Medicinal Plants Mediated Green Biosynthesis of Zinc Oxide Nanoparticles - A Review

Viyaanchi I S[1], Mona S[2]

[1]Department of Biotechnology, Bharathidasan University, Palkalaiperur, Tiruchirappalli, Tamil Nadu 620024, India
Email: *viyaanchiahv01[at]gmail.com*

[2] Shri A.M.M. Murugappa Chettiar Research Centre, Taramani, Chennai, Tamil Nadu 600113, India
Corresponding Author Email: *monasadasivam[at]gmail.com*

Abstract: ***Nanotechnology encompasses the production and utilization of materials at the nanoscale, leading to nanoparticles with unique properties due to their large surface area-to-volume ratio. Zinc oxide nanoparticles (ZnO NPs) are notable metal oxide nanoparticles widely used in various industries and research institutions. To meet the high demand for ZnO NPs, different synthesis methods have been employed. The biological method of synthesis using plant sources has emerged as a promising and novel approach for producing ZnO NPs, as it is cost-effective, medicinally benefit, and environment friendly compared to chemical and physical synthesis methods. Using plants for synthesis enables scalability to large-scale production without the need for toxic chemicals, making it an attractive alternative. Additionally, their large bandwidth and high excitation binding energy make them suitable for antibacterial, antifungal, and wound healing applications. Various characterization methods are employed to assess the properties of ZnO NPs include X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), Fourier-transform infrared spectroscopy (FTIR), UV Vis spectroscopy, and others. These techniques provide crucial information about the structural, morphological, and optical characteristics of ZnO NPs. This review comprehensively discusses the green synthesis of ZnO nanoparticles and the characterization methods used, focusing on their potential applications.***

Keywords: Zinc nanoparticles, green synthesis, medicinal plants, metal oxide nanoparticles

1. Introduction

Nanotechnology is a multidisciplinary field focused on producing novel materials at the nanoscale, which exhibit unique physicochemical properties with applications across various industries. Zinc oxide nanoparticles (ZnO NPs), a type of metal oxide NPs, have garnered significant attention due to their size and shape-dependent properties. ZnO NPs are recognized as multifunctional, nontoxic, and biocompatible materials, making them suitable for diverse applications. One prominent use of ZnO NPs is in personal care products like cosmetics and sunscreen, thanks to their strong UV absorption properties. Additionally, ZnO NPs find applications in concrete production, photocatalysis, electronics, electrotechnology, and the textile industry [1]. There are two main approaches to nanoparticle synthesis: the top-down and bottom-up approaches. The top-down approach involves reducing large macroscopic particles to the nanoscale level through processes like milling or attrition. While effective, this method is costly and slow, limiting its scalability for large-scale production. Interferometric Lithography (IL) is a common technique using the top-down approach for nanomaterial synthesis, involving the synthesis of nanoparticles from miniaturized atomic components through self-assembly [2]. Green synthesis of nanoparticles has emerged as a safe and effective method, utilizing non-hazardous plant sources [3]. This approach avoids the potential presence of toxic chemical species often found in chemical synthesis methods, making it more suitable for medical applications [4]. Various biological organisms, including bacteria, fungi, yeast, and plant extracts, have been used for nanoparticle synthesis [5]. Plant-derived ZnO NPs exhibit excellent antibacterial properties against a range of pathogens, making them valuable for medical and textile applications [6]. They can be used for wastewater treatment, creating antibacterial textile surfaces, and enhancing fabric properties such as UV protection, strength, stiffness, crease recovery, fire resistance, and antimicrobial activities [7] [8]. These properties make plant-mediated ZnO NPs promising for medical textiles and other functional applications in the textile industry [9].

