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Review Article

A REVIEW ON ECO-FRIENDLY APPROACH FOR GREEN SYNTHESIS OF ZINC OXIDE NANOPARTICLES USING PLANT LEAF EXTRACTS

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ABSTRACT

Nanotechnology is concerned with the development and applications of nanoscale materials. Nanoparticles have a high surface area to volume ratio and thus have very unique properties due to their nanoscale dimension. Due to the abundance of zinc and the relatively simple conversion of its oxide to nanostructures, ZnO-based nanomaterials are of great use for many leading applications since the beginning of nanoscience. Zinc oxide nanoparticles (ZnO NPs) have gained a lot of attention because of their wide bandwidth and strong exciton binding energy, and possess antibacterial, antifungal, anti-diabetic, anti-inflammatory, wound healing, antioxidant, and optical properties. Because of its versatility, eco-friendliness, and comprehensive biological activity, plant-mediated green synthesis of nano-metal oxide particles is gaining a lot of traction as a viable alternative to not only physical but also chemical processes, avoiding the use of harmful chemicals and harsh environments. This review article is a study of the green synthesis of Zinc oxide nanoparticles (ZnO NPs) using different plant leaf extract.

Keywords: Zinc oxide, Nanomaterials, Green Synthesis, Leaf Extracts.

1. INTRODUCTION

Nanotechnology has emerged over the past decade as a technology that has revolutionized every area of applied science. One of the avenues of nanotechnology associated with nanoscale materials with very small particle sizes ranging from 1 to 100 nm is the nanoparticles (Nano-particles) sector. Due to their extremely small size and high surface area to volume ratio, nanoparticles exhibit distinctive properties, which have been attributed to major variations in properties compared to their bulk counterparts [1]. In this respect, by offering novel solutions, nanoparticles have been introduced into different industries.

Including titanium dioxide (TiO_2), indium (III) oxide (In_2O_3), zinc oxide (ZnO), tin (IV) oxide (SnO_2) and silicon dioxide (SiO_2), there are different forms of metal oxides, where ZnO is one of the most abundantly developed metal oxides after SiO_2 and TiO_2 [2]. ZnO is an inorganic material with unusual properties such as semiconductor, broad radiation absorption, piezo-electricity, pyroelectricity, and high catalytic activity [3]. Furthermore, ZnO has been classified by the US Food and Drug Administration (FDA 21CFR182.8991) [4] as 'Generally Accepted as Safe' (GRAS) because of its non-toxic properties [5]. As a result, it is safe to use on both humans and animals. Zinc oxide nanoparticles have gotten a lot of coverage in recent years. This is due to the fact that they have the smallest particles, which increases their chemical reactivity. Due to this, ZnO Nanoparticles have a broader range of applications in electronics, optics, biomedicine, and agriculture [6]. In living organisms, zinc is an essential nutrient [7]. Evidence has shown that there is a great potential for ZnO nano-particles in biological applications, especially as anti-microbial agents [8]. Furthermore, numerous studies have been published on the efficacy of ZnO nanoparticles in inhibiting the growth of a large variety of pathogens [9], indicating that they may eventually replace antibiotics. Besides, zinc is a major trace mineral that plays a vital role in many physiological functions [10].

1.1. Synthetic methods for nanoparticles

For nanoparticle synthesis, two methods have been suggested: bottom-up and top-down. Milling or attrition of large macroscopic particles is used in the top-down method. It involves initially synthesizing large-scale patterns and then reducing them by plastic deformation to the nanoscale level. For large-scale production of nanoparticles, this technique cannot be used because it is an expensive and slow process [11]. The most popular technique employing the function of the top-down approach for nanomaterial synthesis is Interferometric Litho-graphic (IL) [12]. This process involves the synthesis of nanoparticles by self-assembly from already miniaturised atomic components. It requires creation through physical and chemical means. This method is comparatively inexpensive [13]. It is based on the principle of kinetic and thermodynamic equilibrium. MBE is used in the kinetic approach (molecular beam epitaxy).

1.2. Other different techniques and methods used in nanoparticle synthesis

The physical method includes the attraction of nanoscale particles and the creation of large, stable, well-defined nanostructures by physical forces. Nanoparticle synthesis using the colloidal dispersion method is an example. Basic techniques such as vapour condensation, amorphous crystallisation, physical fragmentation and many others are also included [14]. Physical, chemical and green methods are used to make nanoparticles [15-17]. The physical method necessitates the use of expensive machines, high temperatures and pressures [18], and a wide area for system setup. The chemical method requires the use of harmful chemicals that can be dangerous to the environment as well as the person handling them. According to the literature, some of the toxic chemicals used in physical and chemical methods can resurface in the Nanoparticles produced, posing a risk in the field of medical application [19]. As a result, we needed a process for nanoparticle synthesis that was both environmentally friendly and cost-effective. In processes such as pulsed laser deposition, MBE (molecular beam epitaxy), thermal evaporation, etc., the physical process includes the use of high vacuum [20] and chemical methods include chemical microemulsion, wet chemicals, spray pyrolysis, electrodeposition [20], chemical and direct precipitation, and combustion aided by microwaves [21]. In both physical and chemical methods, additional capping and stabilising agents are needed [22].

1.3. Green synthesis approach

Biosynthesis of nanoparticles is a method of synthesising nanoparticles for biomedical applications using micro-organisms and plants parts. This approach is an approach which is environmentally sustainable, cost-effective, biocompatible, healthy and green [23]. Green synthesis requires plant synthesis, bacteria, fungi, algae, etc. They allow the production of ZnO Nanoparticles on a large scale without the presence of additional impurities [24]. Biomimetic-synthesized nanoparticles demonstrate more catalytic activity and limit the use of costly and toxic chemicals.

These natural strains and plant extract secrete certain phytochemicals that act as both reducing agent and capping or stabilising agent; for example, in the presence of ZnO blue (MB) pollutant dye, synthesis of ZnO nanoflowers of uniform size from cell soluble proteins of *B. licheniformis* demonstrated increased photocatalytic activity and photostability clearly shown by 83 percent degradation of methylene blue (MB) pollutant dye in the presence of ZnO nanoflowers, self-degradation of MB was null (observed through the control value), and degradation was found to be 74 percent after three repeated cycles of the experiment at different time intervals, demonstrating photostability of ZnO nano-flowers developed [25].

The fungal strain *Aspergillus fumigatus* TFR-8 was used to synthesise oblate spherical and hexagonal shaped ZnO Nanoparticles with sizes ranging from 1.2 to 6.8 nm. These Nanoparticles showed stability for 90 days, which was verified by measuring the hydrodynamic diameter of nanoparticles using a particle size analyzer, which showed agglomeration formation of nanoparticles only after 90 days, indicating high stability. ZnO 36 nm synthesised nanoparticles from seaweed *Sargassum myriocystum* (microalgae) collected from the Gulf of Mannar showed no visible changes, even after 6 months, clearly demonstrating the stability of the shaped nanoparticles. It has been confirmed from FTIR outcome studies that fucoidan soluble pigments secreted from microalgae were responsible for reducing and stabilising the nanoparticles. For the synthesis of nanoparticles, plant components such as roots, leaves, stems, seeds, fruits have also been used as their extract is rich in phytochemicals that act as both a reduction and stabilisation agent [27]. ZnO synthesized nanoparticles from *Trifolium pratense* flower extract showed similar peaks in the UV-Vis spectrophotometer after 24, 48, 72, 96 and 120 hours of formation of nanoparticles indicating stability of the formed nanoparticles [28].

1.4. Zinc oxide nanoparticles and their applications

ZnO is a semiconducting metal oxide of n-type. Because of its wide range of applicability in the field of electronics, optics, and biomedical systems, zinc oxide

NP has attracted interest in the past two to three years [29]. Several forms of inorganic metal oxides, such as TiO_2, CuO, and ZnO, have been synthesised and have remained in recent studies. ZnO Nanoparticles are the most interesting of these metal oxides because they are inexpensive to make, safe, and easy to prepare [30].

