22-1086 and was compatible with the stated cubic spinel structure. The Scherrer equation yielded an average crystallite size of 18.37 nm. Along with Co–O-related vibrations, FT-IR analysis showed absorption bands at 3376, 1656, 591.99, and 495 cm^{-1} , suggesting the role of hydroxyl-containing and other functional groups in the production and stabilization of the nanoparticles. The produced CoNPs' magnetic nature was validated by VSM analysis. Canola plants were used to assess the synthesized nanoparticles' biological and agronomic applications. At lower concentrations, CoNP treatment increased shoot fresh weight, shoot dry weight, and shoot length; the greatest growth response was shown at 50 ppm. Plant growth decreased at higher doses, suggesting that CoNPs may have a concentration-dependent harmful impact. These results show that magnetic cobalt-based nanoparticles with potential uses in nanotechnology, agriculture, and biomedicine may be produced easily and sustainably by *Moringa oleifera*-mediated synthesis. These results show that magnetic cobalt-based nanoparticles with potential uses in nanotechnology, agriculture, and biomedicine may be produced easily and sustainably by *Moringa oleifera*-mediated synthesis.

Keywords: XRD, FT-IR, VSM, cobalt nanoparticles, green synthesis, *Moringa oleifera*, canola, plant growth, and magnetic nanoparticles.

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1. Introduction

The production, characterization, and use of materials with dimensions typically falling within the nanoscale range are all part of the growing multidisciplinary topic of nanotechnology. Because of their small particle size, huge surface-to-volume ratio, and size-dependent structural and electrical features, nanomaterials can have physicochemical properties that are significantly different from those of their bulk counterparts. Cobalt-based nanoparticles are particularly significant among metallic and metal-oxide nanomaterials due to their optical, biological, magnetic, and catalytic characteristics [1], [2]. For use in magnetic materials, catalysis, sensing,

biomedical technology, and environmental remediation, cobalt nanoparticles have garnered growing scientific attention. Applications requiring magnetic separation, targeted delivery systems, imaging-related technologies, and other magnetically controlled processes find them especially appealing due to their magnetic characteristics. The size, crystal structure, shape, surface chemistry, and magnetic properties of cobalt nanoparticles all have a significant impact on their performance [3],[4].

High temperatures, high pressures, hazardous reducing agents, organic solvents, and other ecologically undesirable substances can all be used in conventional methods for the production of nanoparticles. These methods may raise the expense and environmental impact of producing nanoparticles, as well as produce harmful byproducts. As a result, green synthesis has drawn a lot of interest as a different method for creating nanoparticles [1], [4], [5]. Because plant extracts include naturally occurring biomolecules that can take part in the reduction, nucleation, growth, and stabilisation of nanoparticles, plant-mediated synthesis is one of the most appealing green synthesis techniques. Plant extracts contain polyphenols, flavonoids, proteins, carbohydrates, organic acids, and other phytochemicals that can interact with metal ions and aid in the creation of nanoparticles. Plant-mediated synthesis can offer a rather easy and affordable method for producing nanoparticles in addition to being ecologically benign [3], [6]. Numerous physiologically active phytochemicals may be found in the well-researched medicinal and nutritious plant *Moringa oleifera*. Numerous substances found in its leaves may contribute to the stabilisation and reduction of metal nanoparticles. *Moringa oleifera* leaf extract is therefore a biological substance that shows promise for the environmentally friendly production of nanomaterials [4], [7]. The current work used a green synthesis method to create cobalt nanoparticles utilising leaf extract from *Moringa oleifera*. FT-IR spectroscopy was used to detect significant functional groups linked to the synthesised nanoparticles, VSM was used to examine their magnetic behaviour, and XRD was used to examine their crystal structure and estimate their crystallite size. Additionally, the impacts of the synthesised CoNPs on certain canola plant development indices, such as shoot fresh weight, shoot dry weight, and shoot length, were assessed [5], [7], [8].

Therefore, the study's goals were to create cobalt nanoparticles utilising a green synthesis method and leaf extract from *Moringa oleifera*. Use XRD to examine the crystallite size and structural characteristics of the produced CoNPs [9]. Use FT-IR spectroscopy to identify significant functional groups connected to the produced nanoparticles. Using VSM, ascertain the magnetic characteristics of the produced CoNPs. Examine how various CoNP concentrations affect particular canola plant development characteristics. Analyze the produced CoNPs' potential for use in agriculture and other technical fields [7], [8], [10].