Synthesis of Zinc Oxide Nanoparticles (ZNO NPS):

The biological synthesis of Zinc Oxide nanoparticles (ZnO NPs), also known as green synthesis or biosynthesis, involves using microorganisms such as algae, fungi, yeast, bacteria, and plant extracts as reducing agents. Despite the advantages of using microorganisms as reducing agents, caution is necessary due to the potential toxicity of some microorganisms, and challenges related to incubation are significant issues [10]. Green synthesis of nanomaterials encompasses using organic compounds like plant extracts and solvents with low or zero toxicity, following an ecofriendly approach throughout the nanomaterial's life cycle [11][12]. To initiate the synthesis process, a precursor source is required, which can have an inorganic, organic, or metallic composition. Additionally, organic compounds such as biomolecules play a crucial role in reducing and stabilizing precursor ions to atoms. The initial stage of green synthesis, termed bioreduction, involves bioactive components in plant extracts like flavonoids, carotenoids, and polysaccharides, which can reduce precursor ions to atoms. This step is essential for the biological properties and cytotoxicity of the resulting nanomaterial. Ions are more reactive than atoms due to their higher interaction potential. Following bio-reduction is the nucleation stage, where atoms aggregate with bioactivity shielding, leading to the formation of numerous nanoparticles. These nanoparticles form a nano system with bioactivity, stabilizing the synthesis process. Various physical and chemical factors such as luminosity, thermal and electrical energy, pH, among others, can influence nanoparticle stability and the properties of the nanomaterials produced. Different parts of plants, including leaves, stems, roots, fruits, and seeds, have been utilized for ZnO nanoparticle synthesis [13]. The detailed procedure for the biological synthesis of ZnO nanoparticles is illustrated in Figure 1.

Figure 1: Work flow of green synthesis of nanoparticles using herbal plant leaves (Goutam et al. 2020) [14]
Sources: *Zinc Oxide Nanoparticles Synthesis from Herbal Leaf Extracts:*

List of Medicinal plants in ZnO NPS

1) *Hibiscus rosa-sinensis*:
Hibiscus rosa-sinensis, also known as China rose, belongs to the Malvaceae family and is renowned for its various medicinal properties. It is used traditionally to treat wounds, inflammation, fever, cough, and other ailments. It is also recognized for its anti-tumor, analgesic, antipyretic, anti-asthmatic, and anti-inflammatory properties, earning it the nickname "Queen of tropics." The plant's flowers possess antimicrobial properties, and research on its stems, roots, leaves, and flowers has highlighted its phytochemical components' health benefits (Missoum, 2018) [15]. Devi et al. (2014) [16] conducted research on synthesizing and characterizing ZnO nanoparticles using *Hibiscus rosa-sinensis* leaves via the green synthesis technique. Characterization techniques such as X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) were employed. SEM analysis revealed spongy-shaped nanoparticles with diameters ranging from 30 to 35 nm. XRD analysis confirmed the presence of pure zinc oxide nanoparticles based on peak values ranging from 31.73º to 76.90º. Pavithra et al. (2020) [17] utilized leaf extracts of *Hibiscus rosa-sinensis* for synthesizing ZnO nanoparticles and characterized them using XRD, FTIR, SEM, EDX, among others. XRD analysis provided information about the crystalline size, lattice parameters, and unit cell volume, with an average crystalline size of 18.47 nm. FTIR analysis identified the functional groups present in the plant sample. SEM analysis revealed spherical-shaped nanoparticles. EDX analysis determined the elemental composition, ensuring the purity of the ZnO product. Bala et al. (2015) [18] conducted synthesis and characterization of Zinc oxide nanoparticles from *Hibiscus sabdariffa* leaf extract using UV-Vis Spectroscopy, FTIR, XRD, HRTEM, EDX, and FESEM. They also evaluated the antibacterial properties of the produced ZnO nanoparticles against *Escherichia coli* and *Staphylococcus aureus* bacteria. These studies highlight the potential of *Hibiscus rosa-sinensis* leaf extracts in green synthesis methods for producing ZnO nanoparticles with various applications, including antibacterial properties.

2) Aloe vera:
Aloe vera, known as "kumari" or young girl in Ayurveda, belongs to the Asphodelaceae family and has various therapeutic properties. Aloe vera gel is known for its protective effects on the skin, including anti-inflammatory,

antiviral, antitumor, antibacterial, and antifungal activities. It also moisturizes the skin, has anti-aging effects, and promotes wound healing and protection against radiation damage (Lanka, 2018) [19].