Due to its wide bandgap (3.37 eV) and high exciton binding energy (60meV), ZnO nanoparticles exhibit tremendous semiconducting properties, such as high catalytic activity, optic, UV filtering properties, anti-inflammatory, wound healing [31]. It has been commonly used in cosmetics, such as sunscreen lotions, due to its UV filtering properties [32]. It has a broad range of therapeutic uses, such as drug delivery, anti-cancer, anti-diabetic, antibacterial, antifungal and agricultural properties [33]. While ZnO is used for the delivery of targeted drugs, it still has a cytotoxicity limit that has yet to be resolved [34].

According to research, ZnO Nanoparticles have a much greater antibacterial activity at low concentrations of gramme negative and gramme positive bacteria than chemically synthesised ZnO Nanoparticles [35]. They've also been used in the manufacture of rubber, paint, the removal of sulphur and arsenic from water, the properties of protein adsorption, and dental applications. The piezoelectric and pyroelectric properties of ZnO nanoparticles have been discovered [36]. They are used for aquatic weed disposal that is resistant to all sorts of eradication techniques such as human, chemical and mechanical means [37]. Different morphologies of ZnO nanoparticles have been published, including nanoflake, nanoflower, nanobelt, nanorod, and nanowire [38].

2. SYNTHESIS OF ZINC OXIDE NANOMATERIALS BY GREEN APPROACH

Due to the growing popularity of green methods, numerous works have been carried out using various sources such as bacteria, fungi, algae, plants and others to synthesise ZnO nanoparticles. The literature review on the synthesis of zinc oxide nanomaterials by a green approach using various plant leaf extracts is carried out in this paper. To summarise the useful work done by the researchers in this area, a list of table1 was put up.

Umamaheswar A. et al. [39] synthesised zinc oxide nanoparticles (ZnO NPs) from *Raphanus sativus var. Longipinnatus* leaves extract and investigated their anticancer activity. UV-vis, FTIR, particle size analysis, SEM, XRD and its anticancer activity using A549 cell lines were examined by synthesised ZnO NPs. The UV-vis and particle size of nanoscale ZnO NPs are stated as 66.43 nm. The FTIR studies indicated that different functional groups were present. The partial crystal spherical form and wurtzite crystal character were verified by SEM and XRD images. The findings of cytotoxicity highlighted the improved cytotoxic effect of the synthesised ZnO NPs.

Zinc oxide nanoparticles (ZnO NPs) were synthesised by Dhandapani KV, et al. [40] using *Melia azedarach* leaf extract with zinc nitrate as the initiating source. The Ultra Violet-Visible (UV-Vis) Spectroscopy absorption peak at 372 nm in synthesised nanoparticles is one of the distinguishing features of ZnO NPs. The role of aliphatic amines, alkyl halides, and carboxylic acids in the synthesis and stability of ZnO NPs is indicated by the Fourier Transform Infrared (FTIR) spectrum. The nanocrystal nature of the synthesised zinc oxide particles was confirmed by an X-Ray Diffraction (XRD) spectrum. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) images revealed hexagonal and spherical forms ranging in size from 33 to 96 nm of synthesised zinc oxide nanoparticles. The Energy Dispersive X-Ray Study (EDAX) reported that the existence of zinc content in synthesised nanoparticles of zinc oxide has been confirmed and notes that the biosynthesis process of nanoparticles has been carried out accordingly. Biosynthesized ZnO NPs with powerful biological activities in terms of anti-oxidant and antibacterial potential that could be used in many biological applications.

The green synthesis of zinc oxide nanoparticles using ethanolic extract *Typha latifolia* was reported by Kumar BP, et al. [41]. L leaf without the use of dangerous chemicals Using XRD, SEM, UV, EDAX and FTIR measurements, the acquired properties of ZnO nano-particles, such as crystallite size, morphology, bandgap, elemental composition, were studied. The existence of ZnO is indicated by peaks of between 400 and 600 cm-1. The highly magnified SEM images of the synthesised nanoparticles by the process of biosynthesis clearly display the creation of the structure of nanoflowers. ZnO nanoparticles were used in the photo-degradation experiments. The photo-degradation efficiency of ZnO nanoparticles was found to be significantly higher than that of bulk ZnO.

Vijayakumar S, et al. [42] used *Atalantia monophylla* leaf extract to successfully synthesise Zinc Oxide nano-particles for the first time. This study found that the green, eco-friendly and cost-effective approach is ideally suited for the synthesis of potent anti-microbial hexagonal ZnO nanoparticles using *A. monophylla* leaf extract. The UV-vis absorption peak of these nanoparticles was found to be 352 nm. XRD, FTIR, SEM with EDAX, and TEM were used to classify the ZnO nanoparticles. In the destruction of pathogenic microorganisms, biosynthesized ZnO nanoparticles outperformed traditional antibiotics and plant extracts. Thus, nanoparticles of this form of bio-doped oxide can productively minimise infections caused by micro-organisms. It is stated that, because of its non-toxic and inexpensive material that is suitable for environmental and health-related applications, green synthesis has a strong social relevance.

The synthesis of zinc oxide nanoparticles (ZnO-NPs) using *Ocimum basilicum L. var. purpurascens* Benth.-LAMIACEAE leaf extract and zinc nitrate was reported by Abdul Salam H, et al. [43]. Using leaf extract of Ocimum basilicum L. var. purpurascens Benth., green synthesis of hexagonal (wurtzite) shaped ZnO-NPs of about 50 nm was achieved, thus bringing to light yet another application of the plant, in addition to its normal utilities. The approach stands out mainly because it is eco-friendly and shuts down the demerits of traditional methods of physics and chemistry. In different industries, these particles are anticipated to have broad applications.

Green tea leaves (*Camellia sinensis*) were chosen by Dhanemozhi AC, et al. [44] for the green synthesis of Zinc oxide nanoparticles (ZnO NPs). The formation of nanoparticles was detected by visualising colour changes and was confirmed by the spectrophotometers Scanning Electron Microscope (SEM), UV-Vis and Fourier Transform InfraRed (FT-IR). The absorption spectra were observed using the UV-Vis spectrum, which showed a blue shift absorption peak at 338 nm. Well described peaks occurring at 2 positions corresponding to the hexagonal wurtzite structure of ZnO nanoparticles were revealed by the XRD pattern. The mean size of the nanoparticles measured using XRD data was 54.84 nm, with an energy gap of 3.40eV in the band. The study found that the higher percentage of antioxidant-potential phenolic compounds acting as a reduction agent on metal oxides and substantially present in amino acids, proteins and lipids helped to regulate the growth of nanoparticles. The obtained CV curve reveals excellent capacitance behaviour, low equivalent series resistance (ESR), and thus rapid electrolyte ion diffusion into the composite. This indicates that the best-suited material for supercapacitor applications is the as-prepared ZnO materials.

Sangeetha G, et al. [45] has developed a simple, rapid biological technique to synthesise nanoparticles of zinc oxide with tunable optical properties guided by particle size using varying concentrations of solution extracted from *Aloe vera* leaf broth. There is a distinct poly-dispersity of the zinc oxide nanoparticle and the particle size varies from 25 to 45 nm with an average size of 35 nm. The maximum nanoparticles have a particle size of 30 nm with a separate cap that may be due to the presence of flavonoids, proteins and other functional groups in the aloe vera leaf broth and are likely to be responsible for the formation of nanoparticles of zinc oxide. In biomedical fields and in the cosmetic industry, the eco-friendly, highly efficient zinc oxide nanoparticles produced from Aloe vera leaf broth are expected to have more extensive applications.

