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Biogenic Synthesis and Comprehensive Characterization of Zinc Oxide Nanoparticles Utilizing Hemidesmus indicus Root Extract

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ABSTRACT

Nanoparticles possess distinct characteristics when compared to their larger bulk forms, and they hold promise for a wide range of applications across various areas of biological science domains. Eco-friendly synthesized nanoparticles have attracted significant attention because of their natural characteristics, including speed, environmental friendliness, and affordability. In this study root extract of *Hemidesmus indicus* served as both a reducing and capping agent in the environmentally friendly synthesis of zinc oxide nanoparticles. The synthesized zinc oxide nanoparticles were analysed using Ultraviolet-Visible spectroscopy, Fourier Transform Infrared spectroscopy, X-Ray Diffraction spectroscopy and Field Emission Scanning Electron Microscope techniques. The UV-Vis spectra indicated that the zinc oxide nanoparticles exhibited a maximum absorption peak at 274 nm. The bandgap of the ZnO NPs was also investigated. Different functional groups played a role in the capping and stabilization of the zinc oxide nanoparticles, as verified by FTIR analysis. The XRD pattern was compared with the standard confirmed spectrum of ZnO NPs produced in the current experiments. The XRD pattern indicates that the ZnO nanoparticles are free of contaminants. The morphology of the nanoparticles is examined using FE-SEM.

Keywords: *Zinc oxide, green synthesis, Nanoparticles, Hemidesmus indicus*

1. INTRODUCTION

The survey conducted last year indicated that nanotechnology is emerging as a valuable technology in the scientific field. The nanoparticles created as nanoscale materials are tiny particles that range in size from 1 to 100 nm and display unique characteristics [1]. Nanotechnology allows for the creation of distinctive nano structures, the exploration of their innovative properties, and the use of these structures across various fields. Nanotechnology has garnered considerable interest in the healthcare, engineering, and food sectors by presenting innovative opportunities in these areas [2]. Nanotechnology encompasses a range of synthesis techniques, modifications of particle sizes, and changes in the structures of nanoparticles [3].

Nanoparticles can be categorized into two types: organic and inorganic nanoparticles. Metal and metal-derived oxide nanoparticles fall under the category of inorganic nanoparticles, while solid lipid nanoparticles, polymeric nanoparticles, lipid-based nanocarriers, liposomes, and carbon-based nanomaterials are classified as organic nanoparticles. Inorganic substances like metals and metal oxides are favoured over biological materials because of their strength and longevity [4]. Metal oxide nanoparticles have garnered significant attention for their properties as antimicrobial and anticancer agents. The technique employed to produce metal nanoparticles is a crucial element [5]. Nanoparticles can be produced using chemical, physical, or biological techniques. Various chemical and physical techniques, such as precipitation, microwave processing, hydrothermal methods, lithography, and more, necessitate specialized equipment and trained personnel. Moreover, they have a detrimental impact on human health [6]. On the other hand, the biological techniques employed for nanoparticle synthesis are cost-effective, non-toxic, and environmentally friendly. The use of natural resources like leaves, roots, and flower extracts, along with microorganisms such as bacteria, fungi, and algae, represents environmentally friendly approaches to synthesizing nanoparticles that involve fewer harmful substances [7].

The green synthesis approach offers several benefits compared to chemical and physical methods, including being environmentally friendly, cost-effective, biocompatible, and safe. The possible application of metal and metal oxide nanoparticles is influenced by the type of metal utilized in their biogenic synthesis Various metal and metal oxide nanoparticles, such as Ag, Ce, Zr, MgO, Al_2O_3, MnO_2, CaO, and others, were produced using environmentally friendly methods for a range of biomedical uses [8]. Zinc oxide is a non-toxic, inorganic metal oxide that has garnered considerable interest due to its safety, compatibility with biological systems, and cost-effectiveness. ZnO nanoparticles are particularly noteworthy when compared to other metal oxide nanoparticles due to their wide range of applications, including in optics, energy, pigments, catalysis, and gas sensing. Furthermore, ZnO nanoparticles have been shown to exhibit anticancer, drug delivery, antimicrobial, and antioxidant capabilities [9].

The aim of this research was to bio-fabricate ZnO nanoparticles through a straightforward and environmentally friendly method, utilizing the extract from the *Hemidesmus indicus* root as a reducing agent, along with zinc acetate and zinc nitrate as precursors. The biosynthesized ZnO nanoparticles were analyzed using UV-Vis, FTIR, XRD, and FE-SEM techniques. This research aims to improve the application of *Hemidesmus indicus* derived ZnO nanoparticles in biomedical fields.