Subramani et al. (2018) [20] synthesized Zinc Oxide nanoparticles using Aloe vera leaf extract and characterized them using XRD, SEM, UV-/Vis Spectroscopy, and EDX. The antibacterial activity against *E.coli* and *S.aureus* demonstrated excellent bacterial activity of the nanoparticles. Coating these antibacterial nanoparticles on cotton fabrics enhanced their functional and biological properties, including better UV protection. Xu et al. (2021) [21] utilized Zinc Oxide nanoparticles synthesized from Aloe vera extract for antibacterial textiles. The nanoparticles showed high sensitivity against Gram-negative and Grampositive bacterial strains, making them suitable for textile applications. Techniques like melt mixing, dry-jet wet spinning, and pad dry curing were used to prepare antibacterial fibers. Batool et al. (2020) [22] employed a green synthesis method using Aloe vera extract to synthesize Zinc Oxide nanoparticles. Characterization techniques such as SEM, XRD, UV Spectrophotometer, and FTIR confirmed the crystalline structure of the particles. The nanoparticles exhibited excellent antibacterial, antifungal, and wound-healing properties, making them suitable for oral use. Mondal et al. (2019) [23] combined Aloe vera and chitosan to synthesize Zinc Oxide nanoparticles, which were then coated on cotton fabrics using the pad-dry-cure method. The combination showed higher bacterial resistance compared to individual treatments, with improved UV protection and thermal comfort of the finished cotton fabrics. Shanmugapriya et al. (2019) [24] utilized Aloe vera in the green synthesis of Zinc Oxide nanoparticles, characterizing them using UV-Vis Spectrophotometer, SEM, XRD, and FTIR. The nanoparticles were tested for anticancer activity using MCF-7 cells (Human breast cancer cells), demonstrating potential cytotoxicity against cancer cells. These studies showcase the versatility and potential of Aloe vera in synthesizing Zinc Oxide nanoparticles with various beneficial properties, making them suitable for applications in antibacterial textiles, wound healing, UV protection, and anticancer assays.

3) Neem

Neem is commonly known as the "free tree of India," "wonder tree," "nature drug store," "village dispensary," "divine tree," and "heal all." It is highly valued in Indian culture for its therapeutic properties and is native to tropical and semi-tropical regions. Neem (*Azadirachta indica*) belongs to the Maliaceae family and possesses antiviral, antifungal, antibacterial, antiallergic, and anti-dermatic properties. Neem oil extracted from its seeds is used in medicines, pest control, and cosmetics (Sharma and Vaquil, 2018) [25]. Sharma et al. (2020) [26] synthesized Zinc Oxide nanoparticles using *Azadirachta indica* and characterized by using XRD techniques. The particle size ranged from 16nm to 31nm, exhibiting a crystalline nature. Various characterization techniques like SEM, TEM, UV-Vis Spectroscopy, FTIR, EDX, FESEM, and AFM were employed, along with assessing their antimicrobial activity. These synthesized nanoparticles have potential applications in cosmetics, such as sunblock creams, providing protection against harmful UV light. Dhage and Biradar et al. (2020) [27] utilized *Azadirachta indica* leaf extract for synthesizing Zinc Oxide nanoparticles via green synthesis. Characterization techniques such as UV-Vis spectroscopy showed maximum absorption at 362nm. SEM images confirmed rod-shaped ZnO nanoparticles, and EDX confirmed the presence of Zinc oxide nanoparticles. Neem was used for antibacterial activity in textiles. Ranjan et al. (2020) [28] synthesized Zinc Oxide nanoparticles from herbal plants and coated them on cotton khadi fabrics for UV protection and antimicrobial properties in textiles. Characterization was done using SEM, FTIR, and XRD techniques. Asim and Naeem et al. (2023) [29] synthesized Zinc Oxide nanoparticles using *Azadirachta indica* (neem) and coated them on denim fabrics using the pad dry cure method. Various tests such as the drop test, stain test, and color strength analysis were performed, showing self-cleaning properties of the fabrics. Similarly, Geetha et al. (2016) [30] synthesized Zinc Oxide nanoparticles using *Azadirachta indica* gum via green synthesis and chemical methods. Characterization techniques included UV-Vis absorption spectroscopy, FITR, XRD, and FE-SEM analysis. The green synthesized neem gum nanoparticles exhibited higher potential than the chemical method, especially in terms of antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*, making them suitable for biomedical applications.