The synthesis of zinc oxide nanoparticles (ZnO NPs) using *Azadirachta indica* leaf aqueous extract and its antimicrobial activities have been identified in Elumalai K, et al. [46]. UV-visible spectroscopy, photo-luminescence (PL), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), scanning electron microscope (SEM) analysis, energy dispersive X-ray (EDAX) analysis, field emission scanning electron microscopy (FESEM) and atomic force microscope (AFM) analysis were used to classify the nanoparticles. Researchers also investigated the antimicrobial activity of synthesised green ZnO NPs in this report. The findings showed an increase in the concentration of ZnO NPs (50, 100, 200 μg/ml) and the increase in antimicrobial activity was also attributed to an increase in the concentration of H2O2 on the surface of ZnO. Green synthesised ZnO NPs, on the other hand, is more potent than bare ZnO and A. indica leaf. Finally, the analysis concluded that the zinc oxide nanoparticles displayed interesting antimicrobial activity with micromolar concentrations of both gram-positive and gram-negative bacteria and yeast.

The researchers Darvishi E, et al. [47] used *Juglans regia L.* leaf extract to synthesise zinc oxide (ZnO) nanoparticles. Different concentrations of walnut leaf extract and zinc acetate was reported to have been used, and ZnO NPs with different structures and sizes were produced. Particles showed circular, irregular surface morphology and flower shape. The antimicrobial activity of ZnO nanoparticles has also been studied against resistant strains of Escherichia coli, Pseudomonas aeruginosa and Acinetobacter baumannii. The properties of zinc oxide nanoparticles synthesised using both green and chemical methods were compared. More than a chemical, the antimicrobial effect of ZnO nanoparticles synthesised by the green method was greater. The cytotoxicity assay showed that the cytotoxicity of the green-synthesized ZnO nanoparticles was lower than that of the chemical ZnO. This research has shown that green-synthesized nanoparticles of ZnO have many advantages over chemicals. Chemical ZnO nanoparticles are smaller, have more solubility, have more antibacterial activities, and are less cytotoxic.

In research paper, Ramesh P, et al. [48] identified the synthesis and antibacterial activity of biocompatible zinc oxide nanoparticles (ZnO Nps) from zinc acetate employing an eco-friendly green process using *Cassia auriculata* leaf extract. ZnO Nps synthesised is spherical and ranged in size from 20 to 30 nm. Antibacterial activity of green synthesised ZnO Nps against bacterial pathogens was found to be very high. As a result, the environmentally friendly and high-efficiency zinc oxide nanoparticles produced with *C. auriculata* leaf extract are expected to see more widespread use in the food packaging industry to avoid bacterial contamination.

The biodegradation of zinc nitrate hexahydrate using crude leaf extract from *Gulmohar*, by combustion method at 400˚C to form ZnO nanostructures, was studied by Begum JPS, et al. [49]. The synthesised nanoparticles for the formation of polydisperse ZnO NPs have been characterised and confirmed. Using bavistin as a positive control, the antibacterial operation of pure wurtzite ZnO NPs was carried out by the Resazurin plate assay method followed by antifungal evaluation using the food poisoning technique. For the quantitative evaluation of MTT and apoptosis assay, the anticancer potential was evaluated using the HeLa cell line. The antibacterial activity of ZnO NPs on *Escherichia coli* and *Staphylococcus aureus* was within the 0.25e0.0025 mg/ml range and the antifungal effect was within the 100e700 mg/ml range on Fusarium oxysporum and Phomposis azadirachtae. On 24 hours after exposure, the MTT assay and apoptosis study on the HeLa cell line pinpointed optimum cell uptake and toxicity. This biogenic method-based ZnO NPs synthesis paves the way for substantial microbicidal potential against a variety of plant and animal pathogenic microorganisms, as well as a superior cytotoxic effect against HeLa cell lines. As a result, they are promising nano-antibiotics for medicinal use.

The co-precipitation method was used by Park JK, et al. [50] to synthesise *Gynostemma pentaphyllum* zinc oxide nanoparticles (GP-ZnO-NPs) from Gynostemma plant extract using a green chemistry protocol. The decolourization efficiency of GP-ZnO-NPs was evaluated by extracting the toxic Malachite Green (MG) dye under UV illumination. X-ray powder diffraction (XRD) study has confirmed the hexagonal wurtzite structure with a mean size of 35.41 nm. The FE-TEM analysis showed the hexagonal form of the nanoparticles, and the percentage of Zn & oxygen in the nanostructures was analysed by electron diffraction analysis (EDX). The functional group responsible for forming Gp-ZnO-NPs was revealed in the Fourier-transform infrared spectroscopy (FT-IR) study. The study of X-ray photoelectron spectroscopy (XPS) revealed the chemical compositions (Zn, C & O) and the elemental state of the nanostructure. To investigate the photocatalytic behaviour of Malachite Green dye under UV illumination, the newly synthesised nanocatalyst was added. Within 180 minutes of observation, the photocatalyst (GP-ZnO-NPs) decoloured 89 percent (10 mg/L) toxic MG dye. The hexagonal nanoparticle arrangement provides a larger active site for interacting with the poisonous dye molecules, allowing the reaction to proceed more rapidly. The GP-ZnO-NPs are highly recommended by this study as a greener nanocatalyst for removing toxic dye for a safer climate.

Agarwal H, et al. [51] researched the fabrication of nano-sized ZnO particles using zinc oxide as a precursor molecule and *Cinnamomum Tamala* leaf extract as a reducing and capping agent. The hexagonal wurtzite phase was confirmed by XRD analysis on the nanoparticles, which had a particle size of 26.57 nm. The nanoparticles' moderate stability was confirmed by zeta potential analysis, and SEM analysis showed that they were spherical and hexagonal. On selected bacterial organisms, the antibacterial properties of the nano-particle against *Staphylococcus aureus* were investigated using the broth dilution process, protein leakage analysis, membrane stability analysis, and growth curve analysis. The results showed a time- and concentration-dependent reduction in bacterial growth due to membrane damage due to leakage of intracellular proteins and cellular material. This method of producing ZnO NPs from *Cinnamomum Tamala* is simple, environmentally friendly, cost-effective, and convenient, and it is expected to find applications in bioremediation, drug delivery, catalysis, and other medical fields.

Zinc oxide nanoparticles (ZnO-NPs) have been synthesised by Ekennia A, et al. [52] using a simple, low-cost and safe process involving aqueous leaf extracts of *Alchornea laxiflora* and zinc precursor salt. In the degradation of the Congo red dye, ZnO-NPs were assessed for their ability as tyrosinase inhibitors and as catalysts. Within the range of 276456 nm, the UV-vis spectra showed characteristic surface Plasmon bands. The range of the bandgap energies of the ZnO-NPs was 2.50-

3.67 ev. Particles obtained with 1 mL and 2 mL of plant extracts had average sizes of 29 nm and 38 nm, respectively, according to SEM results. The elemental compositions of the nanoparticles with pronounced zinc and oxygen were demonstrated in the EDX map. The ZnO nanoparticles had an IC_{50} of 66.28 g/mL and showed good photocatalytic efficiency of 87 percent degradation of Congo red (CR) dye molecules in 60 minutes. They also had good antityrosinase performance. Overall, biogenic ZnO nanoparticles are promising materials for dual applications as photocatalysts and tyrosinase inhibitors in the degradation of Congo red dye.

