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Biogenic Synthesis of Zinc Oxide Nanoparticles Using *Argemone Mexicana* Leaf Extract and Their Structural Characterization

Kaustubh P. Risbud, Pralhad Rege, Pranjali T. Maskar
Department of Chemistry, B.K. Birla College of Arts, Science & Commerce (Autonomous), Kaylan

Abstract

The present study demonstrates a green and sustainable approach for synthesizing zinc oxide (ZnO) nanoparticles using aqueous leaf extract of *Argemone Mexicana* as a natural reducing and stabilizing agent. The bio-fabricated nanoparticles were characterized to confirm successful formation and structural properties. FTIR analysis revealed major functional groups from the leaf extract, including O–H, C=O, and C–H vibrations, suggesting the involvement of polyphenols, proteins, and other phytochemicals in the reduction and capping of Zn^{2+} ions. A distinct Zn–O stretching band appearing below 500 cm^{-1} confirmed nanoparticle formation. XRD studies further validated the crystalline nature of the synthesized material, exhibiting well-defined diffraction peaks corresponding to the hexagonal wurtzite phase of ZnO. The crystallite size calculated using the Debye–Scherrer equation confirmed nanoscale dimensions. These results collectively demonstrate that *A. mexicana* leaf extract provides an effective green route for producing crystalline ZnO nanoparticles without the use of toxic reagents.

Keywords:
Green synthesis, Zinc nanoparticles, *Piper betle* leaf extract, FTIR; XRD, Eco-friendly synthesis

INTRODUCTION

Nanotechnology is a multidisciplinary field of science and engineering that deals with the design, production, and manipulation of materials and devices on the Nano scale level. It involves the study and application of materials with at least one dimension in the range of 1 to 100 nanometers.

At this scale, materials exhibit unique and often unexpected physical, chemical, and biological properties that are not observed in their bulk counterparts. These properties arise due to the large surface area-to-volume ratio, quantum effects, and other phenomena that occur at the Nano scale. Nanotechnology encompasses various disciplines such as physics, chemistry, and biology. Materials science, engineering, and computer science. Researchers in these fields work together to develop new materials, tools, and techniques that enable the fabrication and manipulation of Nano scale structures and devices. Some of the applications of nanotechnology include the development of new materials with improved properties such as strength, durability, and conductivity, the production of high-efficiency energy devices such as solar cells and batteries, the creation of advanced drug delivery systems for targeted cancer treatment, and the development of sensors and devices for early disease diagnosis and detection. Nanotechnology is expected to revolutionize many fields, including medicine, electronics, energy, and materials science, and has the potential to create new products, industries, and markets. However, the field also poses potential risks and ethical considerations that must be addressed as nanotechnology continues to advance. Nanotechnology is a relatively new field that emerged in the 1980s, although the idea of manipulating matter on a small-scale date back to Richard Feynman's famous lecture "There's Plenty of Room at the Bottom" in 1959. Since then, advances in instrumentation and fabrication techniques have enabled researchers to design and produce increasingly complex Nano scale structures and devices.

One of the most important tools in nanotechnology is the scanning probe microscope (SPM), which allows scientists to image and manipulate materials at the atomic and molecular level. Another important technique is molecular self-assembly, which involves the spontaneous organization of molecules into a desired structure without external intervention.

Nanotechnology has numerous potential benefits, including improved medical treatments, more efficient energy production, and more effective pollution remediation. For example, researchers are exploring the use of nanomaterials in drug delivery systems that can target specific cells or tissues, which could reduce side effects and improve treatment outcomes. However, nanotechnology also raises concerns about potential risks and unintended consequences. Some researchers worry that certain types of nanoparticles could have toxic effects on human health and the environment. In addition, there are concerns about the ethical implications of manipulating matter at such a small scale, particularly if these technologies are used to enhance human abilities or create new forms of life. To address these concerns, many governments and organizations have established guidelines for the safe development and use of nanotechnology. These guidelines include risk assessments, safety protocols, and ethical standards that are designed to ensure the responsible development and use of nanotechnology.