4) Symplocos racemosa (Lodhra)

Symplocos racemosa, also known as Lodhra, is a common indigenous drug mentioned in Ayurvedic classics for treating various human ailments. It belongs to the Symplocaceae family and is used in the Indian System of Medicine (ISM) either as a single drug or in combination with other ingredients. Lodhra possesses cardiotonic, antipyretic, anti-helminthic, and laxative properties. It is beneficial for conditions like billow fever, urinary discharge, blood disorders, burning sensation, leucoderma, jaundice, and has shown anticancer activity as well (Maitra and Satardekar, 2017) [31]. Princeton et al. (2022) [32] conducted the green synthesis of Zinc Oxide nanoparticles using *Symplocos racemosa* and Cinnamon extracts and evaluated their antifungal activity against *Candida albicans*. The results indicated that ZnO nanoparticles exhibited higher antifungal activity compared to standard antibiotics against *Candida albicans*, suggesting their potential as potent antifungal agents. Sowbaraniya et al. (2022) [33] also synthesized Zinc Oxide nanoparticles using *Symplocos racemosa* and Cinnamon bark extracts via green synthesis. Characterization techniques such as UV-Vis spectroscopy and TEM were employed. The synthesized nanoparticles showed antiinflammatory activity, indicating their potential applications in various pharmaceutical industries. These studies highlight the potential of *Symplocos racemosa* and Cinnamon extracts in green synthesis methods for producing Zinc Oxide nanoparticles with desirable properties such as

Paper ID: SR24709145734 DOI: https://dx.doi.org/10.21275/SR24709145734

antifungal and anti-inflammatory activities, paving the way for potential applications in pharmaceutical industries.

5) *Terminalia chebula* (Myrobolan)

Terminalia chebula, also known as Myrobolan, is a plant species belonging to the Combretaceae family. It is an evergreen tree with flowering capabilities and is commonly referred to as the black myrobolan in English. The fruit of *Terminalia chebula* goes through three stages of maturity: Small myrobolan (unripe fruit), Yellow myrobolan (mature fruit after seed development), and Large myrobolan (fully matured fruit). Myrobolan is rich in tannins and is highly valued for its medicinal properties, earning it the title of the "King of Medicines." *Terminalia chebula* leaves also exhibit wound healing activity (Chattopadhyay and Bhattacharyya, 2007) [34]. Kumar et al. (2017) [35] conducted the green synthesis of Alumina Zinc oxide (AZO) Nanoparticles using *Terminalia chebula* (Myrobolan) fruit extract.

Characterization techniques such as UV-Vis Spectrophotometer, XRD, TEM, and SEM were employed. XRD analysis revealed that the synthesized particles exhibited a wurzite shape with a size of 53nm. UV-Vis Spectroscopy showed a transmission spectra of about 85% at 400nm, confirming the nanoparticles' photo catalytic degradative activity. This study demonstrates the potential of *Terminalia chebula* fruit extract in the green synthesis of AZO Nanoparticles, highlighting their photo catalytic degradative activity, which can have applications in various fields such as environmental remediation and catalysis.

