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Eco-friendly Synthesis of Zinc Oxide Nanoparticles Using *Moringa oleifera* Leaf Extract

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ABSTRACT

This work investigates the environmentally friendly generation of Zinc oxide nanoparticles (ZnO NPs) by employing plant extract from Moringa oleifera [MO] as a stabilizing and reducing agent. The synthesized NPs were characterized using various techniques, including XRD, FT-IR, and UV-Vis. The XRD study confirms the hexagonal wurtzite-structured ZnO nanoparticles. This study highlights the use of MO extract in environmentally friendly manufacturing of ZnO nanoparticles, contributing to the development of nanomaterials.

Keywords: *Coprecipitation method, green synthesis, Moringa oleifera, Sodium hydroxide, Zinc Oxide (ZnO).*

1. Introduction

Metal oxide nanoparticles, particularly ZnO NPs, have garnered significant attention [1]. Traditionally, the manufacture of these NPs employs chemical methods, which often involve harmful reagents and energy-intensive processes. In response to the need for sustainable practices, researchers have been developing green synthesis methods, which utilize natural substances to produce nanoparticles without compromising the environment [2,3]. Using natural extracts eliminates toxic chemicals, reduces production costs, and provides an effective route to creating nanoparticles with enhanced biological activity [2,4]. The appeal of plant-mediated synthesis lies in its simplicity and compatibility with numerous applications. *Moringa oleifera* (MO), commonly called the drumstick tree or miracle tree is a fast-growing tree found predominantly in tropical regions [5]. These compounds are linked to a range of health benefits, including anti-inflammatory, antioxidant, anticancer, and immuno modulatory effects, making MO an excellent candidate for green synthesis [6]. In the manufacture of NPs, the bioactive chemicals in MO work as natural reducing agents, streamlining the manufacturing process. These phytochemicals not only facilitate the ZnO

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NPs formation but also enhance their functional properties. In biomedicine, they exhibit potential in cancer therapy, and wound healing [5,7]. The adaptability of ZnO NPs makes them a crucial focus for researchers seeking to improve their synthesis and functionality through green methods. When used in green synthesis, MO contributes additional biological activity to the resulting ZnO NPs, making them more effective in various biomedical and environmental applications [8]. Using MO leaf extract for environmentally friendly ZnO NP generation provides multiple advantages. It gets rid of the use of hazardous chemicals, supports low-cost production, and enhances the nanoparticle's biological activity [3]. However, ongoing research is focused on optimizing green synthesis parameters to improve reproducibility and efficiency [9]. Future research may explore hybrid methods and combinations with other biocompatible materials to enhance the functional properties of *Moringa oleifera* ZnO NPs (MO-ZnO NPs) [10,11]. The outcome of this research contributes to the application of MO-ZnO NPs in biomedicine, environmental protection, and cosmetics, supporting an eco-friendly approach to advancing nanotechnology. This green synthesis method represents a step toward sustainable nanoparticle production, with potential benefits across various scientific and industrial fields.

2. Materials and methods

2.1 Synthesis of ZnO NPs

Synthesis procedure, 0.2 M of Zinc acetate dihydrate is mixed in double distilled water and stirred in a magnetic stirrer continuously until the Zinc precursor is fully dissolved, creating a homogeneous solution. Slowly add a solution of Sodium hydroxide (NaOH) to the Zinc solution. The pH of this solution was adjusted to 10 using NaOH and continuously stirred for 1h to make a homogeneous mixture. Then being dried at 100 ℃ in a hot air oven. The dried ZnO powder underwent calcination at 350 ºC for 2h in a muffle furnace. After cooling, a light white ZnO nano-powder was obtained.

2.1 Green synthesis of *Moringa oleifera*-Zinc Oxide Nanoparticles (MO-ZnO NPs)

In a typical MO-ZnO NPs synthesis process, Fresh MO leaves were dried for 10 days. Following that, the leaves were mashed into a fine powder. 5 grams of MO powder was mixed in distilled water and stirred continuously at a temperature of 60℃. After heating, the mixed solution was permitted to cool to ambient temperature and then filtered to obtain a clear MO leaf extract. A 0.2 M solution of Zinc precursor was prepared by dissolving it in distilled water. The filtered MO extract was added to the Zinc acetate dihydrate solution in a 1:1 volume ratio while stirred continuously. The pH of this solution was adjusted to 10 using NaOH and continuously stirred for 1h to make a homogeneous mixture. They were dried at

100 ℃ in a hot air oven. The dried MO-ZnO powder underwent calcination at 350 ºC for 2h in a muffle furnace. After cooling, a MO-ZnO nano-powder was obtained.