2. Materials and Methods

2.1. Green Cobalt Nanoparticle Synthesis and Characterizations

A green synthesis method was used to mix the plant extract with a 1 M cobalt nitrate solution. The leaf extract's phytochemical components reacted with the cobalt precursor to promote the creation of nanoparticles. After that, the material was treated to produce powdered cobalt nanoparticles for further analysis. Three main methods were used to characterize the synthesized CoNPs: Fourier transform infrared spectroscopy, vibrating sample magnetometry, and X-ray diffraction. Confirmation of magnetism was carried out using VSM (Lakeshore, 7407 USA). For XRD, a Bruker D8 Advance X-ray diffractometer ($\text{CuK}\alpha$: $\lambda = 1.5407 \text{ \AA}$; $1.5^\circ/\text{min}$ scanning rate: $40 \text{ kV}/35 \text{ mA}$) was used. MRI was carried out using a Siemens 0.35T MRI open MRI (Hi Tech, USA).

2.2. X-Ray Diffraction Analysis

The crystalline structure of the synthesized material was studied by X-Ray diffraction (XRD) analysis. Bruker-D8 Advance Laboratory Diffractometer (with $\text{CuK}\alpha 1$ radiation, $\lambda = 1.54 \text{ \AA}$). XRD analysis along with the Scherrer equation ($D_{hkl} = k \lambda / \beta \cos \theta$) was employed to study phase identification, crystallinity, and average particle size [11].

2.3. Vibrating Sample Magnetometer Analysis

A vibrating sample magnetometer (VSM) was used to verify the synthetic material's magnetic properties. According to the previous protocol, the Saturation magnetization, Retentivity, and Coercivity of the hysteresis loop were studied with a VSM (Lakeshore 7407) [12], [13].

3. Results

3.1. Size and Morphology Analysis

The size and structural composition of a single unit cell are examined using the X-ray diffraction method. For X-ray diffraction, the generated Cobalt nanoparticles (CoNPs) were used in powder form.

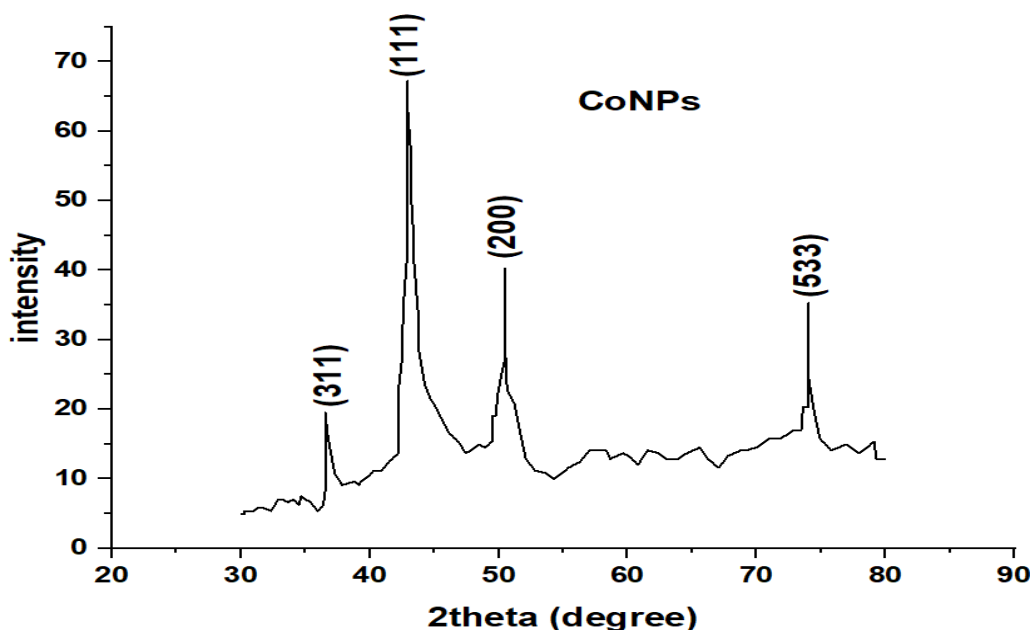


Figure 1. XRD pattern of the produced CoNPs.