6) *Cynodon dactylon*

Cynodon dactylon, commonly known as Bermuda grass, is a widely prevalent weed in India belonging to the Poaceae family. It possesses several medicinal properties, including being diuretic, anti-diabetic, antibacterial, antimicrobial, antioxidant, wound-healing, cardio-protective, blood-purifying, and even exhibiting anti-cancer effects. This makes it a highly versatile herb with potential applications in various fields. (Amritkar et al. 2024) [36]. Research by Meenatchi et al. (2020) [37] focused on synthesizing zinc oxide nanoparticles (ZnO NPs) using *Cynodon dactylon* leaf extract. The X-ray diffraction (XRD) analysis revealed a particle size of 35 nm with a crystalline structure. Scanning electron microscopy (SEM) showed that the ZnO nanoparticles had a uniform distribution and a hexagonal rodshaped structure. In UV-Vis Spectrophotometer analysis, the spectrum ranged at 318 nm. These synthesized ZnO NPs exhibited antibacterial activity against gram-negative bacteria such as *E. coli* and *K. pneumoniae.* Another study by Singh and Heer (2017) [38] explored the green synthesis of ZnO NPs using *Cynodon dactylon* leaf extract. Characterization using energy-dispersive X-ray spectroscopy (EDX), XRD, and field-emission scanning electron microscopy (FE-SEM) revealed a nanoparticle size range of about 86.84 nm with a crystalline structure. This study highlighted the enhanced anti-fungal activity of the ZnO nanoparticles against *Candida albicans*, *Candida parapsilosis*, and *Aspergillus niger*. This property makes them suitable for applications in medicine, food, and cosmetic industries. Anuforo et al. (2023) [39] synthesized ZnO NPs using the aqueous extract of *Cynodon dactylon* and characterized them using various techniques including UV-Visible spectrophotometer, Fourier-transform infrared spectroscopy (FTIR), dynamic light scattering (DLS), XRD, and transmission electron microscopy (TEM). The grass extract's phytochemical composition facilitated the reduction and capping of metal ions to form nanoparticles. The resulting ZnO nanoparticles showed effectiveness against bacteria such as *E.coli* and *S.aureus*. In a recent study by Acharya et al. (2024) [40], ZnO nanoparticles were synthesized using the green synthesis method with *Cynodon dactylon*. Characterization using UV-Vis spectroscopy, SEM, FTIR, EDX, and XRD confirmed the nanoparticles' spherical shape and properties. Cell viability and toxicity analysis demonstrated good antibacterial activity suitable for biomedical applications. Overall, *Cynodon dactylon* has shown promise in the green synthesis of ZnO nanoparticles with various biomedical applications, including antibacterial and anti-fungal activities, making it a valuable natural resource for nanotechnology research and development.

7) *Ocimum tenuiflorum*

Ocimum tenuiflorum, commonly known as Tulsi or Holy basil, is a versatile Ayurvedic herb with distinct therapeutic properties found in its various parts such as stems, roots, seeds, leaves, flowers, and fruits. These parts contain a diverse range of active chemical compounds, including terpenoids, phenols, flavonoids, phenylpropanoids, fatty acid derivatives, essential oils, fixed oils, and steroids. The extraction of these compounds from the *Ocimum tenuiflorum* plant has been associated with significant therapeutic benefits, including anti-diabetic, antioxidant, antiinflammatory, antimicrobial, antiviral, cardioprotective, antihypertensive, and other activities (Pooja and Anil Kumar 2023) [41]. Zinc oxide nanoparticles have been synthesized using the herbal plant *Ocimum tenuiflorum* (black Tulsi). The resulting nanopowder underwent characterization through various analytical techniques such as X-ray diffraction, scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray fluorescence (XRF), and particle size analysis. TEM and X-ray diffraction studies reported a size range of 50-63 nm and confirmed the crystalline nature of the nanoparticles (Chennaiah et al. 2017) [42]. In a study by Khan et al. (2023), [43] Zinc oxide nanoparticles were synthesized using *Ocimum sanctum.* The characterization of these nanoparticles was carried out using UV-Vis spectrophotometry, revealing an absorption spectrum around 364 nm. The study also hinted at promising anti-inflammatory activity, suggesting potential applications in treating conditions like rheumatoid arthritis, although further analysis using HPLC was planned. Yasotha et al. (2020) [44] conducted green synthesis of Zinc oxide nanoparticles using *Ocimum tenuiflorum* as a reducing agent in the preparation of nanoparticles. The synthesized nanoparticles underwent characterization using X-ray diffraction, Fourier-transform infrared spectroscopy (FITR), SEM, and energy-dispersive X-ray spectroscopy (EDAX). The analysis confirmed their crystalline nature, needle-like structure, and size ranging from 35 to 61 nm, validating them as Zinc oxide nanoparticles. Moreover, Raut et al. (2013) [45] focused on the green synthesis of Zinc oxide nanoparticles using *Ocimum tenuiflorum* leaves. The nanoparticles were found to have a hexagonal shape with a diameter range of 11-25 nm, and their particle size was calculated to be 13.86 nm using Scherre's formula. A characteristic peak of ZnO at 668.29 nm further supported their identification as Zinc oxide nanoparticles. These synthesized nanoparticles were highlighted for their potential applications in various industries such as active mediums for lasers, luminescent materials for fluorescent tubes, and paints.

