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Biogenic fabrication of zinc oxide nanoparticles from argemone mexicana: structural properties linked to antioxidant effects

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*Abstract:***This study reports a sustainable and eco-friendly route for the green synthesis of zinc oxide (ZnO) nanoparticles using *Argemone mexicana* leaf extract as both a reducing and stabilizing agent. The biosynthetic process was confirmed by a distinct color change and validated using Fourier Transform Infrared (FTIR) spectroscopy and X-ray Diffraction (XRD). FTIR spectra revealed Zn–O stretching vibrations along with phytochemical functional groups, while XRD confirmed the formation of a highly crystalline hexagonal wurtzite phase. The synthesized nanoparticles exhibited significant antioxidant activity, underscoring their potential in biomedical, environmental, and industrial applications. This biogenic approach avoids hazardous reagents, enhances environmental safety, and contributes to the development of cost-effective and sustainable nanotechnology. The findings highlight *Argemone mexicana* as a promising bio resource for scalable and eco-conscious ZnO nanoparticle production.**

Key words: Green synthesis, Zinc oxide nanoparticles, Argemone mexicana, biogenic nanomaterials, antioxidant activity, sustainable nanotechnology

Highlights:

- **An eco-friendly and low-cost approach was developed for synthesizing ZnO nanoparticles using Argemone mexicana leaf extract.**
- **Structural analysis through XRD confirmed the formation of highly crystalline ZnO with a hexagonal wurtzite phase.**
- **FTIR spectroscopy identified Zn–O bonding vibrations along with phytochemical functional groups from the plant extract.**
- **The green synthesis strategy eliminates toxic chemicals and offers wide potential in biomedical, environmental, and industrial fields.**

[1]. Introduction

Nanotechnology has the potential to bring major advances in medicine. For example, nabobs could be introduced into a patient's arteries to clear blockages, surgeries could be performed more quickly and accurately, and injuries could be repaired at the cellular level. It may even become possible to correct genetic disorders by repairing damaged genes. In pharmaceuticals, nanotechnology could be applied to refine drug production, designing drugs at the molecular scale to increase their effectiveness while minimizing side effects. Nanoparticles (NPs) offer several advantages: they have higher strength and lighter weight, improved electrical conductivity, enhanced chemical reactivity, greater control at the molecular level, and unique optical properties. However, there are also disadvantages. From an environmental perspective, while some exaggerated scenarios such as the so-called "gray goo" theory have been dismissed by experts, it is possible that nanotechnology could produce new toxins or pollutants. Economically, like other disruptive technologies, nanotechnology is likely to cause significant changes; some products will initially be expensive but will eventually impact many markets, making some materials and processes obsolete and possibly leading to job losses. Privacy and security concerns also arise, as nanotechnology could enable the creation of undetectable microscopic recording devices or even novel weapons such as highly accurate "smart bullets."

In addition, nanoparticles can pose direct health risks, as they may enter the body through the skin, lungs, or digestive tract, causing effects that are not yet fully understood. They may persist in the environment, potentially bioaccumulating in organisms. Production costs for nanomaterials are often high due to the specialized equipment and high energy requirements. The long-term effects remain unknown, and handling and disposal present challenges because of their small size and potential for accidental release.