Varadavenkatesan T, et al. [53] announces a green synthesis of zinc oxide nanoparticles (ZnONPs) using *Cyanometra ramiflora* leaf extracts and zinc acetate precursor. The extract's phyto-components helped reduce and shape nanoparticles. The formation of ZnONPs was confirmed by a sharp absorption limit at 360 nm in the UV-Vis results. The nanoflower morphology was revealed in the SEM image and EDS showed clear signals for zinc and oxygen components. The XRD spectrum indicated a crystalline structure of 13.33 nm hexagonal wurtzite. BET research confirmed a substantial broad surface area of $16.27m^2/g$ with mesopores. The presence of the characteristic zinc and oxygen bonding vibrations at 557 cm^{-1}, 511 cm^{-1} and 433 cm^{-1} was substantiated by FTIR. Using the pollutant dye, Rhodamine B, the photocatalytic function of ZnONPs was examined. Under sunlight irradiation, a remarkable degradation efficiency of 98 percent within 200 min was achieved and a degradation constant of 0.017 min^{-1} was obtained. ZnONPs synthesised using a cheap and abundant source can therefore play a promising role in the degradation of toxic dyes present in wastewater, the leaf extract of C. ramiflora.

The green, eco-friendly synthesis of zinc oxide nanoparticles (ZnO NPs) using *Cucurbita pepo* leaf extract was reported by Hu D' et al. [54]. TEM images verified that NPs with an average size of 8 nm were developing. The crystalline nature of prepared ZnO NPs was demonstrated by XRD. This shows that, in a concentration-dependent manner, the ZnO NPs induced cytotoxicity that affected the proliferation of MG63 osteoblast-like cells. Fluorescein diacetate hydrolysis (FDA) staining confirmed the ZnO NPs-induced reduction in cell proliferation. The FDA staining results indicated a decrease in fluorescence intensity as the concentration of ZnO NPs increased. When compared to ZnO NPs treated samples, the untreated control displayed the highest fluorescence. The fluorescence of samples incubated with 80ppm ZnO NPs was substantially reduced. In conclusion, these cell test results indicated that the ZnO NPs produced are an essential substitute for the formation of osteoporotic and bone tissue.

Fahimmnisha B, et al. [55] used *Aloe socotrina* (As) leaf extract to synthesise ZnO NPs and classify them by UV, FTIR, XRD, SEM, and TEM. The overall absorption was found to be about 315 nm using UV spectroscopy. The structure of ZnO NPs ranging in size from 15 to 50 nm was determined by TEM images, while their crystallinity was revealed by XRD spectra. Extensive experiments were carried out to understand the antibacterial activity of NPs, including agar well diffusion, minimum inhibitory concentration, growth kinetics, intracellular uptake, reactive oxygen species (ROS) production, and antibiofilm activity. The *A. socotrina* capped ZnO NPs (As-ZnO NPs) showed substantial activity against biofilms produced by four bacterial pathogens, which may make it difficult to treat drug-resistant bacterial diseases caused by these biofilms.

Rad SS, et al. [56] produced a simple and environmentally friendly synthesis of zinc oxide nanoparticles (ZnO NPs) using *Mentha pulegium L.* leaf extract. The XRD data showed that the nanoparticles and EDX measurements were crystalline in nature, suggesting a high zinc content of 56.26 percent and 43.74 percent oxygen. The existence of functional groups in both leaf extract and ZnO NPs was confirmed by FT-IR. The size and morphology of the particles were determined using FE-SEM and TEM, and the UV visible absorbance spectrum of ZnO NPs showed an absorbance band at 370 nm. On Escherichia coli and Staphylococcus aureus, the antibacterial properties of synthesised ZnO nanoparticles were investigated. The reported findings indicate that aqueous extracts of *Mentha pulegium* (L.) are efficient reducing agents with important antimicrobial potential for the green synthesis of ZnO NPs.

Zinc oxide nanoparticles (ZnONps) were synthesised by Singh A, et al. [57] using *Azadirachta Indica* leaf extract. Various analytical techniques, including UV-Visible spectroscopy, FTIR, XRD, SEM, FESEM and EDAX, were then characterised by ZnONps. ZnONps interaction experiments with Calf-Thymus DNA (CT-DNA) have been further investigated using UV-Visible, UV-thermal, fluorescence, spectroscopy of circular dichroism, and electrophoresis of agarose gel. In absorption spectra, ZnONps showed a sharp peak of about 368 nm, confirming their synthesis. SEM and FESEM were used to investigate the surface morphology of ZnONps, and the size was found to be in the 20-40 nm range. After analysing all of the results, the interaction of CT-DNA with ZnONps indicated that DNA was stabilised. These physicochemical studies may provide additional knowledge for biosensing and biomedical applications.

Pai S, et al. [58] used an aqueous extract of *Peltophorum pterocarpum* leaves to investigate the synthesis of zinc oxide nanoparticles (ZnO NPs) by reducing zinc acetate. Zinc acetate was reduced to ZnONPs by the phenolic compounds present in the leaf extract. The synthesis process was visually monitored, and the formation of ZnO NPs was confirmed by a high absorption peak at 365 nm in the UV-vis spectrum. 3.39 eV was measured as the bandgap capacity. The FE-SEM picture revealed isolated flower-shaped ZnO NPs, and the EDS spectrum revealed characteristic zinc and oxygen peaks. In the XRD spectrum, the hexagonal wurtzite structure was confirmed, and the crystallite size was determined to be 11.64 nm. Moreover, the values of the lattice parameters were consistent with the normal values for ZnO NPs. The mesoporous structure (pore diameter = 10.77 nm) with a relatively high surface area (13.56 m^2 /g) was confirmed by BET analysis. A TGA curve in which only 12 percent weight loss was observed demonstrated the thermal stability of the ZnO NPs. The degradation of methylene blue (MB) dye under sunlight irradiation demonstrated the photocatalytic ability of ZnO NPs. 95 percent of the dye could be degraded within 120 min. The study stated that synthesised ZnO NPs can be used for the degradation of dyes from wastewater as photocatalysts.

Ahmad W, et al. [59] proposed using *Euphorbia hirta* leaves extract to synthesise ZnO nanoparticles in a greenway. The leaf extract was used for the synthesis of ZnO nanoparticles from zinc nitrate as a biological reduction agent. Using various analytical and spectroscopic instruments, such as UV visible spectroscopy, Fourier transform infrared spectroscopy (FT-IR), X-ray diffraction (XRD) and scanning electron microscopy (SEM) study, the prepared nanoparticles were characterised. Along with the synthesis and characterization of ZnO nanoparticles, this research uses the disc diffusion approach to test the antimicrobial activity of bio synthesised nanoparticles against clinical and normal strains of *Streptococcus mutans, Streptococcus aureus, Clostridium absonum, Escherichia coli, Arthogrophis cuboida, Aspergillius fumigates,* and *Aspergillius nigar*. Therefore, it is stated that synthesised ZnO NPs may be a potential candidate for various applications related to medicine and biology.

Yedurkar S, et al. [60] focuses on the green synthesis of nanoparticles of zinc oxide by zinc acetate and the use of bio-components of *Euphorbia milii* leaves extract. The zinc oxide nanoparticles prepared were spherical and XRD, FTIR, EDX, DLS, UV-Vis absorption and SEM techniques were used to classify them. The SEM images revealed that the majority of the nanoparticles are spherical and have a diameter of 90-110 nm. The characteristic absorption of zinc oxide bonds is shown by FTIR at 536 cm^{-1}, confirming the formation of zinc oxide nanoparticles. X-ray diffraction confirms the formation at ambient conditions of a hexagonal wurtzite phase, which is the most stable type of zinc oxide. The particle size was 110nm and the polydispersity index was 0.2, suggesting a uniform distribution of nanoparticles in size. 24.64 mV was considered to be the zeta potential. The high value confirms the stability of nanoparticles with zinc oxide. The authors reported that there are many benefits to the green chemistry approach to the synthesis of zinc oxide nanoparticles, such as the ease with which the process can be escalated, economic feasibility, etc. The use in bactericidal wound healing and other medical and electronic applications of such eco-friendly nanoparticles allows this process potentially exciting for large-scale synthesis of other inorganic materials.