8) *Acalypha indica*

Acalypha indica, commonly known as Kuppaimeni, is an herbaceous annual plant from the Euphorbiaceae family, valued for its medicinal properties including antibacterial, antifungal, and acaricidal effects. It contains secondary metabolites such as terpenoids, tannins, alkaloids, and flavonoids. Researchers have utilized *Acalypha indica* in the synthesis of Zinc oxide nanoparticles, particularly for UV protection in textiles (Surendra Kumar et al. 2021) [46]. Karthik et al. (2017) [47] conducted a study on the synthesis of Zinc oxide nanoparticles using *Acalypha indica* leaf extract. They characterized the nanoparticles using techniques like X-ray diffraction, particle size analysis, SEM, and TEM. Their analysis revealed antibacterial properties in the synthesized nanoparticles. Coating cotton fabrics with these nanoparticles enhanced UV protection, hydrophobicity, and resistance to UV exposure, washing treatments, and microbial infections, making them suitable for textile applications. Additionally, Kamarajan et al. (2022) [48] investigated the synthesis of Zinc oxide nanoparticles from *Acalypha indica* leaves. They used various analytical techniques such as XRD, UV-Vis spectrophotometry, FT-IR, SEM, EDAX, DLS, and zeta potential analysis. The synthesized nanoparticles had a size range of 16 nm, high purity, and a spherical shape. They exhibited strong antibacterial activity against bacterial strains, with *Escherichia coli* showing the highest zone of inhibition (25.2 mm). These findings highlight *Acalypha indica* as a promising source for developing nanoparticles for environmental protection and human health applications.

Application of ZnO NPs:

Figure 2: Application of Zinc oxide nanoparticles (Kundu et al. 2021) [77]

Zinc oxide nanoparticles (ZnO NPs) offer diverse applications due to their unique properties, including photocatalytic, electrical, optical, dermatological, and antibacterial characteristics. These applications have been reviewed extensively by Becheri et al. (2008) [78]. Table 1 briefed the application of ZnO NPs.

Table 1: Plant mediated synthesis of ZnO nanoparticle (Source: Melese et al. 2024) [1].

Nano particle	Plant source	Size (nm)	Morphology	Application	Reference
ZnO	*Aloe vera peel*	50–220	Hexagonal	Antimicrobial activity (49)	
ZnO	*Pandanus odorifer*	90	Spherical	Anticancer and antimicrobial activity (50)	
ZnO	*Foeniculum vulgare*	22–51	Spherical	Antimicrobial and anticancer (51)	
ZnO	*Prosopis juliflora*	31.80–32.39	Sphere like	Antibacterial and degradation of methylene blue dye (52)	
ZnO	*Beta vulgaris*	20 ± 2	Spherical	Antibacterial and antifungal activity	(53)
	Commamum tamala	30 ± 3	Rod shape		
	Cinnamomum verum	46 ± 2	Spherical		
	Brassica pleracea var. Itallica	47 ± 2	Spherical		
ZnO	*Sambucus ebulus*	40–45	Spherical	Antibacterial activity	(54)
ZnO	*Calotropis gigantea*	149.4–304.8	Agglomerated	Antibacterial and anticancer agent	(55)
ZnO	*Punica granatum (pomegranate)*	32.98 and 81.84	Spherical and hexagonal respectively	Antibacterial and cytotoxicity	(56)
ZnO	*Capsicum chinense*	24.0	Agglomerated and	Cytotoxicity and antioxidant assay	(57)
ZnO	*Myristica fragrans*	41.23	pseudo spherical Spherical or elliptical	Biomedical and environmental	(58)
ZnO	*Hibiscus subdariffa*	190–250	Dumbbell	Antibacterial and anti-diabetic	(18)
ZnO	*Cycas pschannae*	177–249	Nanorods	Antioxidant, and Anticancer Nanomedicine for lung	(59)
ZnO	*Lippia adoensis (Koseret)*	18.5–26.7	1:1 Ratio = Spherical	cancer treatment Antibacterial activity	(60)