Overall, nanotechnology is a rapidly growing field with enormous potential for scientific and technological advances. However, it is important to carefully consider the potential benefits and risks associated with these technologies to ensure that they are developed and used in a responsible and ethical manner. Nanotechnology involves the study and manipulation of matter at the Nano scale, which is the scale of atoms and molecules. This scale is important because materials at this size exhibit unique and often unexpected properties that are not observed at larger scales. For example, materials at the Nano scale can have different optical, electrical, magnetic, and mechanical properties compared to the same material at a larger scale.

One of the key challenges in nanotechnology is the ability to design and produce Nano scale structures and devices with a high degree of precision and control. This requires the development of new fabrication techniques that can create structures with dimensions that are measured in nanometers. Examples of such techniques include lithography, electron beam lithography, and molecular beam epitaxy. Another important aspect of nanotechnology is the study of how materials behave at the Nano scale. This includes the study of surface chemistry, surface area, and particle-particle interactions. Understanding these properties is essential for developing new materials and devices with novel properties and functionality. In addition to advances in basic science, nanotechnology has numerous practical applications.

In recent years, nanotechnology has gained more attention and the research providing more innovation in many fields like electronics, drugs industry, Ceramic industry etc. Nowadays, we are witnessing the development and advancement of a new interdisciplinary scientific field nanoscience. Nobel laureate Richard P. Feynman was presented "nanotechnology" during his well famous 1959 lecture "There's Plenty of Room at the Bottom" (1), there have been made various revolutionary developments in the field of nanotechnology. Nanotechnology produced materials of various types at nanoscale level. Nanoparticles (NPs) are wide class of materials that include particulate substances, which have one dimension less than 100 nm at least (2). Depending on the overall shape these materials can be OD, ID, 2D or 3D (3). The importance of these materials realized when researchers found that size can influence the physiochemical properties of a substance e.g. the optical properties. A 20- nm gold (Au), platinum (Pt), silver (Ag), and palladium (Pd) NPs have characteristic wine red color, yellowish gray, black and dark black colors, respectively. These NPs showed characteristic colors and properties with the variation of size and shape, which can be utilized in bio-imaging applications (4). The alteration of any of the above discussed factor influences the absorption properties of the NPs and hence different absorption colors are observed.

NPs are not simple molecules itself and therefore composed of three layers i.e. (a) the surface layer, which may be functionalized with a variety of small molecules. Metal ions, surfactants and polymers. (b) The shell layer, which is chemically different material from the core in all aspects, and (c) The core, which is essentially the central portion of the NP and usually refers the NP itself (5, 6). Owing to such exceptional characteristics, these materials got immense interest of researchers in multidisciplinary fields. Mesoporousity imparts additional characteristics in NPs. The NPs can be employed for drug delivery (7), chemical and biological sensing (8), gas sensing (9-11), CO2 capturing (12-13) and other related applications (14). NPs are broadly divided into various categories depending on their morphology, size and chemical properties. There are many methods for the synthesis of nanoparticles but one of the most conventional methods is green synthesis because it is an eco-friendly, non-toxic, very less expensive and very pure method. (15) Nanoparticles having unique properties arising from their nanoscale dimensions. Nanoparticles have many important properties and various applications in many areas such as a drug, food, nutrition, electronics etc. (16) The biological synthesis of nanoparticles which is very monodispersed particles with very specific sizes and shapes.

The huge application in the application in a pharmaceutical company for successful treatment as for disease. (17,18) Green synthesis nanoparticles have great properties, which is synthesized by every part of a plant such as, root, leaf, stem, flower, bark etc. In Synthesis of nanoparticles dried from being used. (19) Every plant has terpenoids, alkaloids. Flavonoids, total phenolic content, which is a help to synthesized the nanoparticles (20). The most researchers studied nanoparticles. Today those nanoparticles are synthesized which are noble metals like silver, zinc oxide, gold lead etc. But among the nanoparticles, zinc oxide nanoparticles play an excellence role in the field of biological and drug industry (21).