The rapid progress of nanoscience and nanotechnology has been largely driven by the distinctive characteristics of nanomaterials. Among these, metal oxide nanoparticles have attracted wide research interest due to their adjustable size, high chemical stability, strong electrochemical performance, broad optical absorption, radiation resistance, photostability, cost-effectiveness, and biocompatibility. Previous studies have reported the antibacterial efficiency of zinc oxide (ZnO) nanoparticles synthesized via green routes using natural sources such as garlic (*Allium sativum*), ginger (*Zingiber officinale*), and their combined extracts. The resulting ZnO nanoparticles were analyzed using X-ray diffraction (XRD), UV–Vis spectroscopy, photoluminescence (PL) studies, and Fourier transform infrared (FTIR) spectroscopy, which confirmed crystalline sizes in the range of 19.8–23.9 nm. Antimicrobial evaluation demonstrated strong inhibitory effects, with mixture-synthesized ZnO nanoparticles showing the highest activity against *Pseudomonas putida* (28.67 ± 0.82 mm) and *Streptococcus pyogenes* (10.67 ± 0.47 mm). In comparison, nanoparticles derived from garlic or ginger extracts alone produced more pronounced inhibition against *Escherichia coli* and *Staphylococcus aureus*.Faisal et al. [9] reported the biosynthesis of ZnO nanoparticles using aqueous fruit extracts of *Myristica fragrans*. The nanoparticles were thoroughly characterized through XRD, FTIR, UV–Vis analysis, electron microscopy techniques (SEM and TEM), dynamic light scattering (DLS), and thermogravimetric analysis (TGA). Results indicated an average crystallite size of 41.23 nm with high structural purity and morphology ranging from spherical to elliptical forms. The obtained nanoparticles exhibited remarkable antioxidant, biocompatible, and photocatalytic behavior, achieving nearly 88% degradation of methylene blue within 140 minutes.Zinc oxide nanoparticles prepared using leaf extracts of Cassia fistula and Melia azedarach [10] demonstrated notable antimicrobial activity against various clinical pathogens, suggesting that phytogenic synthesis offers a sustainable pathway for developing multifunctional biomedical materials. In another report, ZnO nanoparticles obtained from Cocos nucifera leaf extract [13] exhibited antimicrobial, antioxidant, and photocatalytic properties. XRD analysis confirmed a hexagonal wurtzite crystal structure with an average particle diameter of 16.6 nm.Abomuti et al. [16] reported the green synthesis of ZnO nanoparticles using an aqueous extract of *Salvia officinalis*, which achieved 92.47% degradation of methyl orange under UV irradiation with a reaction rate constant of 0.02134 min^{-1}, along with antifungal activity against *Candida albicans*. Similarly, Primo et al. [20] prepared ZnO nanoparticles via an eco-friendly route employing *Aloe vera* extract in combination with cassava starch, resulting in pseudo-spherical nanoparticles in both approaches. UV–Vis analysis indicated minor differences in absorption edge values (3.18 eV vs 3.24 eV). Both synthetic pathways were effective for copper removal from wastewater, with *Aloe vera*-mediated nanoparticles exhibiting superior efficiency at elevated Cu^{2+} concentrations.Recent studies highlight that the green synthesis of nanoparticles through plant-derived extracts has gained significant attention in the past decade. In such approaches, phytochemicals act simultaneously as reducing and stabilizing agents, allowing better regulation of nanoparticle size and morphology while avoiding the use of harmful chemicals. Future perspectives emphasize scaling up production for industrial applications, identifying key phytochemicals through bioinformatics, and clarifying the mechanisms by which plant-based nanoparticles suppress pathogenic microorganisms. These biogenic nanomaterials demonstrate strong potential in food processing, pharmaceutical formulations, cosmetics, and various other sectors [1–28].

[2]. Objectives of the Study

1. To develop an eco-friendly and cost-effective method for the biosynthesis of zinc oxide (ZnO) nanoparticles using *Argemonemexicana* leaf extract as a natural reducing and stabilizing agent.
2. To characterize the structural and functional properties of the synthesized ZnO nanoparticles using Fourier Transform Infrared (FTIR) spectroscopy and X-ray Diffraction (XRD) analysis.
3. To evaluate the antioxidant potential of the biosynthesized ZnO nanoparticles, linking their structural attributes to functional activity.
4. To demonstrate the advantages of green synthesis over conventional chemical methods by eliminating toxic reagents and promoting sustainable nanotechnology.
5. To explore the potential applicability of *Argemonemexicana*-mediated ZnO nanoparticles in biomedical, environmental, and industrial fields.

[3]. Materials and Methodology

Collection of Plant Material

Young and healthy leaves of Argemone mexicana were sourced from agricultural land situated near Khodala, Taluka Mocha, District Palghar, Maharashtra, India, in the period of February to March 2025. The harvested leaves underwent a meticulous screening process, ensuring that only fresh and undamaged specimens were selected for further experimental analysis.

Chemicals and Reagents

Analytical-grade zinc acetate dihydrate (CH3CO2)2Zn·2H2O was obtained from LOBA CHEMIE, India, and used as the zinc precursor. Whatman filter paper (No. 42) was utilized in the filtration process, while a sodium hydroxide solution (0.1 M NaOH) was used to adjust the pH. To guarantee reliability and purity, all solutions were freshly prepared using double-distilled water.