2. MATERIALS AND METHODS

Materials

The roots of *Hemidesmus indicus* were collected in Chennai. Zinc nitrate hexahydrate (Zn $(NO_3).5H_2O$), sodium hydroxide (NaOH), and ethanol were obtained from SRL Chemicals in India.

Preparation of root extract

The collected *Hemidesmus indicus* roots were thoroughly washed in distilled water to eliminate all dust and dirt. The dried roots were ground into a fine powder to create the powdered form. Ten grams of the dried powder were boiled with 100 mL of distilled water and extracted using reflux conditions at a temperature of 60-80 °C for two hours. The aqueous root extract was prepared by allowing the mixture to cool to room temperature and then filtering it with Whatman No. 1 filter paper. Prior to its application in the production of ZnO nanoparticles, the aqueous extract was kept in a refrigerator at 4 ℃.

Green synthesis of ZnO NPs

Approximately 0.1 M of zinc nitrate hexahydrate was dissolved in distilled water. Subsequently, 20 mL of the root extract solution was incorporated. The mixture was stirred vigorously in a magnetic stirrer for two hours at a temperature of 80 ℃. Once the reaction was finished, the resulting precipitate was permitted to settle, and it had formed. The precipitate was isolated from the reaction solution by centrifuging at 10,000 rpm for 20 minutes. After washing with distilled water and ethanol, the samples were dried in an air oven at 80 ℃ for 6 hours. Once dried, the ZnO nanoparticles were ground into a powder and kept in a sealed container.

Characterization

The ZnO nanoparticles produced using plant-based methods were analysed for their morphology using various techniques, including UV-vis, FT-IR, XRD, and FE-SEM. The synthesis of ZnO nanoparticles was confirmed by examining the absorption band observed with a UV-visible spectrophotometer (JAZ Ocean optics, USA). In a similar manner, the stretching of the Zn-O bond and the secondary metabolites found in the plant extracts were examined using FT-IR (Perkin Elmer Spectrum 2, USA). An X-ray diffraction pattern was obtained using the (Rigaku smart lab, Japan) to assess the level of crystallinity in the synthesized ZnO nanoparticles. The surface composition and particle size of ZnO nanoparticles were examined using FE-SEM (ZEISS SIGMA 300, Germany).

3. RESULT AND DISCUSSION

X-ray diffraction analysis

Powder X-ray diffraction spectroscopy verified the creation of ZnO nanoparticles that were produced using the green synthesis technique. Figure 1 displays the XRD pattern of ZnO nanoparticles that were synthesized using a green method. The sharp and intense diffraction peaks indicate the well-crystalline quality of the synthesized nanoparticles. The XRD analysis of ZnO nanoparticles revealed seven distinct peaks within the 2Θ range of 20º to 80º. The diffraction pattern displayed prominent peaks at 2θ angles of 31.46º, 34.88º, 36.66º, 46.86º, 54.99º, 61.54º, and 68.26º, which are associated with the indices (100), (002), (101), (102), (110), (103), and (112) respectively [10]. The acquired data was analyzed in relation to JCPDS card number 36-1451 [10]. The sizes of nanoparticle crystallites were determined using Scherrer's method (1) by analyzing the most prominent peak in the XRD pattern [11].

$$D = K\lambda/\beta \cos\Theta \quad (1)$$

In this equation, D represents the average size of the crystallites (nm), K is a constant value set at 0.9, λ denotes the wavelength of the X-ray radiation, β indicates the full width at half maximum (FWHM), and θ refers to the Bragg's diffraction angle expressed in degrees. It is anticipated that zinc oxide nanoparticles will have an average crystallite size of

1.09 nm.