Green synthesis of ZnO NPs has been carried out by extracting different plants such as Cassia fistula and Melia Azadarch (122), garlic (Allium sativum) (23), Z. officinale (ginger), Aloe vera (24), coffee (25), orange peel extract (26), Cardamom (27), and Lippia adoensis (koseret) (28) In present investigation deals with Green method for synthesis of ZnO nanoparticles by aqueous leaf extracts of Argemone Mexicana.

Review of Literature

The novel properties of nanomaterials bring the rapid development of nanoscience and Nanotechnology. Among nanomaterials, metal oxide nanoparticles received exceedingly attention from the scientific community because of their size-tunable several unique properties, such as high chemical stability, high electrochemical coupling coefficient, broad range of radiation absorption, high photo stability, easily availability, low cost, and nontoxicity [1-7]

Antibacterial activities of zinc oxide (ZnO) nanoparticles synthesized through green method using garlic bulb (Allium sativum), ginger (Zingier of ficinale) extracts, and their mixture was reported by Urge et-al (8). The synthesized ZnO NPs were characterized by X-ray diffraction (XRD), ultraviolet visible (UV-vis), photoluminescence (PL), spectroscopy and Fourier transform infrared (FTIR) spectroscopy. The crystalline sizes of ZnO NPs synthesized using garlic bulb (Allium sativum) extract, ginger (Zingier officinal) root extract, and their mixture were 19.8, 21.94, and 23.86 nm, respectively.

The antibacterial activities of synthesized ZnO NPs were tested by them against gram-negative bacteria Escherichia coli (E. coli) and Pseudomonas putida (P. putida) and gram-positive bacteria Staphylococcus aureus (S. aureus) and Streptococcus pyogenesis (S. pyogenesis). The ZnO NPs synthesized using the mixture of garlic bulb (Allium sativum) and ginger (Z officinal) root extract have shown maximum inhibition zone against gram-negative bacteria (P. putida: 28.67±0.82 mm) and gram-positive bacteria (S. pyogenes: 10.67±0.47 mm) as compared to ZnO NPs synthesized using the two extracts separately. On the other hand, ZnO NPs obtained from garlic bulb and Z. of ficinale root extracts exhibited maximum inhibition zone against E coli (190.82 mm) and S. aureus (16.4±0.47 mm), respectively. They reported that ZnO NPs synthesized using the mixture of garlic bulb and Z. of ficinale root extract, reported for the first time, exhibited high inhibition zone against gram-negative bacteria, P. putida (28.67+0.82).

Faisal et-al (9) reported bio augmented zinc oxide nanoparticles (ZnO-NPs) were prepared from aqueous fruit extracts of Myristica fragrance. The ZnO-NPs were characterized by different techniques such as X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy, ultraviolet (UV) spectroscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM), dynamic light scattering (DLS), and thermogravimetric analysis (TGA). The crystallites exhibited a mean size of 41.23 nm measured via XRD and were highly pure, while SEM and TEM analyses of synthesized NPs confirmed their spherical or elliptical shape. The biosynthesized NPs were found to be excellent antioxidant and biocompatible nanomaterials. Biosynthesized ZnO-NPs were also used as photocatalytic agents, resulting in 88% degradation of methylene blue dye in 140 min. Owing to their eco-friendly synthesis, nontoxicity, and biocompatible nature, ZnO-NPs synthesized from At fragrance can be exploited as potential candidates for biomedical and environmental applications.