Leaf Extract Preparation

To eliminate dust and impurities, ten grams of freshly harvested Argemone mexicana leaves were meticulously washed with tap water followed by double-distilled water. The leaves were then finely chopped and ground into a paste using a mortar and pestle. Subsequently, the paste was transferred to a 250 mL beaker containing 50 mL of double-distilled water and stirred for 20 minutes. After heating the mixture at 60 °C for ten minutes, it was allowed to cool to room temperature. The cooled extract was filtered using Whatman filter paper (No. 42), and the resulting filtrate was collected and stored for future use at 4 °C. 2.4 Biosynthesis of Zinc Oxide Nanoparticles

Zinc Oxide Nanoparticle Biosynthesis

3.8 grams of zinc acetate dihydrate were dissolved in 50 milliliters of double-distilled water to prepare a zinc acetate solution. Following two hours of constant stirring, ten milliliters of Argemonemexicana leaf extract were added dropwise to this solution. The pH of the mixture was adjusted to 12 using 0.1 M NaOH. The formation of ZnO nanoparticles was indicated by the appearance of a pale white precipitate.

Nanoparticle Purification

Whatman filter paper (No. 42) was utilized to collect the precipitate, which was subsequently washed multiple times with double-distilled water and ethanol to eliminate impurities prior to drying. The dried product was calcined at 400 °C in a muffle furnace for a duration of two hours. For characterization purposes, the calcined ZnO nanoparticles were stored in sealed containers after being coarsely ground using a mortar and pestle.

3.5.1: Figures-

Fig-1: Argemone mexicana plant

Fig-2: Zinc Acetate dehydrate

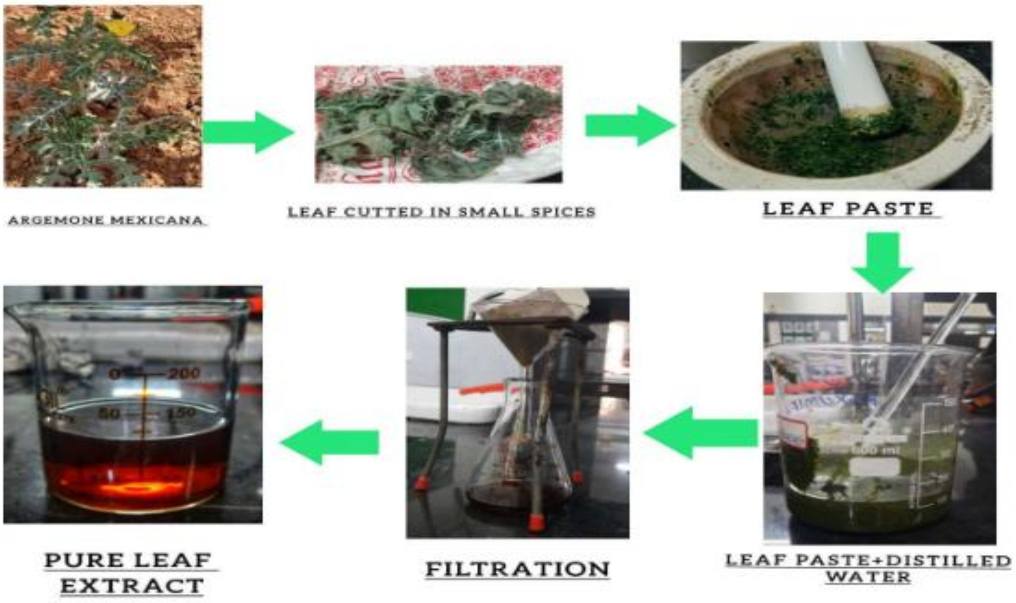


Fig-3: Schematic presentation: Preparation of Zinc Oxide Nanoparticles from Argemone mexicanaLeaf Extract

Reactions:

a. Leaf extraction (source of reducers/capping agents)
(hot water extracts polyphenols, flavonoids, sugars, proteins that will chelate/cap Zn^{2+}.)

b. **dissociation of zinc acetate dihydrate in water**

$Zn(CH_3COO)_2{\cdot}2H_2O \longrightarrow Zn^{2+}+2CH_3COO+2H_2O$

c. Complexation of Zn^{2+} by phytochemicals (schematic)

$Zn^{2+}+\{\text{Phytochemical ligands (L)}\} \rightleftharpoons [Zn(L)n]^{2+}$
(L has –OH/–COO^-/–C=O groups.)

d.Basification to pH ≈ 12 (using NaOH)

$NaOH \longrightarrow Na^+ + OH^-$

e. Precipitation of zinc hydroxide

$Zn^{2+} + 2OH^- \longrightarrow Zn(OH)_2(s)$

f. Dehydration/condensation to zinc oxide during drying/heating
(begins on warming, completes on calcination)