The leaves extract of a medicinally essential plant, watercress (*Nasturtium officinale*), was obtained by an ultrasound-facilitated method and used by Bayrami A. et al. [61] for the preparation of ZnO nanoparticles utilizing a joint ultrasound-microwave-assisted technique. SEM, TEM, XRD, EDX, BET, FTIR, TGA, and UV-Vis DRS analyses were used to determine the characteristics of extract enriched nanoparticles (Ext/ZnO) and to compare them with those of ZnO prepared in the absence of extract (ZnO). Several differences between ZnO and Ext/ZnO verified the relation of extract over nanoparticles due to the presence of carbon and carbon bonds, changes in morphology, size, bandgap energy, and weight-decay percentage. To treat alloxan-diabetic Wister rats, Ext/ZnO, watercress leaf extract, ZnO, and insulin therapies were administered and their healing efficacy outcomes were compared to each other. Serum levels of the main diabetic indices, such as insulin, fasting blood glucose and lipid profiles (total triglycerides, total cholesterol and high-density lipoprotein cholesterol) have been calculated for balanced, diabetic and rehabilitated rats with the therapeutic agents tested. The watercress extract-enriched ZnO nanoparticles worked the best and stopped diabetic rats from developing diabetes.

Moreover, the activity of *Staphylococcus aureus* and *Escherichia* coli bacteria was satisfactorily inhibited by both ZnO samples. According to the findings, *Nasturtium officinale* leaf extract will significantly enhance the anti-diabetic and antibacterial activities of ZnO nanoparticles.

Chinnasamy C, et al. [62] applied a green approach using *Costusigneus leaf* extract for the synthesis of zinc oxide nanoparticles. The Costusigneus leaves serve as both a reduction and capping agent and assist in the synthesis of nanoparticles of zinc oxide. By selecting different levels in each parameter using the Design of Experiments L9 orthogonal array, the parameters that affect the yield of the synthesis process are defined and optimised. The results of the characterization support the development of ZnO nanoparticles and the particle size is found to be 31 nm with a spherical shape. Characterization findings from XRD, FTIR, EDX and UV-Vis spectroscopy demonstrated the formation of ZnO nanoparticles.

Santhoshkumar J, et al. [63] synthesised zinc oxide nanoparticles (ZnO NPs) from *Passiflora caerulea* fresh leaf extract and zinc acetate. UV-visible spectroscopy, XRD, FTIR, SEM, EDAX, AFM have characterised the ZnO NPs produced. The size of the particle is found to be 37.67 nm and in cubical form. The study reveals that the green synthesis of multifunctional ZnO NPs using P. caerulea is an inexpensive, eco-friendly and simple process. As compared to plant extract, the synthesised nanoparticles displayed a very strong zone of inhibition against the pathogenic culture.

Sohail MF, et al. [64] was designed to develop, along with multiple biomedical applications, green synthesised zinc oxide nanoparticles (ZnO-NPs) as possible nano-antibiotics against drug-resistant microbes. The developed ZnO-NPs with an average size of 19.57 nm were characterised for zeta potential, crystalline structure using X-ray diffraction, surface morphology using scanning electron microscopy, and FTIR analysis using *Azadirachta indicia* leaf extract when compared to a standard comparison, the ZnO-NPs demonstrated much superior antioxidant and enzyme inhibition activity, with a significantly lower IC50 value. Besides, ZnO-NPs demonstrated substantially greater antibacterial activity against pneumococcal strains resistant to levofloxacin with an IC_{50} value of 0.014 μM compared to 2.048 mM for levofloxacin. Slight changes in liver function tests, especially renal functional tests, were observed in an in vivo acute toxicity study in mice when compared to the control group. No major improvements were shown by full blood analysis. Also, the treatment group's histopathology of vital organs indicated no anatomical changes in major organs. Overall, the results indicated that ZnO-NPs based on the current green synthesised *Azadirachta indicia* leaf could be produced as a therapeutic agent with antioxidant, enzyme inhibition and good antibacterial potential for safe administration against antibiotic-resistant bacteria.

Nano-zinc oxide (nano-ZnO) particles were successfully prepared by an eco-friendly method using plant *Barleria gibsoni* (B. gibsoni) aqueous leaf extract, according to Shao F, et al. [65]. The *B. gibsoni* water leaf extract is responsible for reducing not only the source but also the protective agent. XRD studies showed the hexagonal (wurtzite) structure of the shaped nano-ZnO particles. The TEM analysis confirmed the range between 30 and 80 nm of nanoparticles, which is followed by DLS analysis. When bacterial pathogens were used to test the antibacterial properties of synthesised nano-ZnO particles, the findings were positive. Another tropical antimicrobial formulation for the healing of burn infections serves as an effective and superior nano-ZnO gel. Furthermore, in rats, the nano-ZnO gel had a remarkable wound healing ability.

Green synthesised zinc oxide nanoparticles from methanolic leaf extract of *Glycosmis pentaphylla* were reported by Vijayakumar S, et al. [66]. UV-VIS spectroscopy, fluorescence spectrometer, FT-IR, XRD, SEM with EDAX, and TEM were used to classify the synthesised nanoparticles. The UV-VIS spectrum and photoluminescence spectrum of synthesised nanoparticles were characterised by peaks at 351 and 410 nm, respectively. The functional group of the nanoparticles was discovered using FT-IR analysis. The XRD data revealed the crystalline nature of the nanoparticles and 20.70 percent of the highly pure zinc oxide metal was shown by EDAX measurements. SEM and TEM were used to investigate the morphological characterization of synthesised zinc oxide nanoparticles, which ranged in size from 32 to 36 nm. The antimicrobial activity of the synthesised zinc oxide nanoparticles against pathogenic species was intriguing. Furthermore, this is the first study on leaf mediated synthesis of *Glycosmis pentaphylla* nanoparticles of zinc oxide (ZnO).

Letsholathebe D, et al. [67] has been synthesized zinc oxide (ZnO) using *Moringa Oleifera* leaf extract by hydrothermal method. The XRD patterns of ZnO nanoparticles synthesised were investigated. The wurtzite process is confirmed by the high diffraction peaks found in the sample. The enlargement of diffraction peaks from various polycrystalline aggregates at different crystal sizes. The average particle size was calculated using the

Scherrer equation from the full width at the half maximum (FWHM) of the diffraction peaks. The average particle size of zinc oxide nanoparticles was found to be 25 nm. The UV-vis absorption spectrum shows substantial absorption in the 200-450 nm range (visible light region).

Sharmila G, et al. [68] synthesised zinc oxide nanoparticles (ZnO NPs) using the green method of *Tecoma castanifolia* leaf extract. UV-Vis spectroscopy, TEM, EDAX, XRD and FTIR have been characterised by ZnO NPs. GC-MS studied the phytochemical constituents of *T. castanifolia* leaf extract. UV-Vis absorption revealed a 370-400 nm SPR band, confirming the formation of ZnO NPs. TEM analysis reveals a spherical form with a size of 70-75 nm and the hexagonal step of the wurtzite structure was revealed by XRD results. GC-MS detected the presence of bioactive phytochemical constituents in the methanolic extracts of T. castanifolia. For both Gram-positive and Gram-negative bacteria, excellent antibacterial activity was observed. The antioxidant activity of ZnO nanoparticles was found to increase as the concentration of the nanoparticles increased. Anticancer behaviour with an IC50 value of 65μg/mL with stronger cytotoxic effects of ZnO NPs on A549 cell line proliferation. The study reported that the pharmacologically active compounds present in the green synthesised nanoparticles of ZnO pave the way for their successful use in the delivery systems of biomedical and nano-drugs.