Zinc oxide (ZnO) nanoparticles (NPs) were synthesized using leaf extracts of two medicinal plants Cassia fatula and Melio atodarach (10) 0.01M zinc acetate dihydrate was used as a precursor in leaf extracts of respective plants for NPs synthesis. They reported that the C. fatula and M. azodarach mediated ZnO NPs showed strong antimicrobial activity against clinical pathogens compared to standard drugs, suggesting that plant based synthesis of NP's can be an excellent strategy to develop versatile and eco-friendly biomedical products.

Zinc oxide nanoparticles (ZnO NPs) have been successfully prepared using Cocos nucifera leaf extract and their antimicrobial, antioxidant and photocatalytic activity investigated (13). The structural, compositional and morphological properties of the NPs were recorded and studied systematically to confirm the synthesis. The aqueous suspension of NPs showed ultraviolet-visible (UV-Vis) absorption maxima of 370 nm, indicating primarily its formation. X-ray diffraction analysis identified the NPs with hexagonal wurtzite structure and an average particle size of 16.6 nm. Fourier transform infrared analysis identified some biomolecules and functional groups in the leaf extract as responsible for the encapsulation and stabilization of ZnO NPs. Energy-dispersive Abomuti and coworker (16) examined the facile synthesis of ZnO NPs using aqueous extract of Salvia officinal is without any additional stabilizing/capping agents. When compared to chemically synthesized nanoparticles, green chemistry-based synthesis using medicinal plants has less harmful effects. The photocatalytic degradation of methyl orange under UV light irradiation was performed with 92.47% degradation efficiency, and

the reaction rate Constant (kapp) was found to be 0.02134 min-1. In addition, the antifungal activity of bio fabricated ZnONPs was determined against Candida albicans isolates by standard protocols of broth micro dilution and dies diffusion assay. Phytofabricated ZnONPs using S. officinalis were found to be more effective against drug-resis (21.49, 25.26) nm for the synthesized nanoparticles by zinc acetate and zinc nitrate respectively. EDX analyses confirmed high purity for the synthesized Nanoparticles.

Primo and coworker (20) reported, synthesis of Zinc Oxide nanoparticles by two simple routes using Aloe Vera (green synthesis, route 1) or Cassava starch (gelatinization, route II). The XRD patterns and Raman spectra show that both synthesis routes lead to single-phase ZnO. XPS results indicate the presence of zinc atoms with oxidation state Zn, SEM images ofthe ZnO nanoparticles synthesized using Cassava starch show the presence of pseudo-spherical nanoparticles and Nano sheets, while just pseudo-spherical nanoparticles were observed when Aloe Vera was used. The UV-Vis spectra showed a slight difference in the absorption edge of the ZnO particles obtained using Aloe Vera (3.18 eV) and Cassava starch (3.24 eV). The ZnO nanoparticles were tested as adsorbents for the removal of copper in wastewater, it is shown that at low Cu ion concentration the nanoparticles synthesized by both routes have the same removal efficiency, however, increasing the absorbate concentration (> 80 mg/L) the ZnO nanoparticles synthesized using Aloe Vera have a higher removal efficiency. The synthesized ZnO nanoparticles can be used as effective and environmental-friendly metal trace absorbers in wastewater.

Literature survey reveals that Green synthesis of nanoparticles using eco-friendly approach has been the area of focused research in the last decade. Green sources act as both stabilizing and reducing agent for the synthesis of shape and size controlled nanoparticles. Future prospect of plant-mediated nanoparticle synthesis includes an extension of laboratory-based work to industrial scale, elucidation of phytochemicals involved in the synthesis of nanoparticles using bioinformatics tools and deriving the exact mechanism involved in inhibition of pathogenic bacteria. The plant-based nanoparticle can have huge application in the field of food, pharmaceutical, and cosmetic industries and thus become a major area of research.

MATERIAL & METHODOLOGY

The materials required and the methods used for preparation of ZnO nanoparticles using leaf extracts of Argemone Mexicana discussed below:

1) Collection of Plant Material: The green leaves of Argemone Mexicana were collected from Agricultural land nearby Khodala Tal. Mokhda Dist. Palghar 401604. State Maharashtra during the month of February and March, 2025.