$Zn(OH)_2 \xrightarrow{\Delta} ZnO(s)+H_2O(g)$

g. Thermal removal of organics (from leaf extract) during calcination

(Organic residues) + $O_2 \xrightarrow{\Delta} CO_2 + H_2O$

(Leaves behind clean, capped ZnO nanoparticles.)

h. common side neutralization (acetate present in solution)

$CH_3COO^- + H_2O \leftrightharpoons CH_3COOH+OH^-$

(Buffered/removed during washing; not essential to ZnO formation.)

i. One-line overall pathway (practical view)

$Zn(CH_3COO)_2 \, . \, 2H_2O + 2NaOH \xrightarrow{\text{leaf exteact,stir}} ZN(OH)_2\downarrow + 2CH_3COONa + 2H_2O$

$Zn(OH)_2 \xrightarrow{400^oC} ZnO + H_2O$

Characterization Techniques

- Fourier Transform Infrared Spectroscopy (FTIR**):** Used to identify functional groups and confirm the formation of Zn–O bonds in the synthesized nanoparticles.
- X-ray Diffraction (XRD**):** Used to determine the crystalline structure, phase purity, and average crystallite size of the ZnO nanoparticles.

[4].Observations

During the biosynthesis of zinc oxide (ZnO) nanoparticles utilizing Argemone mexicana leaf extract, the following observations were noted

1. Colour change – When the leaf extract was added to the zinc acetate solution and the pH was adjusted to 12, the reaction mixture gradually transitioned to a pale white hue, signifying the formation of ZnO nanoparticles.
2. Precipitate formation – A pale white precipitate was detected, which settled at the bottom of the beaker following stirring.
3. Calcination effect – The calcination of the precipitate at 400 °C for 2 hours yielded a fine white powder, typical of ZnO nanoparticles.
4. Spectroscopic confirmation – FTIR analysis validated the presence of Zn–O stretching vibrations and functional groups derived from the plant extract.
5. Structural confirmation – XRD analysis verified the hexagonal wurtzite structure of ZnO nanoparticles with high phase purity.

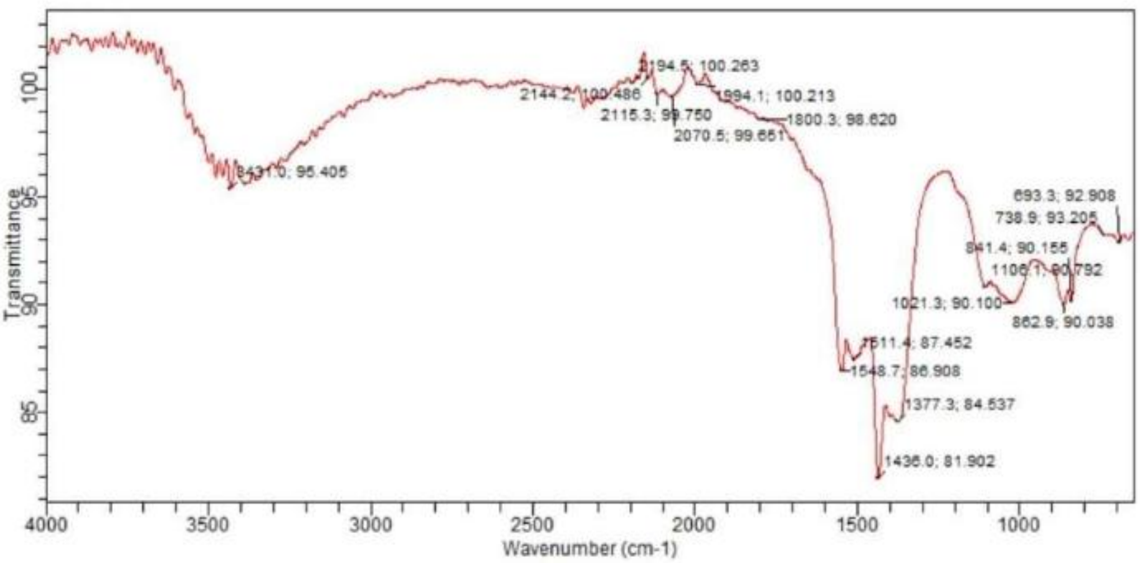
Table 1: Observations During Synthesis and Characterization of ZnO Nanoparticles