The XRD pattern of the produced CoNPs is shown in Figure 1, with diffraction peaks at angles of 36.70, 43.10, 50.40, and 73.90. The hkl values corresponding to these peaks are (311), (400), (422), and (533). The XRD card number 22-1086 matches all of the produced sample's peaks and their locations on the 2theta scale, which are compatible with the distinctive cubic spinel peaks [1], [13], [14]. It was discovered that the cobalt crystallite size was 18.3 ± 7 nm.

3.2. Fourier Transform Infrared Spectroscopy Analysis

The relationship between different species and modifications in the mixture's chemical structure is investigated using Fourier transform infrared spectroscopy. Figure 2 displays the infrared spectra of CoNPs obtained using the green method, which were recorded in the 400–4000 cm^{-1} range. CoNPs made using the green synthesis approach exhibit absorption peaks at 3376, 1656, 591.99, and 495 cm^{-1} , respectively, which represent the stretching vibration of Co-O, the bending mode of the water molecule, and O-H stretching [15], [16].

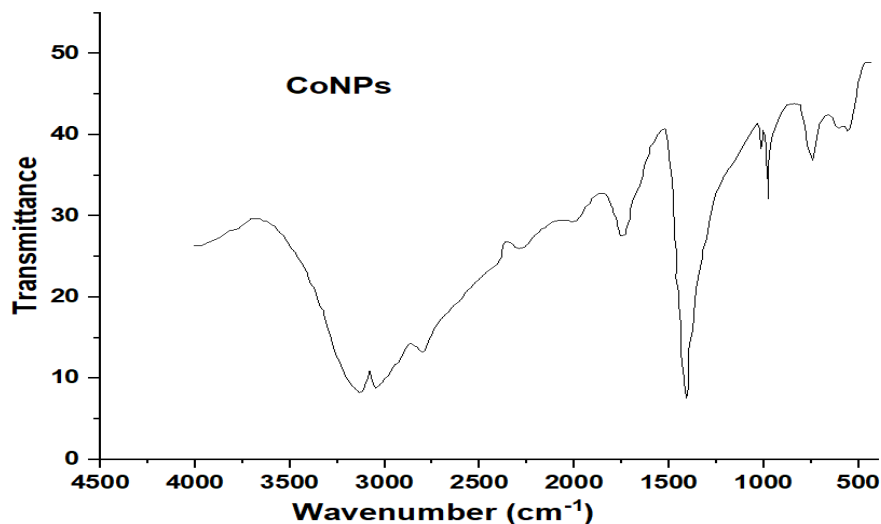


Figure 1. FTIR analysis of Cobalt nanoparticles using *Moringa oliefera* leaves extract.

3.3. Vibrating Sample Magnetometer

The magnetic properties of the produced Cobalt nanoparticles made from the extract of *Moringa oliefera* leaves were investigated using VSM analysis. Figure 3 displays the magnetization vs. magnetic field curve [16], [17]. The magnetic property of the synthesized cobalt nanoparticles is supported by their maximum saturation magnetization of 24.083 emu/s. The ferromagnetic nature of these synthetic cobalt nanoparticles is demonstrated by the VSM analysis graph. Cobalt nanoparticles have a coercivity of 495 Oe and a retentivity of 8.606 emu/g. Soft magnetic materials are anticipated to be used in a variety of biological applications, including gene transfer, immunological testing, cell separation, magnetic resonance imaging (MRI), and drug administration.