Fig.1 Argemone Mexicana Plant

2) Chemicals: For the present work. Zinc Acetate dihydrated was procured from LOBA CHEMIE Company which is used as precursor. Whatman filter paper (no. 42), 0.1 NaOH was used for pH adjustment of solution. For preparation of all the solution double distilled water was used.

Fig.2 Zinc acetate dehydrate

3) Preparation Method of Leaf Extract:

1) Argemone Mexicana: The fresh leaves of Argemone Mexicana were carefully washed by that water, then sterilized using double distilled water and after washing we have 10 gm leaves. The leaf extract was prepared by the procedure described by Selvaraj et al (1). The leaves cut into small spices, and then a paste was prepared by crushing the pieces of leaves of Argemone Mexicana using mortar and pestle. Then addition of50 ml of distilled water and paste into the 250 ml beaker mixed for 20 min. then the solution was heated at 60°C for 10 min. After cooling the solution was filtered through Whatman filterpaper (no. 42), the filtrate was collected and stored for preparation of ZnO nanoparticles.

4) Biosynthesis of Zn Oxide Nano Particle 4) Preparation of Zinc acetate solution: The solution of zinc acetate dihydrate was prepared by dissolving 3.8 gm (CH, CO_2), Zn, $2H_2O$ in 50 ml of double distilled water. The 10 ml of leaf extract solution is added drop by drop wise in zinc acetate solution and stirring for two hours until nanoparticles are formed the pH value is maintained at 12 by the addition of0.1 M NaOH. Finally, the color of the solution results in a change of colour of the mixture to pale white, which is usually an indication of formation of nanoparticles. Subsequently, the pale white precipitate was observed and was washed with distilled water followed by ethanol to get rid of any impurities from precipitate. White colour paste of nanoparticle was deposited at the bottom in the beaker. The clear solution is removed through Whatman filter paper (no. 42). After filtration the particles were collected in a silica crucible and heated in muffle furnace at400°C for two hours. The sample was finally ground into a mortar to obtained fine powder. This material was then used for characterization and optical studies.