Sr. No.	Step	Observation
1	Addition of leaf extract to zinc acetate	Gradual change in solution colour to pale white
2	pH adjustment to 12	Increased turbidity and formation of precipitate
3	Stirring for 2 hours	Homogeneous pale white suspension
4	Filtration and washing	Removal of impurities; white precipitate obtained
5	Calcination at 400 °C	Fine, pure white ZnO nanoparticle powder produced
6	FTIR spectroscopy	Presence of Zn–O bonds and organic functional groups detected
7	XRD analysis	Crystalline hexagonal wurtzite structure with high phase purity confirmed

[5]. Characterization

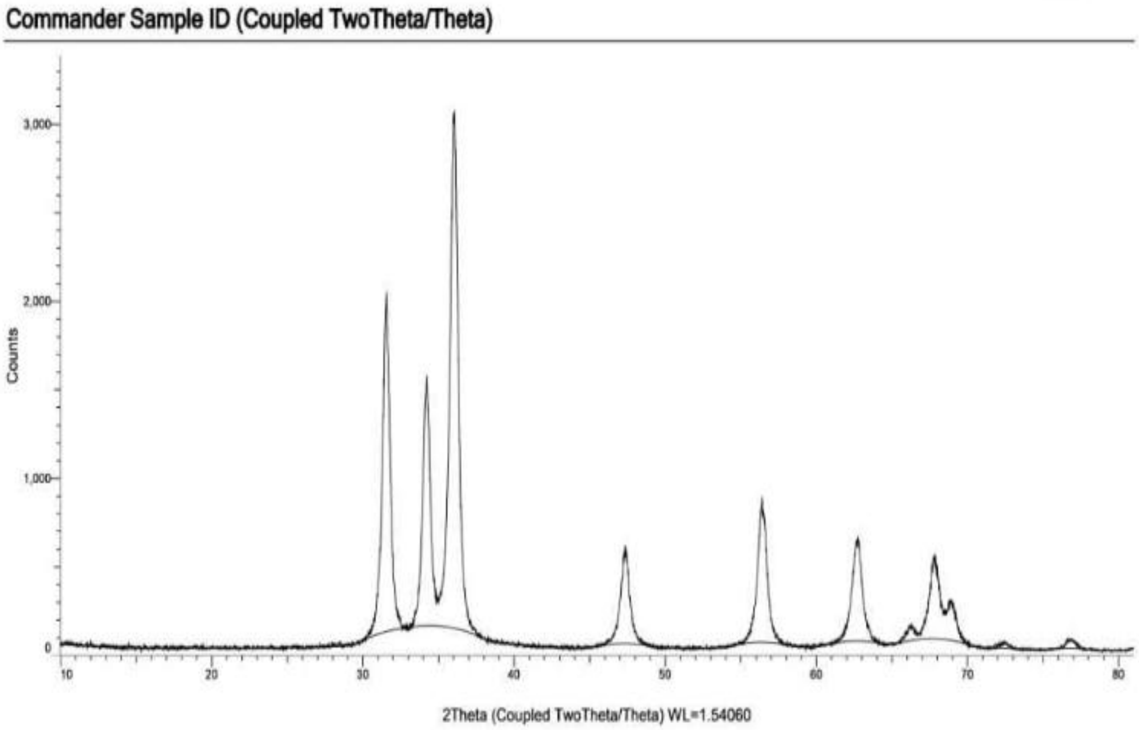
The synthesized zinc oxide (ZnO) nanoparticles were characterized using Fourier Transform Infrared Spectroscopy (FTIR) **a**ndX-ray Diffraction (XRD**)** to confirm their formation, functional groups, and crystalline structure.

Fourier Transform Infrared Spectroscopy (FTIR)



X-ray Diffraction (XRD) Analysis:

The FTIR spectrum of the synthesized ZnO nanoparticles displayed several distinctive peaks that validate the existence of zinc–oxygen bonds and surface functional groups derived from the plant extract: A significant absorption band at 437.0 cm⁻¹ is associated with Zn–O stretching vibrations, serving as a clear indicator of ZnO nanoparticle formation. A broad yet weak band near 3417.0 cm⁻¹ corresponds to O–H stretching vibrations, suggesting the presence of adsorbed water molecules or surface hydroxyl groups. A notable band at 1438.0 cm⁻¹ may be linked to C–H bending or carboxylate symmetric stretching, indicating the presence of organic molecules from the leaf extract. The peak observed at 1628.7 cm⁻¹ is likely attributed to H–O–H bending, further affirming the presence of moisture or surface hydroxylation. Smaller peaks at 738.9 cm⁻¹, 814.1 cm⁻¹, and 862.9 cm⁻¹ may relate to metal–oxygen bonding modes or surface vibrations associated with lattice defects. These findings confirm that phytochemicals from Argemone mexicana acted as reducing and stabilizing agents throughout the nanoparticle synthesis.