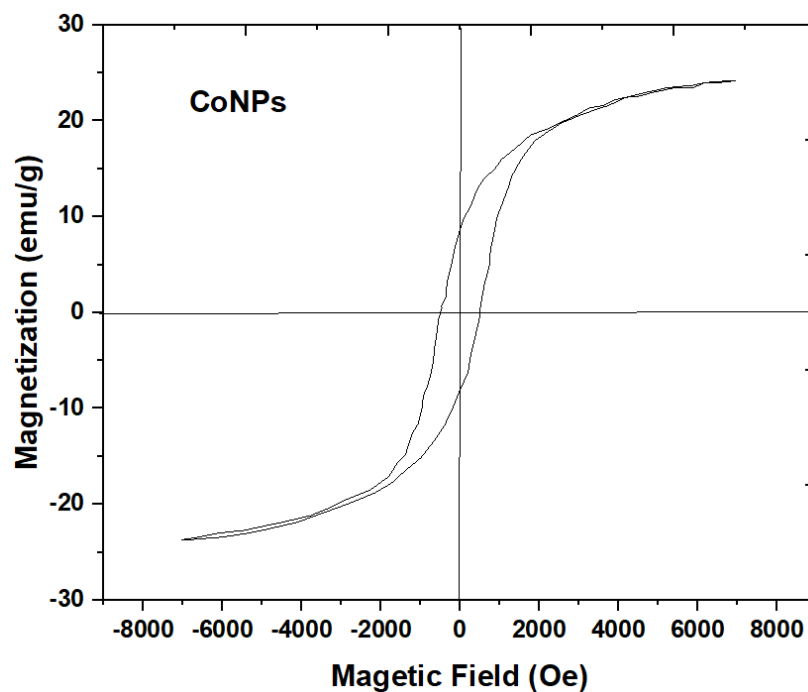


Figure 3. VSM analysis of Cobalt nanoparticles using *Moringa oliefera* leaves extract.

3.4. Effect of Cobalt Nanoparticles on Canola Plant Growth

The impact of the synthesized CoNPs on certain canola plant development traits was further examined. Shoot fresh weight, shoot dry weight, and shoot length were the factors that were assessed. The findings show that the reaction is concentration-dependent. Plant growth was typically enhanced by lower concentrations of CoNPs, but growth characteristics decreased when the concentration was raised above the optimal threshold. This behaviour suggests that, whereas cobalt nanoparticles may be advantageous at suitable doses, they may become harmful at higher doses. When considering nanoparticles for agricultural uses, such concentration-dependent reactions are crucial. Because it reflects the mass of recently harvested plant tissue, shoot fresh weight is a crucial metric for evaluating plant development and biomass buildup.

Plants treated with 50 ppm CoNPs (T1) had the maximum fresh weight of canola shoots, measuring about 2.75 g plant⁻¹. The fresh weight of plants treated with 100 ppm CoNPs (T2) was around 2.60 g plant⁻¹. By contrast, the fresh weight of about 2.30 g plant⁻¹ was the lowest for the untreated control (T0). These findings show that, in comparison to the untreated plants, CoNP treatment at comparatively low concentrations increased the generation of fresh biomass. The increased fresh weight could suggest that plant physiological processes can be positively impacted by a suitable concentration of CoNPs. The decrease at greater concentrations, however, indicates that there may be an optimal concentration for the positive impact, after which plants may experience stress from nanoparticle exposure.

9. Discussion

The results of this study show that *Moringa oleifera* leaf extract may be used to successfully synthesize cobalt-based nanoparticles utilizing a green synthesis method. Using the Scherrer equation, XRD examination yielded an average crystallite size of 18.37 nm, confirming the synthesized material's crystalline nature [2], [16], [18]. The existence of significant functional groups connected to the synthesized substance was shown by the FT-IR data. Oxygen-containing vibrations and the O–H-related band show how phytochemical components from *Moringa oleifera* leaves contribute to the synthesis and stabilization of nanoparticles. Co–O vibrations were linked to the low-wavenumber bands that were seen.

The magnetic nature of the produced nanoparticles was further shown by the VSM data. Retentivity of 8.606 emu/g, coercivity of 495 Oe, and saturation magnetization of 24.083 emu/g were recorded [7], [15], [19]. These characteristics lend credence to the synthetic material's possible usage in magnetic applications. The plant-growth experiment showed that the nanoparticles can also have concentration-dependent effects on biological systems. In comparison to the untreated control, canola shoots treated with reduced CoNP concentrations had better fresh weight, dry weight, and shoot length. At 50 ppm, the greatest reaction was often seen. However, plant growth was significantly reduced at higher doses, especially 500 ppm.

An interesting finding for the possible application of nanoparticles in agriculture is this concentration-dependent reaction. At the right doses, nanomaterials may have positive benefits, but too much exposure might cause physiological stress and stunted growth. Therefore, prior to actual agricultural use, nanoparticle concentration optimisation is crucial. Cobalt nanoparticles produced by *Moringa oleifera* show promise as a multifunctional nanomaterial due to their green production, nanoscale crystallite size, magnetic behaviour, and biological activity. However, further research is needed to determine their exact magnetic structure, shape, elemental composition, surface chemistry, and long-term biological impacts.

Author Contributions

All authors contributed equally to conceptualization, methodology, writing, and editing.

Conflict of Interest

The authors declare no conflicts of interest.

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