Umavathi S, et al. [69] used *Parthenium hysterophorus* leaf extract to synthesise zinc oxide (ZnO) nanoparticles using green approaches. With a bandgap value of 3.26 eV, the optical property of synthesised ZnO nanoparticles showed UV-vis absorption at 380 nm. The structural analysis of X-ray diffraction reveals the development of ZnO nanoparticles with hexagonal stage structures. Surface morphologies of ZnO nanoparticles are exposed by SEM and TEM analysis, and the majority of them are spherical with a size range of 10 nm. Good antimicrobial activity against both bacterial and fungal strains has been shown in ZnO nanoparticles. *Sesamum indicum's* seed germination and vegetative growth have been significantly enhanced.

As an environmentally friendly approach, Vijayakumar S, et al. [70] reported green synthesis of ZnO nanoparticles using *Acalypha fruticosa* leaf extracts. UV-Visible spectroscopy with a maximum absorbance of 310 nm was used to classify ZnO nanoparticles. The crystalline structure was demonstrated by XRD analysis and the purity of the ZnO nanoparticle was verified by EDAX analysis. The size of the nanoparticles in the range of 50-60 nm was revealed by FE-SEM analysis, and SAED pattern analysed the crystalline nature of the nano-particles. Also, the green ZnO synthesised nanoparticle has proven to be an excellent antimicrobial agent against pathogenic species.

For the production of zinc oxide nanoparticles, Soni N, et al. [71] used the aqueous leaf extract of *Ficus religiosa* (Peepal). The synthesised nanoparticles were tested against Anopheles stephensi larvae as larvicides. The synthesised nanoparticles were further tested against *Escherichia coli* (gramme negative) and *Staphylococcus aureus* (gramme positive) bacteria as antibacterial agents. The research report revealed that rapid biological synthesis of ZnO NPs using F. religiosa aqueous leaf extract would be an efficient potential larvicide for mosquito control as well as eco-friendly antimicrobial agents.

Zinc oxide nanoparticles have been synthesised by Mirgane NA, et al. [72] from leaves of *Abelmoschus esculentus Linn* using the environmentally friendly green route at room temperature. Various phytochemicals include ladyfinger extract leaves or those used in *Abelmoschus esculentus* (L) for the reduction and stabilisation of ZnONP synthesis agents. The stabilisation of ZnONPs by phytochemicals is stronger, as demonstrated by Fourier-transform infrared spectro-scopy. Plant-assisted nanoparticles of zinc oxide display a good 3.37Ev bandgap and have good photocatalytic activity in the UV zone. Plant-assisted ZnO nanoparticles are used under UV light for splitting or cutting or degrading dye. Methylene Blue and Methyl Orange were used as dyes.

Anbuvannan M, et al. [73] identified a simple com-bination reaction involving zinc nitrate and *Anisochilus carnosus* leaf extract to produce ZnO nanoparticles. The prepared ZnO NPs are crystalline and have a hexagonal wurtzite composition, according to the structural analysis. Besides, the photocatalytic output under UV radiation of the ZnO measured against the methylene blue (MB) dye has substantial photo-degradation. Excellent results were seen in the antibacterial activities of the prepared products analysed against some selected human pathogens.

The zinc oxide nanoparticles derived from *Malus pumila* (apple) and *Juglen regia* (walnut) plant leaves are an appealing area of study, according to Mirza AU, et al. [74], because of their widespread use, low cost, and environmentally friendly approach. The extract's biomaterials are responsible for the capping and stabilising action. The form, morphology, and particle size are verified using XRD, SEM, and TEM. DLS, on the other hand, confirms the scale of zinc oxide nanoparticles. The compositional analysis of zinc oxide nanoparticles is demonstrated using EDX. The DPPH radical assay measured the scavenging activity and the free radical potential of *Malus pumila* and its mediated zinc oxide nanoparticle is found to be greater than *Juglen regia* and its synthesised nanoparticles of zinc oxide and their activity increases as extract concentration increases. Against both gram-positive and gram-negative bacteria, the plant extracts and nanoparticles are effective antibacterial agents. For cosmetic, biomedical, and pharmaceutical applications, biosynthesized zinc oxide nanoparticles are also useful.

Rajiv P, et al. [75] used a low-cost, environmentally friendly, and easy method to synthesise and characterise zinc oxide nanoparticles from *Parthenium hysterophorus L.* leaf extract. Using different concentrations of 50 percent and 25 percent parthenium leaf extracts, highly stable spherical and hexagonal zinc oxide nanoparticles were synthesised. For nanoparticle conversion, both concentrations of the leaf extract serve as a reducing and capping agent. Analysis of SEM, TEM and EDAX showed that the nanoparticle sizes of spherical and hexagonal zinc oxide were 27±5 nm and 84±2 nm, respectively, and the chemical composition of zinc oxide was present. In 25 lg/ml of 27±5 nm zinc oxide nanoparticles against *Aspergillus flavus* and *Aspergillus niger*, different sized zinc oxide nanoparticles were synthesised and the size-dependent antifungal activity against plant fungal pathogens was studied and the highest inhibition zone was observed. Nanoparticles of Parthenium hysterophorus L. mediated zinc oxide were synthesised and proved to be good antifungal agents and pleasant to the environment.

Zare M, et al. [76] developed a simple synthetic route and growth mechanism for phytochemically stabilised zinc oxide (ZnO) nanoparticles using *Thymus vulgaris* (Thyme) leaf extract using a hydrothermal process. The existence of flavonoids, phenols and saponins in thyme leaf extract has acted as both reducing and stabilising agents that play a critical role in the development of nanoparticles of ZnO. The obtained ZnO nanoparticles have an irregular shape and a size of 50-60 nm. The DPPH assay showed prominent activity (< 75 percent) for higher concentrations (10 mg/ml) of tested ZnO nanoparticles with *in vitro* antioxidant activity. The antimicrobial activity of ZnO nanoparticles against a range of foodborne pathogens showed that the antimicrobial activity of the tested gram-negative bacteria is greater than the antimicrobial activity of the tested Gram-positive bacteria. Results of this study show that phytochemicals containing thyme leaf extract have decreasing properties for the manufacture of ZnO nanosize and the ZnO nanoparticles obtained could be used effectively for biological applications and food science.

Using fresh *Cassia alata* leaf extract, Happy A, et al. [77] investigated the antibacterial activity of green synthesised zinc oxide nanoparticles (ZnO NPs). The successful synthesis of spherical nanoparticles with an average size range of 60-80 nm is validated by the study results. In terms of size and purity, SEM and EDAX data support the results obtained by the XRD pattern. The antibacterial activity of ZnO NPs against *Escherichia coli (E. coli)* was dose-dependent, with an IC_{50} value of about 20 g/mL. In the presence of nanoparticles, growth kinetics research was conducted which demonstrated the bacteriostatic effect of ZnO NPs. For its antibacterial activity, the study recommends the potential use of ZnO NPs in industries such as agricultural, pharmaceutical, food, and cosmetic industries.

Kavya JB, et al. [78] used aqueous leaf extract of *Sida rhombifolia Linn* for biofabrication of ZnO-NPs. The biofabricated ZnO-NPs showed a peak of absorption at 307 nm and a 3.51 eV bandgap energy with a mean size of ~30 nm. The XRD analysis showed stiff narrow peaks, suggesting that the particles were free of impurities, and this was confirmed by the EDS analysis. With a MIC of 0.25 mg mL^{-1} against E. coli, the biofabricated ZnO-NPs exhibited substantial antibacterial activity, compared to 0.5 mg mL^{-1} against *B. subtilis* and *S. typhi*. The study of the live and dead cells of the nanoparticles indicated that the antibacterial activity was due to the damage of the test pathogens to the cell walls. Also, with an IC_{50} of 974.5 μg mL^{-1} and 548.4 μg mL^{-1}, respectively, the nanoparticles also offered important antioxidant and genotoxic properties.