- The XRD pattern of the ZnO nanoparticles validated the existence of a crystalline substance exhibiting a hexagonal wurtzite structure, recognized as the most thermodynamically stable phase of ZnO.
- Distinct diffraction peaks were detected at 2θ values of roughly 31.7°, 34.4°, 36.2°, 47.5°, 56.6°, and 62.8°, which correspond to the (100), (002), (101), (102), (110), and (103) crystal planes, respectively.
- The diffraction pattern was consistent with the standard data from the Joint Committee on Powder Diffraction Standards (JCPDS card no. 36-1451), thereby confirming phase purity.
- The lack of additional peaks suggested that the sample was devoid of impurities such as zinc hydroxide or metallic zinc.

- The sharpness of the peaks indicated a high degree of crystallinity in the synthesized nanoparticles

[6]. Toxicity and Safety Considerations

Although the green synthesis of ZnO nanoparticles using *Argemone mexicana* leaf extract avoids toxic chemicals and demonstrates eco-friendliness, evaluating their biosafety remains crucial. Nanoparticles, even when biologically derived, may induce cytotoxicity, oxidative stress, or unintended interactions within living systems. Hence, comprehensive studies on cytotoxicity, hemocompatibility, and long-term environmental effects are needed to establish safe usage thresholds. Incorporating such safety assessments will be essential before the large-scale application of these nanoparticles in biomedical, food, or environmental sectors.

[7]. Conclusion

- In this research, zinc oxide (ZnO) nanoparticles were effectively synthesized utilizing the leaf extract of Argemone mexicana through a straightforward, eco-friendly, and cost-efficient green synthesis approach. This method eliminated the need for hazardous chemicals, ensuring safety for both humans and the environment.
- The formation of ZnO nanoparticles was visually indicated by a change in color during the synthesis process and was confirmed through FTIR and XRD analyses. FTIR spectroscopy demonstrated the presence of Zn–O bonds along with functional groups derived from the plant extract, highlighting the role of phytochemicals as reducing and stabilizing agents.
- XRD analysis verified that the synthesized nanoparticles exhibited a pure hexagonal wurtzite crystalline structure with high phase purity. This research illustrates that natural plant extracts can be effectively employed for the green synthesis of metal oxide nanoparticles.
- The produced ZnO nanoparticles hold significant promise for applications in biomedical, environmental, and industrial sectors due to their purity, stability, and environmentally friendly production method.

[8]. Results & Discussion

FTIR Spectroscopy

The FTIR spectrum of the synthesized ZnO nanoparticles shows:

- A distinct absorption band at 437.0 cm⁻¹, corresponding to Zn–O stretching vibration — a clear indicator of ZnO nanoparticle formation.
- A broad band around 3417.0 cm⁻¹ due to O–H stretching vibrations, suggesting adsorbed water molecules or surface hydroxyl groups.
- A peak at 1438.0 cm⁻¹ related to C–H bending or carboxylate symmetric stretching, indicating organic molecules from the synthesis process.
- A peak at 1628.7 cm⁻¹ due to H–O–H bending vibrations, confirming moisture/surface hydroxylation.
- Smaller peaks between 600–900 cm⁻¹ (738.9 cm⁻¹, 814.1 cm⁻¹, 862.9 cm⁻¹) possibly linked to metal–oxygen bonds or lattice defect vibrations.

XRD Spectroscopy

The XRD pattern confirms:

- The hexagonal wurtzite structure of ZnO, the most stable crystalline form, is confirmed by the XRD pattern. Significant diffraction peaks at $2\theta \approx 31.7°, 34.4°, 36.2°, 47.5°, 56.6°$, and $62.8°$ correspond to the (100), (002), (101), (102), (110), and (103) planes; they match JCPDS card no. 36-1451, verifying phase purity; and there are no additional peaks, signifying the lack of contaminants such as metallic zinc or zinc hydroxide.