			3:2 = Spherical and nano rod 9:1 = Both nanorod and		
ZnO	*Atalantia monophylla*	30	flake type Sphere shape	Antimicrobial analysis	(61)
ZnO ZnO	*Cassia fstula and Melia azadarach* *Lycopersicon esculentum*	3–68 10–50	More or less spherical in nature Hexagonal wurtzite	Antibacterial potential Antimicrobial and anticancer	(62) (63)
ZnO	*Canthium dicoccum (L.)*	33	Rod shaped nature	Antimicrobial, anti-tuberculosis and antioxidant activity	(64)
ZnO ZnO	*Pterolobium hexapetalum (Roth)* *Santapau & Wagh* *Pelargonium odoratissimum (L.)*	10–93 34.12	Spherical-shape Hexagonal pure wurt	Antibacterial, radical scavenging, anticancer and larvi- cidal activities Antioxidant, antibacterial and anti-inflammatory	(65) (66)
			zite structure	activities	
ZnO	*Limonia acidissima* L 12 and 53		Spherical shape	Potent tool against *Mycobacterium tuberculosis*	(67)
ZnO	*Ficus palmate* 35		Hexagonal or	Antioxidant, antibacterial and antidiabetic activity	(68)
ZnO	*Salvia officinalis* 26.14		crystalline Hexagonal wurtzite	Photocatalytic and antifungal activities	(69)
ZnO	*Raphanus sativus* 66.47		Structure Hexagonal wurtzite	Biomedical applications (antibacterial)	(70)
ZnO	*Ailanthus altissima* 13.27		Structure Spherical shape	Antibacterial and antioxidant activity	(71)
ZnO	*Eryngium billardieri* 34 and 27		Hexagonal structure	Anti-diabetic application	(72)
ZnO	*Echinops kebericho* 14.67		Hexagonal wurtzite	Photocatalytic degradation of methylene blue	(73)
ZnO	*Vaccinium arctostaphylos L,* 15.5 and 13.9		Hexagonal wurtzite	Anti-diabetic activity evaluation	(74)
ZnO	*Carica papaya* 14		Semi-spherical and some monoclinic	Antioxidant and antifungal activities	(75)
ZnO	*Delphinium uncinatum* 16–28		Spherical Hexagonal wurtzite Structure	Antioxidant, cytotoxic, antimicrobial, anti-diabetic, anti inflammatory, and anti-aging activities	(76)

Agricultural application of ZnO Nanoparticles:
In agriculture, ZnO NPs have emerged as a promising tool for enhancing crop yield and growth. Nanotechnology plays a significant role in revolutionizing agricultural practices by offering controlled and efficient delivery of agrochemicals like pesticides and fertilizers. Conventional agrochemicals often face challenges such as leaching, drifting, hydrolysis, photolysis, and microbial degradation, resulting in reduced effectiveness and environmental impact. However, nanoparticles and nanocapsules provide a solution by enabling precise and targeted delivery, thereby minimizing collateral damage.