3. Results and Discussion

3.1 X-Ray Diffraction

The ZnO NPs and ZnO NPs with MO leaf extract and the structure of hexagonal-wurtzite was verified using X-ray diffraction. For pure ZnO NPs, the main diffraction peak appeared at 2θ angles of 31.25°, 34.87°, 36.62°, 47.89°, 56.22°, 62.90°, 66.24°, 67.54°, and 68.34°, corresponding to the (100), (002), (101), (102), (110),(103), (200), (112), (201) planes, for the green-synthesized ZnO NPs the prominent peaks observed at angles of 31.18°, 34.53°, 36.37°, 47.07°, 56.44°,62.98°, 66.40°, 67.58°and 68.87°correspond to the same plane (100), (002), (101), (102), (110), (103), (200), (112), (201). In green synthesis ZnO one extra peak due to the plane (001) was obtained at 2θ value at 27.82º, organic compounds or biomolecules from the MO leave extract could also contribute to the extra peak [4,7]. The pure ZnO NPs and green-synthesized ZnO NPs correspond to the hexagonal-wurtzite phase which is the common phase of ZnO [11].

By using the Scherrer equation the mean crystallite size was calculated

$$D = K\lambda / \beta \cos \theta$$

Where:

D - average crystallite size (nm)

K - Scherrer constant (typically taken as 0.9)

λ - X-ray wavelength

β - full width at half maximum (FWHM) of the peak in radians

θ - diffraction angle

The mean crystalline size for pure ZnO NPs is 25 nm and the crystalline size for biosynthesized ZnO NPs is 24 nm. The smaller crystalline size in leaf extract produced by ZnO NPs is by their natural capping agent [12] such as polyphenols, flavonoids, proteins, and carbohydrates [8] that act as reducing agents during the nanoparticle formation process. These capping agents stabilize the nanoparticles by preventing their agglomeration and controlling their growth during synthesis [3,9]. This results in smaller crystallites. In chemical synthesis, the growth of nanoparticles is usually driven by chemical precursors and physical conditions like pH, and reaction time, and the lack of natural capping agents like those in green synthesis might result in larger crystalline sizes [5,12,13].

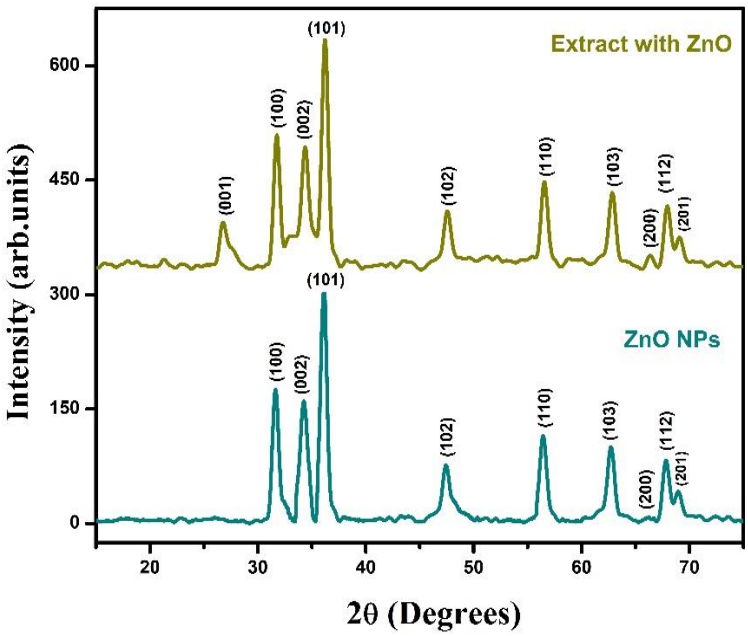

Fig. 1. XRD pattern of the synthesized ZnO NPs and MO leaf extract with ZnO NPs

3.2 Fourier Transform Infrared Spectroscopy (FT-IR)

Utilizing FT-IR spectroscopy the functional group was identified on their surface and identified how the ZnO NPs and the green-synthesized ZnO NPs were formed. However, the ZnO NPs and MO extract ZnO NPs were recorded in the 4000 cm^{-1} to 400 cm^{-1} regions. Fig.2. compares the ZnO NPs FT-IR spectrum with that of green-produced ZnO NPs and tabulated in Table 1.