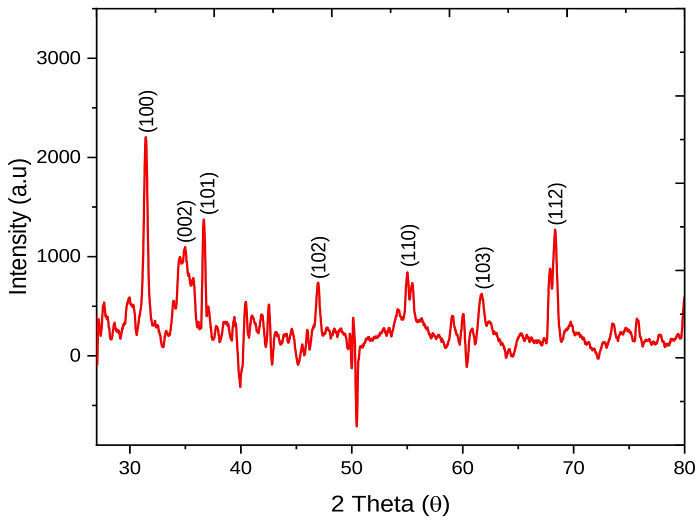

Figure 1. X-ray diffraction pattern of ZnO NPs.

UV-Vis Spectroscopy analysis

Figure 2 illustrates the ZnO nanoparticles synthesized using *Hemidesmus indicus* root powder, which were analysed through UV-Visible spectroscopy. UV-Visible spectral measurements were conducted in the range of 200 to 800 nm. The absorbance value is solely influenced by several factors, including the size of the nanoparticles and any imperfections or flaws in the grain structure. The creation of ZnO nanoparticles was validated by detecting a peak absorbance at 274 nm, which is the characteristic wavelength associated with this process [12]. The energy of the optical band gap can be determined using this equation (2) [13].

$E = hc/\lambda = 1240/\lambda$ (2)

In this equation, E represents the energy, h denotes Planck's constant, c stands for the speed of light, and λ indicates the wavelength. The energy of the band gap for the ZnO nanoparticles was determined to be 5.02 eV.

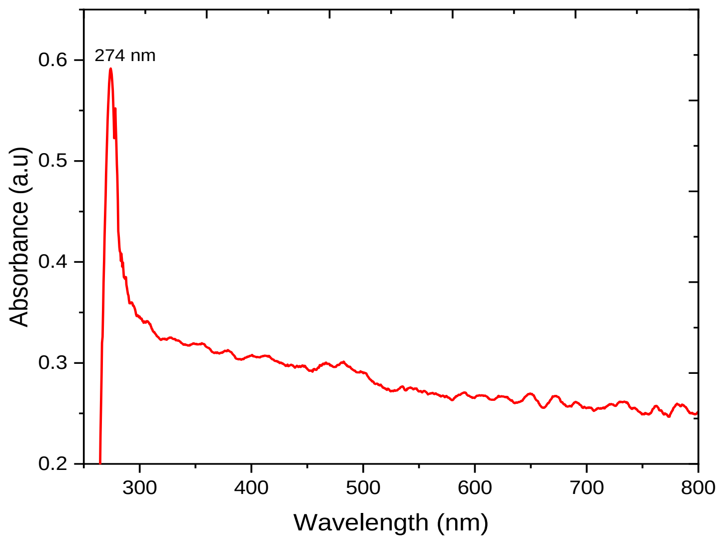

Figure 2. UV-vis spectra of ZnO NPs.

FT-IR spectroscopy analysis

The chemical structures and functional groups of the zinc oxide nanoparticles synthesized from *Hemidesmus indicus* were analyzed using FTIR spectroscopy, as shown in Figure 3. The FTIR spectroscopy results display prominent peaks at 3304 cm^{-1}, 1618 cm^{-1}, 1021 cm^{-1}, and 519 cm^{-1}. The wide absorption peaks at 3304 cm^{-1} suggest the existence of O-H hydrogen bonds. The band at 1618 cm^{-1} was linked to the stretching vibrations of the C=O bond. The peak observed at 1021 cm^{-1} signifies the stretching vibrations of C-O bonds [14]. Additionally, the peaks detected in the range of 600 to 400 cm^{-1} have been attributed to the metal-oxygen bonds. The strong peak at 519 cm^{-1} is due to the presence of zinc and oxygen [15]. The FTIR spectroscopy results indicate that the extract of *Hemidesmus indicus* contains organic compounds that function as stabilizers, capping agents, and reducing agents in the biosynthesis of zinc oxide nanoparticles.