Patil BN, et al. [79] conducted research to synthesise zinc oxide nanoparticles from *Limonia acidissima L.* leaf extract and evaluate their efficacy against *Mycobacterium tuberculosis* development. T A atomic force microscope, X-ray diffraction, and a high-resolution transmission electron microscope were used to validate the shape and scale. The microplate alamar blue assay technique was used to see how these nanoparticles affected M. tuberculosis growth. An absorbance peak at 374 nm confirms the formation of zinc oxide nanoparticles, which are spherical in shape and range in size from 12 nm to 53 nm, according to the UV-visible results. At 12.5

mg/mL, these nanoparticles inhibit M. tuberculosis development. Since it is inexpensive and pollution-free, phytosynthesis of zinc oxide nanoparticles is a green, environmentally friendly technology.

Cui P, et al. [80] reprted a novel concept for the manufacture of zinc oxide nanoparticles (ZnO-NPs) by using an environmentally friendly approach to the extract of *Cinnamon zeylanicum* leaf. The results of the Dynamic Light Scattering (DLS) method and TEM analysis demonstrated the formation of spherical shaped ZnO-NPs with an average size of 20 nm. The capping of ZnO NPs with polyphenols from *Cinnamon zeylanicum* extract was revealed by FTIR and Zeta potential results. Furthermore, the activity of local anaesthesia was tested in frog models, and it was discovered that ZnO NPs is responsible for the important activity of local anaesthesia.

Vidya C, et al. [81] used a green method to make zinc oxide (ZnO) nanoparticles from *Artocarpus Heterophyllus* leaf extract. As stabilising agents, the phytochemicals present in the leaf act. The SEM images revealed agglomerated structures that were porous and sponge-like. TEM analysis showed that the ZnO nanoparticles were formed to have a structure of hexagonal wurtzite and particles ranging from 15-25 nm. The green synthesised ZnO nanoparticles displayed outstanding efficiency of photodegradation (> 80%, 0.24 g/L, 1h) against Rose Bengal dye, a major water pollutant released by the textile industry. The results of the characterization verified that ZnO nanoparticles can be synthesised efficiently using *Artocarpus Heterophyllus* leaf extract as a stabiliser and the results of the photodegradation demonstrated the efficacy of green synthesised ZnO nanoparticles to degrade Rose Bengal dye.

Nava OJ, et al. [82] deals with the low-cost, non-toxic green synthesis of nanoparticles of zinc oxide prepared with various quantities of *Camellia Sinensis* leaf extract. At 618 cm^{-1}, the Zinc Oxide nanoparticles presented the desired Zn-O bond, demonstrated growth in a strictly hexagonal Wurtzite crystal structure, and displayed distinct size and shape homogeneity depending on the quantity of extract used. The photocatalytic activity of the Zinc Oxide nanoparticles obtained has been studied. At a 1:1 molar ratio of methylene blue to zinc oxide nanoparticles under UV light, photocatalytic degradation studies were performed. The results showed a faster rate of decomposition than commercially available Zinc Oxide nanoparticles.

Elumalai K, et al. [83] researched the production of zinc oxide nanoparticles (ZnO NPs) from *Murraya koenigii* leaf extract, using zinc nitrate as a precursor. The crystalline structure was shown by X-ray diffraction (XRD) analysis, and atomic force microscopy (AFM) showed the morphology of the ZnO NPs to be spherical with an average size of 12 nm. The results showed that synthesised ZnO NPs is moderately stable and hexagonal, with a spherical form of less than 100 nm maximum particle size.

Raja A, et al. [84] reported an environmentally friendly green synthesis of Zinc Oxide Nanoparticles (ZnO NPs) using aqueous *Tabernaemontana divaricata* green leaf extract. The existence of a pure hexagonal wurtzite crystalline structure of ZnO is confirmed by XRD pattern analysis, with an average crystallite size of 36.82 nm. The TEM images show the formation of ZnO NPs with sizes varying from 20-50 nm in spherical form. The FTIR study indicates that through the interactions of steroids, terpenoids, flavonoids, phenyl propanoids, phenolic acids and enzymes found in the leaf extract, the ZnO NPs obtained have been stabilised. Compared to the normal pharmaceutical formula, the ZnO NPs demonstrate greater antibacterial activity against *S.aureus* and *E.coli* and less antibacterial activity against *S. Paratyphi*. In 90 minutes with ZnO NPs, almost complete degradation of methylene blue dye occurred. The results show that for bacterial decontamination and industrial dye wastewater treatment, the prepared catalyst will be applicable.

3. CONCLUSION

The synthesis of nanoparticles using traditional physical and chemical methods has some disadvantages, such as critical temperature and pressure conditions, costly and toxic materials, long reaction reflux times, toxic by-products, and so on. In recent years, green nanoparticle synthesis has increased in popularity and has become one of the most popular methods. Green synthesis procedures have many benefits, including simplicity, low cost, good nanoparticle stability, reduced time consumption, non-toxic byproducts, and large-scale synthesis. The review's goal was to provide information on the synthesis of zinc oxide nanoparticles using various plant extracts, as well as their applications in various fields. Several studies have shown that zinc oxide nanoparticles (ZnO NPs) can be produced using a green synthesis method involving a variety of plant leaf extracts. Furthermore, the studies cited here show that these substrates, regardless of their source, act as reducing and stabilising agents or chelating agents. It's worth noting that, in addition to the variations in composition found in biological extracts, variables including temperature, reaction time, pH, and concentrations have a major effect on the final properties of the synthesised nanoparticles. The concentrations of biological extract and zinc source, as well as the pH of the solution, play a major role in the final properties of ZnO NPs obtained using the green path, according to the literature cited. While evaluating the green synthesis of nanoparticles remains difficult due to the complexity of biological substrates, further research into the mechanism of formation of the biological synthesis of ZnO NPs is required to gain a better understanding of the chemical processes and reactions that occur during the synthesis. It appears that by naming the described mechanism, it will be possible to monitor and optimise the green synthesis process, which is crucial for large-scale ZnO NP development. As a consequence, the rapidly advancing understanding of green synthesis outlined herein indicates that ZnO NPs have tremendous potential for industrial production using biological extracts close to expectations.

Table 1: Green synthesis of zinc oxide nanoparticles reported by different researchers