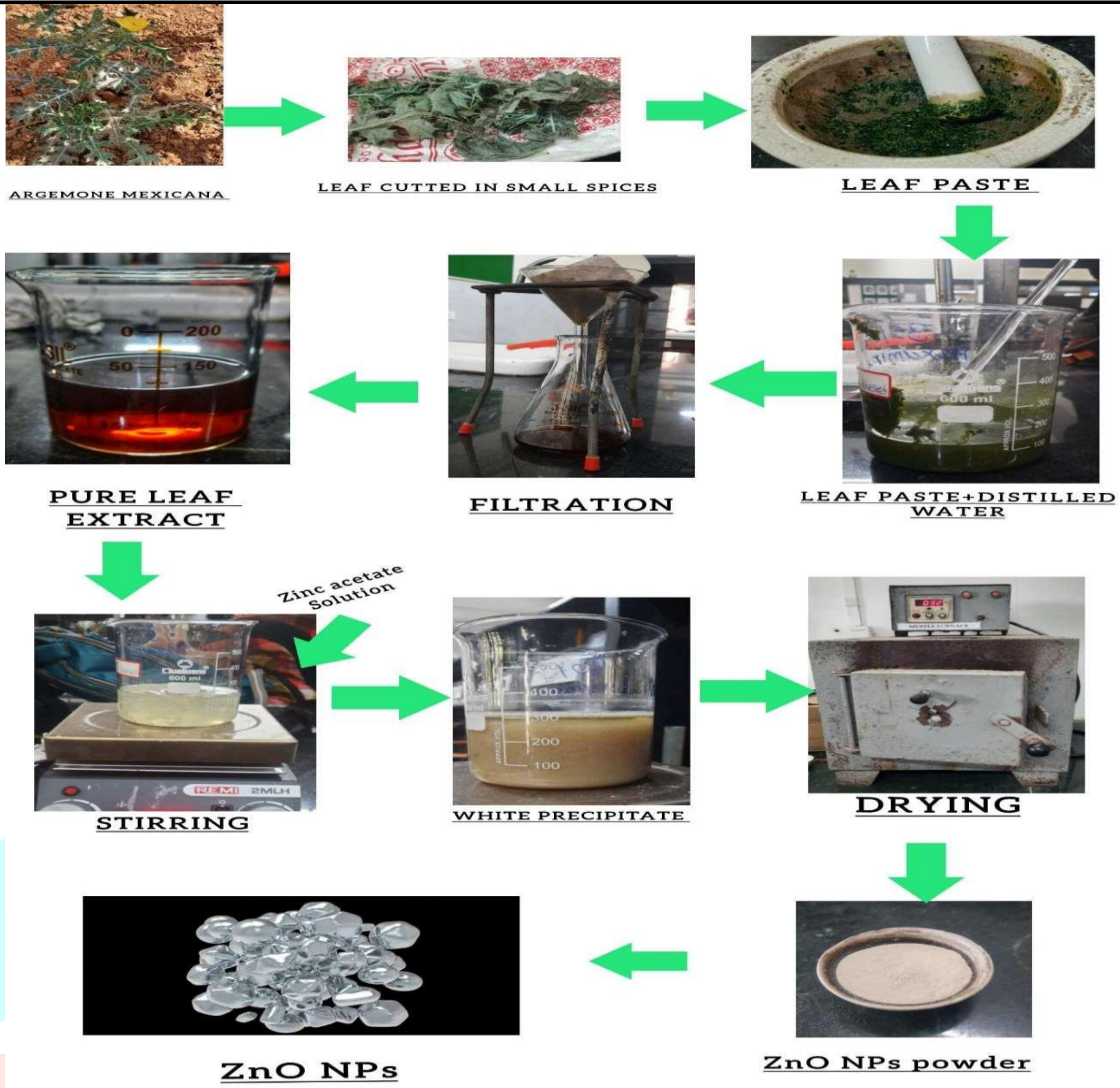

Fig.3 Schematic representation of ZnO NPs synthesis using the leaf extract of Argemone Mexicana and zinc acetate dehydrate

Result & Discussion

1. FTIR SPECTROSCOPY

The FTIR spectrum of the synthesized zinc oxide Nanoparticles shown in fig.1 reveals several. Characteristic peaks that confirm the presence of both zinc–oxygen bonds and surface functional groups from precursors.

A notable absorption band is observed at 437.0 cm^{-1}, which corresponds to the Zn– O stretching vibration, a definitive marker for the formation of zinc oxide nanoparticles. Moving up the spectrum, a broad but weak band around 3417.0 cm^{-1} indicates O–H stretching vibrations, suggesting the presence of adsorbed water molecules or surface hydroxyl groups.

A prominent absorption band at 1438.0 cm^{-1} could be associated with C–H bending or carboxylate symmetric stretching, which may suggest the presence of organic molecules used during synthesis. Another peak at 1628.7 cm^{-1} is likely due to H–O– H bending, further supporting the presence of moisture or surface hydroxylation. Small peaks between 600–900 cm^{-1}, such as at 738.9 cm^{-1}, 814.1 cm^{-1}, and 862.9 cm^{-1}, may also correspond to metal–oxygen bonding modes or surface vibrations involving lattice defects.