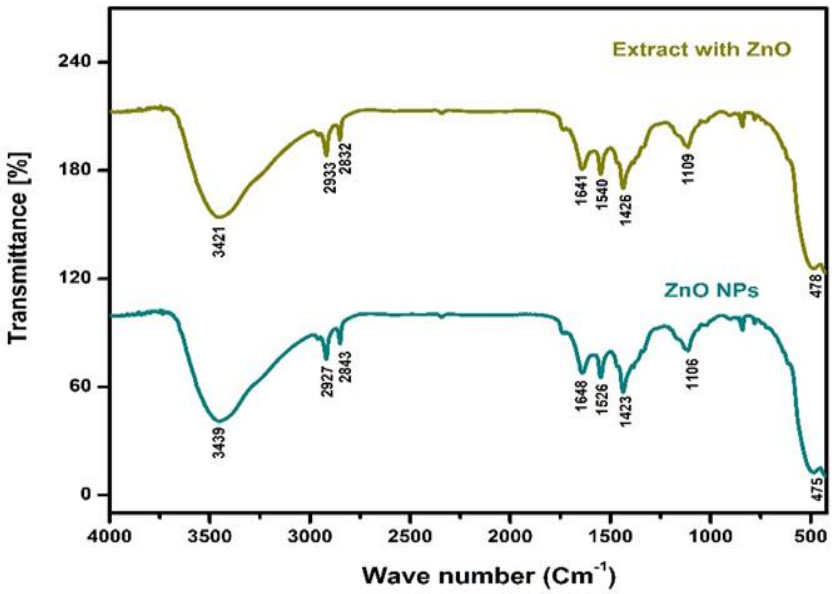

Fig. 2. FT-IR spectrum of synthesized ZnO NPs and *Moringa oleifera* leaf extract with ZnO NPs

Table. 1. shows the Peak position and functional group of synthesized ZnO NPs and Extract with ZnO NPs

Peak Position (cm^{-1})		Functional Groups
ZnO NPs	Extract with ZnO NPs	
3439	3421	O-H Stretching
2927	2933	C-H Stretching
2843	2832	C-H Stretching
1648	1641	C=O Stretching
1526	1540	C-H Bending
1423	1426	C-H Bending
1106	1109	C-O Stretching
475	478	Zn-O Stretching

The environmentally friendly ZnO NPs FT-IR spectra displayed a minor shift marginally altered in peaks, indicating that the extract's main biomolecules had bound toZnO NPs surface [13].

3.3 UV-Visible Spectroscopy (UV-Vis)

UV-Vis Analysis of ZnO and MO extract synthesized ZnO NPs are illustrated in Fig. 3, the produced ZnO NPs absorption spectrum shows that the peak is 370 nm, and the absorption spectrum of the produced green-synthesized ZnO NPs with the absorption peak is 374 nm. Higher UV absorption of green-synthesized ZnO NPs than the ZnO NPs is primarily due to their smaller crystalline size, the increased surface area-to-volume ratio [14], and surface interactions with biomolecules [15], all of which contribute to the enhanced light absorption in the UV region.

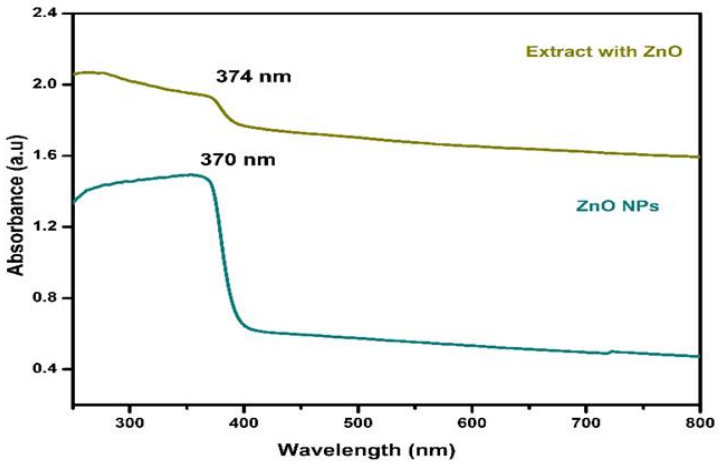

Fig. 3. UV-Visible analysis of synthesized ZnO NPs and MO leaf extract-ZnO NPs

4. Conclusion

ZnO NPs' environmentally friendly production employing MO leaf extract demonstrates a sustainable approach to nanoparticle production. The green synthesised MO-ZnO NPs show higher absorption. The use of MO leaf extract not only underscores the green synthesis methods but also promotes natural resources, reducing the reliance on harmful chemical processes. Future research could focus on optimizing the synthesis parameters of MO-ZnO NPs further and exploring their efficacy in specific applications, thereby advancing the development of environmentally friendly nanomaterials.

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