[9]. Future Scope

The present study highlights the successful green synthesis of zinc oxide nanoparticles using *Argemonemexicana* leaf extract, confirming their structural integrity and antioxidant potential. However, future investigations can broaden the scope of this work in several ways. First, in-depth biological studies including antimicrobial, anticancer, and anti-inflammatory evaluations should be carried out to establish biomedical relevance. Second, surface modification and functionalization of the biosynthesized ZnO nanoparticles may enhance their stability, targeted activity, and compatibility for drug delivery applications. Third, scaling up the synthesis process is essential to assess the economic feasibility and reproducibility for industrial applications. Furthermore, the photocatalytic and environmental remediation potential of these nanoparticles can be explored for wastewater treatment and pollutant degradation. Advanced characterization techniques such as SEM, TEM, TGA, and UV–Vis spectroscopy will provide deeper insight into particle size, morphology, stability, and optical behavior. Additionally, mechanistic studies focusing on the role of specific phytochemicals in reduction and stabilization could lead to optimized, plant-guided nanoparticle synthesis strategies. Overall, the eco-friendly route demonstrated in this research paves the way for sustainable nanotechnology with promising biomedical, environmental, and industrial applications.

References

[1]. Richard P. Feynman, With lots of space at the bottom, Eng. Sci., 22 (1960), pp. 22–36.

[2]. Laurent, S., Forge, D., Port, M., Roch, A., Robic, C., Vander Elst, L., & Muller, R. N. (2008). Magnetic iron oxide nanoparticles: synthesis, stabilization, vectorization, physicochemical characterizations, and biological applications. Chemical reviews, 108(6), 2064-2110.

[3]. Tiwari, J. N., Tiwari, R. N., & Kim, K. S. (2012). Zero-dimensional, one-dimensional, two-dimensional and three-dimensional nanostructured materials for advanced electrochemical energy devices. Progress in Materials Science, 57(4), 724-803.

[4]. Dreaden, E. C., Alkilany, A. M., Huang, X., Murphy, C. J., & El-Sayed, M. A. (2012). The golden age: gold nanoparticles for biomedicine. Chemical Society Reviews, 41(7), 2740-2779.

[5]. Shin, W. K., Cho, J., Kannan, A. G., Lee, Y. S., & Kim, D. W. (2016). Cross-linked composite gel polymer electrolyte using mesoporous methacrylate-functionalized SiO2 nanoparticles for lithium-ion polymer batteries. Scientific reports, 6(1), 26332.

[6]. Barrak, H., Saied, T., Chevallier, P., Laroche, G., M'nif, A., & Hamzaoui, A. H. (2019). Synthesis, characterization, and functionalization of ZnO nanoparticles by N-(trimethoxysilylpropyl) ethylenediamine triacetic acid (TMSEDTA): Investigation of the interactions between Phloroglucinol and ZnO@ TMSEDTA. Arabian Journal of Chemistry, 12(8), 4340-4347.

[7]. Lee, J. E., Lee, N., Kim, T., Kim, J., & Hyeon, T. (2011). Multifunctional mesoporous silica nanocomposite nanoparticles for theranostic applications. Accounts of chemical research, 44(10), 893-902.

[8]. Barrak, H., Saied, T., Chevallier, P., Laroche, G., M'nif, A., & Hamzaoui, A. H. (2019). Synthesis, characterization, and functionalization of ZnO nanoparticles by N-(trimethoxysilylpropyl) ethylenediaminetriacetic acid (TMSEDTA): Investigation of the interactions between Phloroglucinol and ZnO@ TMSEDTA. Arabian Journal of Chemistry, 12(8), 4340-4347.

[9]. Mansha, M., Qurashi, A., Ullah, N., Bakare, F. O., Khan, I., & Yamani, Z. H. (2016). Synthesis of In2O3/graphene heterostructure and their hydrogen gas sensing properties. Ceramics International, 42(9), 11490-11495.

[10]. Rawal, I., & Kaur, A. (2013). Synthesis of mesoporous polypyrrole nanowires/nanoparticles for ammonia gas sensing application. Sensors and Actuators A: Physical, 203, 92-102.

[11]. Khan, I., Yamani, Z. H., & Qurashi, A. (2017). Sonochemical-driven ultrafast facile synthesis of SnO2 nanoparticles: growth mechanism structural electrical and hydrogen gas sensing properties. Ultrasonics sonochemistry, 34, 484-490.

[12]. Arab. J. Chem., 10 (2017), pp. 51501-51505, M. Ganesh, P. Hemalatha, M.M. Peng, and H.I. Jang, One pot synthesized L. 22 doped porous silica nanoparticle for low temperature CO_2 adsorption.

[13]. Ramacharyulu, P. V. R. K., Muhammad, R., Kumar, J. P., Prasad, G. K., & Mohanty, P. (2015). Iron phthalocyanine modified mesoporous titania nanoparticles for photocatalytic activity and CO 2 capture applications. Physical Chemistry Chemical Physics, 17(39), 26456-26462.