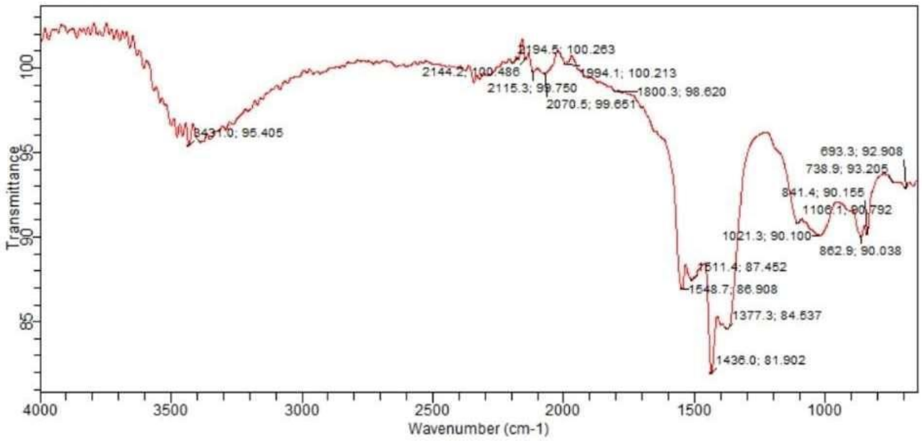

Fig No. 4 FTIR Spectra synthesized zinc oxide Nanoparticles

2. XRD SPECTROSCOPY

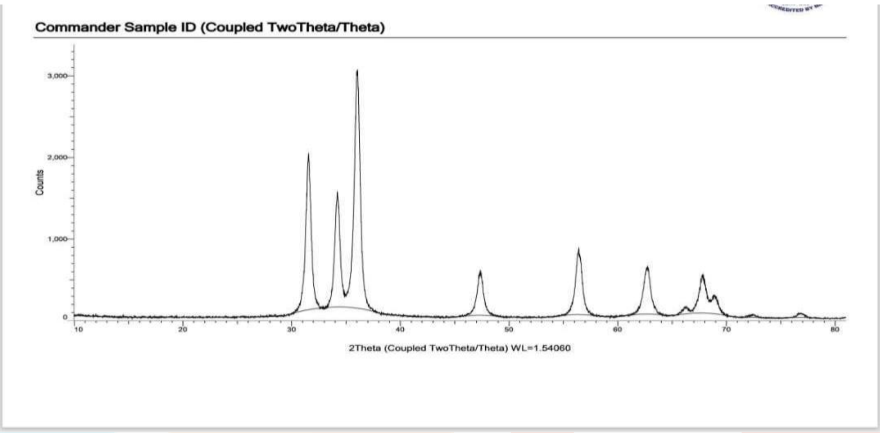

Fig No. 5 ZnO Nanoparticle X-Ray diffraction

The X-Ray Diffraction pattern presented below as fig.2 for the synthesized zinc oxide (ZnO) nanoparticles clearly indicates the formation of a crystalline material with a hexagonal wurtzite structure, which is the most thermodynamically stable form of ZnO.

The diffraction peaks observed at 2θ values around 31.7°, 34.4°, 36.2°, 47.5°, 56.6°, 62.8°, and beyond correspond to the (100), (002), (101), (102), (110), and (103) crystal planes, respectively. These peak positions closely match the standard data from the Joint Committee on Powder Diffraction Standards (JCPDS card no. 36-1451), confirming the identity and phase purity ofthe ZnO nanoparticles.

The absence of any additional peaks suggests that the sample is free from impurities or secondary phases such as zinc hydroxide or metallic zinc, indicating successful synthesis of pure ZnO

CONCLUSION

In this Paper, I was able to successfully synthesize zinc oxide (ZnO) nanoparticles using the leaf extract of Argemone Mexicana through a green and eco-friendly method. This approach is simple, cost-effective, and avoids the use of harmful chemicals, making it safer for both humans and the environment.

The formation of ZnO nanoparticles was confirmed by visible color change and further supported by FTIR and XRD analysis. The FTIR results showed the presence of functional groups and Zn- O bonds, while the XRD pattern confirmed that the particles were pure and had proper crystalline structure.

Overall, this project shows that using natural plant extracts is a good alternative to chemical methods for making nanoparticles. The synthesized ZnO nanoparticles have great potential in areas

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