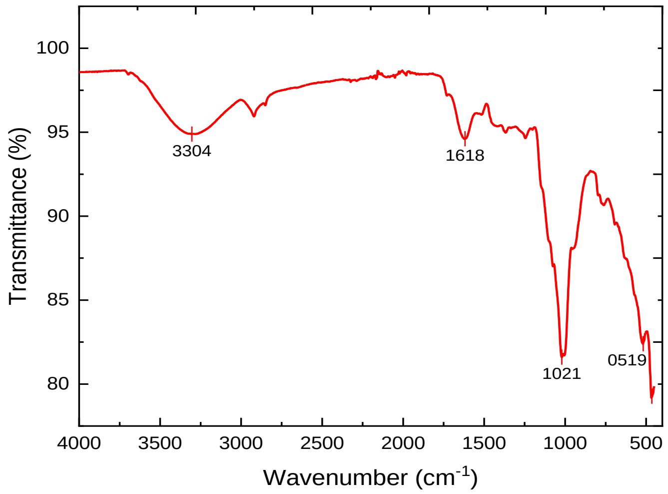

Figure 3. FT-IR spectra of ZnO NPs.

FE-SEM analysis

FE-SEM is a technique for high-resolution surface imaging that provides insights into nanostructures and other materials at a microscopic level, utilizing an electron beam for imaging the surface. The increased magnification and greater depth of field in FE-SEM images make them valuable for obtaining surface topological information about different nano objects, which varies based on the electron density of the surface. The morphological characteristics of the synthesized nanomaterials were examined using FE-SEM, as illustrated in Figure 4. The FE-SEM image of ZnO nanoparticles verified the creation of nanoparticles with an irregular shape [16]. The shape of the ZnO nanoparticles formed clusters into larger particles with voids, but they lacked a distinct structure. This clustering could be a result of the secondary metabolites found in the leaf extracts.

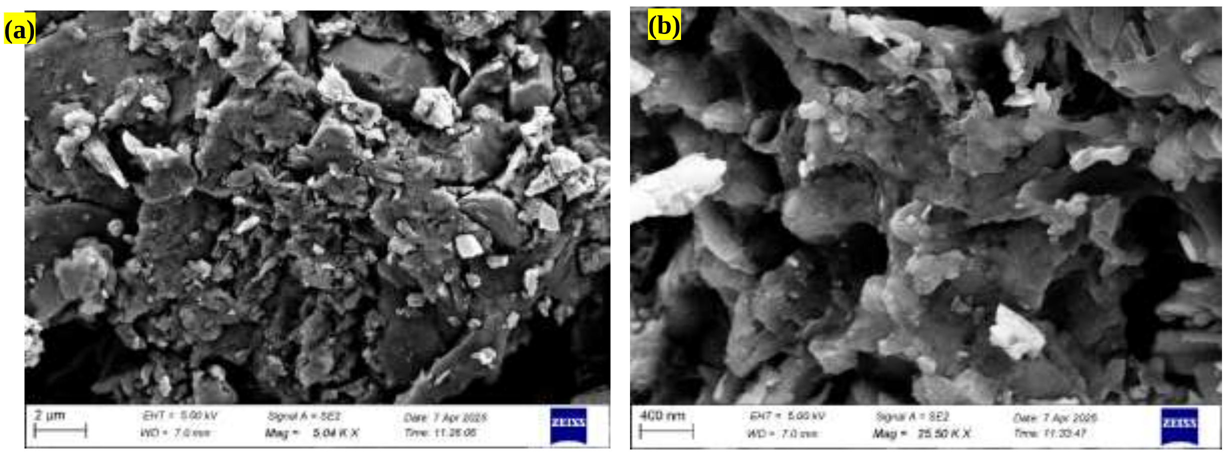

Figure 4. FE-SEM images of ZnO NPs.

4. CONCLUSION

In this study, the researchers introduce an eco-friendlier method for producing ZnO nanoparticles by utilizing the bioactive compounds extracted from the roots of *Hemidesmus indicus*. This approach is straightforward, environmentally safe, non-toxic, and biological. The morphological and structural properties of the synthesized ZnO nanoparticles were analysed using UV-Vis, FT-IR, XRD, and FE-SEM techniques. The XRD analysis of all the prepared samples revealed a distinct peak, confirming the presence of zinc oxide in nanoscale form, with an average crystal size of 1.09 nm. The infrared spectra indicated the existence of ZnO nanoparticles. The FE-SEM image of zinc oxide nanoparticles shows that their structure is elongated, resulting in an irregular look. Since the green-synthesized ZnO nanoparticles are biocompatible, they are suitable for biological applications. Future studies should concentrate on combining these nanoparticles with bacterial systems to improve bioremediation effectiveness, guarantee environmental safety, and broaden the types of pollutants that can be addressed. This novel integration has significant potential for creating sustainable and efficient environmental remediation technologies.

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