Plant leaf extract	Zinc source material	*Characterization techniques used	Average size /range (nm)	Shape	Reference
Raphanus sativus var. Longipinnatus leaf extract	Zinc acetate	SEM, TEM, XRD, FTIR, UV-visible	66.43	spherical	[39]
Melia azedarach leaf extract	Zinc nitrate	SEM, TEM, XRD, FTIR, EDAX, UV-visible	33 - 96	hexagonal and spherical	[40]
Typha latifolia.L leaf extract	Zinc chloride	SEM, TEM, XRD, FTIR, EDAX, UV-visible	--	hexagonal wurzite	[41]
Atalantia monophylla leaf extract	Zinc acetate	SEM, TEM, XRD, FTIR, EDAX, FS, UV-visible	30	hexagonal wurtzite	[42]
Ocimum basilicum L. var. purpurascens Benth.-lamiaceae leaf extract	Zinc nitrate	XRD, TEM, EDX	50	hexagonal wurtzite	[43]
Green tea leaf (*Camellia sinensis*) extract	Zinc acetate	SEM, XRD, FTIR, UV-Vis, EIS	54.84	hexagonal wurtzite	[44]
Aloe barbadensis miller leaf extract	Zinc nitrate	SEM, TEM, XRD, FTIR, UV-Vis	25 to 40	spherical	[45]
Azadirachta indica (L.) leaf extract	Zinc nitrate	SEM, XRD, EDAX, FTIR, UV-Vis, PL, FESEM	18	spherical and hexagonal wurtzite	[46]
Juglans regia L. leaf extract	Zinc acetate	XRD, FTIR, UV-Vis, FESEM	--	spherical	[47]
Cassia auriculata leaf extract	Zinc acetate	XRD, EDAX, FTIR, UV-Vis, FESEM, PL	20-30	hexagonal	[48]
Delonix regia leaf extract (Gul Mohar)	Zinc nitrate	SEM, TEM, XRD, FTIR, UV-Vis	20	hexagonal	[49]
Gynostemma pentaphyllum leaf extract	Zinc nitrate	TEM, EDAX, XRD, FTIR, PS	35.41	hexagonal wurtzite	[50]
Cinnamomum Tamala leaf extract	Zinc nitrate	SEM, EDAX, XRD, FTIR, UV-Vis, ZPA	26.57	hexagonal wurtzite	[51]
Alchornea laxiflora leaf extract	Zinc chloride	SEM, EDAX, XRD, FTIR, UV-Vis,	29-38	hexagonal	[52]
Cyanometra ramiflora leaf extract	zinc acetate	SEM, EDAX, XRD, FTIR, UV-Vis, BET	13.33	hexagonal wurtzite	[53]
Cucurbita pepo leaf extract	Zinc acetate	TEM, XRD, FTIR, UV-Vis	8	hexagonal wurtzite	[54]
Aloe socotrina leaf extract	Zinc acetate	SEM, TEM, EDAX, XRD, FTIR, UV-Vis	15 to 50	hexagonal wurtzite	[55]
Mentha pulegium (L.) leaf extract	Zinc nitrate	FESEM, TEM, EDAX, XRD, FTIR, UV-Vis	44.94 n	quasi spherical	[56]
Azadirachta Indica (Neem)	Zinc acetate	SEM, FESEM, EDAX,	20-40	hexagonal	[57]

leaf extract		XRD, FTIR, UV-Vis		wurtzite	
Peltophorum pterocarpum leaf extract	zinc acetate	SEM, FESEM, EDAX, XRD, FTIR, UV-Vis, BET	11.64	hexagonal wurtzite	[58]
Euphorbia hirta leaf extract	Zinc nitrate	SEM, XRD, FTIR, UV-Vis,	20 to 25	hexagonal	[59]
Euphorbia milii leaf extract	Zinc acetate	SEM, EDAX, XRD, FTIR, UV-Vis, DLS, ZPA	90-110	hexagonal wurtzite	[60]
Nasturtium officinale (watercress) leaf extract	Zinc nitrate	SEM, TEM, XRD, EDX, BET, FTIR, TGA, UV-Vis	14-19	hexagonal wurtzite	[61]
Costusigneus leaf extract	Zinc nitrate	SEM, EDAX, XRD, FTIR, UV-Vis	100	spherical	[62]
Passiflora caerulea fresh leaf extract	Zinc acetate	SEM, EDAX, XRD, FTIR, UV-Vis, AFM	37.67	cubic	[63]
Azadirachta indica leaf extract	Zinc sulphate	SEM, XRD, FTIR,	19.57	non-spherical	[64]
Barleria gibsoni leaf extract	Zinc nitrate	TEM, XRD, FTIR, UV-Vis, PL, TGA, DLS	30 -80	hexagonal wurtzite	[65]
Glycosmis pentaphylla leaf extract	Zinc acetate	SEM, TEM, EDAX, XRD, UV-Vis	32 to 36	hexagonal wurtzite	[66]
Moringa Oleifera leaf extract	Zinc nitrate	XRD, FTIR, UV-Vis, PL	25	hexagonal wurtzite	[67]
Tecoma castanifolia leaf extract	Zinc nitrate	SEM,TEM, EDAX, XRD, FTIR, UV-Vis,	70-75	spherical and hexagonal	[68]
Parthenium hysterophorus leaf extract	Zinc nitrate	SEM,TEM, XRD, FTIR, UV-Vis,	5 and 20	spherical and hexagonal	[69]
Acalypha fruticosa leaf extract	Zinc Acetate	SEM,TEM, XRD, FTIR, UV-Vis,	50- 60	hexagonal wurtzite	[70]
Ficus religiosa leaf extract	Zinc nitrate	SEM,TEM, XRD, EDAX, UV-Vis	70.29 to 84.93	spherical and hexagonal	[71]
Abelmoschus esculentus Linn leaf extract	Zinc acetate	SEM,TEM, XRD, EDAX, UV-Vis	20 to 45	spherical	[72]
Anisochilus carnosus leaf extract	Zinc nitrate	FESEM,TEM, XRD, EDAX, FTIR UV-Vis, PL	30 to 40	quasi-spherical	[73]
Malus pumila leaf extract	Zinc acetate	SEM,TEM, XRD, FTIR, EDAX, UV-Vis, DLS	12	spherical	[74]
Juglen regia leaf extract	Zinc acetate	SEM,TEM, XRD, FTIR, EDAX, UV-Vis, DLS	16	spherical	[74]
Parthenium hysterophorus L. leaf extract (25% extract)	Zinc nitrate	SEM,TEM, XRD, FTIR, EDAX, UV-Vis	22- 35	spherical and hexagona	[75]
Parthenium hysterophorus L. leaf extract (50% extract)	Zinc nitrate	SEM,TEM, XRD, FTIR, EDAX, UV-Vis	75-90	spherical and hexagonal	[75]
Thymus vulgaris leaf extract (1 ml extract)	Zinc nitrate	TEM, XRD, FTIR, EDAX, UV-Vis, DLS	46.74	hexagonal wurtzite	[76]
Thymus vulgaris leaf extract (0.5 ml extract)	Zinc nitrate	TEM, XRD, FTIR, EDAX, UV-Vis, DLS	132.54	hexagonal wurtzite	[76]
Cassia alata leaf extract	Zinc acetate	SEM, XRD, FTIR, EDAX, UV-Vis, AFM	60-80	spherical	[77]
Sida rhombifolia Linn leaf extract	Zinc nitrate	SEM, XRD, FTIR, EDAX, UV-Vis,	30	hexagonal wurtzite	[78]
Limonia acidissima L. leaf extract	Zinc nitrate	TEM, XRD, FTIR, EDAX, UV-Vis, AFM	12 to 53	spherical	[79]
Cinnamon zeylanicum leaf	Zinc nitrate	SEM, TEM, XRD,	20	hexagonal	[80]

extract		EDAX, FTIR, ZPA, DLS			
Artocarpus Heterophyllus leaf extract	Zinc nitrate	SEM, TEM, XRD, EDAX, FTIR	15-25	hexagonal wurtzite	[81]
Camellia Sinensis leaf extract	Zinc Nitrate	TEM, XRD, FTIR	9.04 - 17.47	hexagonal wurtzite	[82]
Murraya koenigii leaf extract	Zinc nitrate	FESEM, TEM, XRD, EDAX, FTIR, UV-Vis, AFM	22	hexagonal wurtzite	[83]
Tabernaemontana divaricata leaf extract	Zinc nitrate	SEM, TEM, XRD, FTIR, UV-Vis, TGA	36.82	hexagonal wurtzite	[84]

**Abbreviations' used*

*UV-Visible spectroscopy (UV-Vis); Fourier transform infrared (FTIR); X-Ray diffraction (XRD); Scanning electron microscopy (SEM); Transmission electron microscopy (TEM); Fluorescence spectrometer (FS); Electrochemical impedance spectroscopy (EIS); Photo-luminescence (PL); Field emission scanning electron microscopy (FESEM); Zeta Potential analysis (ZPA); Dynamic light scattering analysis (DLS); Thermo-gravimetric analysis (TGA); Brunauer-Emmett-Teller (*BET*) and Atomic force microscopy (AFM).*

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