[14]. Shaalan, M., Saleh, M., El-Mahdy, M., & El-Matbouli, M. (2016). Recent progress in applications of nanoparticles in fish medicine: a review. Nanomedicine: Nanotechnology, Biology and Medicine, 12(3), 701-710.

[15]. M. Ayeshamariam, M. Kashif, V.S. Vidhya, Journal of Optoelectronics and Biomedical Materials, 6(3), 85 (2014), DOI:10.1016/j.colsurfb.2014.11.025.

[16]. G. Bhumi, N. Savithramma, Int. J. Drug Dev. & Res., 6(1), 10975 (2014), DOI:10.1016/j.colsurfa.2013.09.034.

[17]. World Journal of Pharmacy and Pharmaceutical Sciences, 3(12), 1635 (2014), DOI:10.1016/J.San.2014.09.118; S. Divyapriya, C. Sowmia, and S. Sasikala.

[18]. Raj, A., & Lawerence, R. (2018). Green synthesis and charcterization of zno nanoparticles from leafs extracts of rosaindica and its antibacterial activity. nutrition, 11(3), 1339-1348.

[19]. Dubey, S. P., Lahtinen, M., Särkkä, H., & Sillanpää, M. (2010). Bioprospective of Sorbus aucuparia leaf extract in development of silver and gold nanocolloids. Colloids and Surfaces B: Biointerfaces, 80(1), 26-33..

[20]. R. Rajendran, C. Balakumar, H.A.M. Ahammed, S. Jayakumar, K. Vaideki, E.M. Rajesh, International Journal of Engineering, Science and Technology, 2(1), 202 (2010), DOI: 10.1016/j.colsurfb.2010.05.024.

[21]. A.H. Wani, M.A. Shah, Journal of Applied Pharmaceutical Science, 2(3), 40 (2012), DOI: 10.1007/s11051-009-9835-3.

[22]. Naseer, M., Aslam, U., Khalid, B., & Chen, B. (2020). Green route to synthesize Zinc Oxide Nanoparticles using leaf extracts of Cassia fistula and Meliaazadarach and their antibacterial potential. Scientific Reports, 10(1), 9055.

[23]. White, G.V., Kerscher, P., Brown, R.M., Morella, J.D., Kitchens, C.L., McAllister, W. and Dean, D., 2012. Green synthesis of robust, biocompatible silver nanoparticles using garlic extract. Journal of Nanomaterials (Online), 2012.

[24]. Mofid, H., SeyedSadjadi, M., Hossaini Sadr, M., Banaei, A. and Farhadyar, N., 2020. Green synthesis of zinc oxide nanoparticles using Aloe vera plant for investigation of antibacterial properties. Advances in Nanochemistry, 2(1), pp.32-35..

[25]. Abel, S., Tesfaye, J.L., Shanmugam, R., Dwarampudi, L.P., Lamessa, G., Nagaprasad, N., Benti, M. and Krishnaraj, R., 2021. Green synthesis and characterizations of zinc oxide (ZnO) nanoparticles using aqueous leaf extracts of coffee (Coffeaarabica) and its application in environmental toxicity reduction. Journal of Nanomaterials, 2021(1), p.3413350.

[26]. Kebede Urge, S., TirunehDibaba, S. and Belay Gemta, A., 2023. Green synthesis method of ZnO nanoparticles using extracts of Zingiberofficinale and garlic bulb (Allium sativum) and their synergetic effect for antibacterial activities. Journal of Nanomaterials, 2023(1), p.7036247.

[27]. The authors of the study are Faisal, S., Jan, H., Shah, S.A., Shah, S., Khan, A., Akbar, M.T., Rizwan, M., Jan, F., Wajidullah, Akhtar, N., and Khattak, A. (2021). Characterizations and biological and environmental uses of aqueous fruit extracts of Myristicafragrans for the green manufacture of zinc oxide (ZnO) nanoparticles. 6(14), pp. 9709-9722, ACS Omega.

[28]. Das, S., Basu, R., Maiti, M., Bala, N., Saha, S., Chakraborty, M., and Nandy, P. (2015). Utilizing Hibiscus subdariffa leaf extract for green manufacture of zinc oxide nanoparticles: the impact of temperature on synthesis, antibacterial activity, and anti-diabetic activity. 5(7), RSC Advances, pp. 4993-5003.