Zinc oxide nanoparticles have been found to promote stem and root growth in crops like peanuts. The use of colloidal solutions of ZnO NPs as fertilizers has become increasingly important in modern agriculture. Nanofertilizers, which are more than just conventional fertilizers, not only supply essential nutrients to plants but also help in revitalizing the soil to an organic state, free from the harmful effects associated with chemical fertilizers. Nano-powders derived from ZnO can also serve as effective fertilizers and pesticides. One of the key advantages of using nanoparticles in agriculture is their high potency, requiring only small quantities for effective results. Therefore, Zinc oxide nanoparticles are actively utilized in agriculture as fertilizers, pesticides, and growth-promoting nutrient supplements, contributing to sustainable and efficient farming practices (Sabir et al. 2014) [79]

Textile application of ZnO nanoparticles:
Zinc oxide nanoparticles (ZnO NPs) play a vital role in textile applications, particularly in providing protection against harmful UV radiation from the sun. UV radiation can lead to the generation of free radical species, contributing to various health issues such as cancer, aging, and Alzheimer's disease. To mitigate these risks, the World Health Organization recommends wearing loose-fitting, full-length clothes with a high protection factor. One crucial aspect in textile applications is wash-fastness, which refers to the ability of fabrics to retain their properties after washing. This property is closely linked to the adhesion of nanoparticles to the fibers. Enhancing wash-fastness can be achieved by applying nanoparticles using a specific binder solution or by forming covalent bonds between nanoparticles and the fabric surface. Studies have shown that fabrics treated with nanoparticles maintain excellent UV blocking properties even after multiple home laundering cycles.

The protective capabilities of treated fabrics depend on various factors such as fiber type, color, presence of UV absorbers and additives, porosity, thickness, mass per unit surface, finishing processes, laundering, and wearing conditions. Nanoparticle coatings can also impact other fabric properties like dyeing capacity, air permeability (which affects comfort), tensile strength, bursting strength, bending strength, and fabric friction, all of which are crucial in the textile industry. Comparing bulk ZnO and nano-ZnO treatments on cotton fabrics, it's observed that nano-sized particles exhibit distinct physical and mechanical properties compared to conventional materials. For example, coating with bulk ZnO reduces air permeability of fabrics, while nano-ZnO treatment improves it, leading to enhanced garment breathability and comfort. Additionally, nano-ZnO coatings result in lower fabric friction due to the small size and uniform distribution of particles, further enhancing the comfort and wearability of treated fabrics (Becheri et al. 2008) [78]

Medical application (Wound healing) Application of ZnO nanoparticles:

The application of Zinc oxide nanoparticles (ZnO NPs) in wound healing, particularly for skin wounds, is significant due to the skin's crucial role in protecting the body from external threats. When the skin is damaged, whether through acute or chronic wounds, the wound healing process initiates to repair and remodel the skin. This process involves four overlapping steps: hemostasis, inflammation, proliferation, and remodeling, encompassing various biochemical and cellular processes and involving numerous cells and growth factors. One of the challenges in wound healing is the risk of severe infection caused by microorganisms like *Staphylococcus aureus* and *Pseudomonas aeruginosa*. These infections can significantly impact the healing process, especially if the microorganisms penetrate deep into the body through wounds and form colonies. Hence, effective treatment of these infections is crucial for proper wound healing. ZnO nanoparticles exhibit antibacterial activity against these infection-causing bacteria. The properties of nanomaterials are enhanced when their size and shape are altered at the nano level, allowing them to enter the nano-sized pores on bacterial cell surfaces. ZnO nanoparticles have the ability to generate hydrogen peroxide, which promotes cell growth and can be utilized for wound healing purposes.

Coating cotton fabrics with ZnO nanoparticles enhances the wound healing properties of the skin and combats the microorganisms responsible for infection. This application demonstrates the potential of ZnO nanoparticles in improving wound healing outcomes and addressing microbial challenges in wound management (Kaushik et al. 2019) [80].

2. Conclusion

In conclusion, the last ten years have seen a notable shift towards eco-friendly methods for producing nanoparticles, particularly through the use of plant extracts as both stabilizing and reducing agents. This approach has allowed for the controlled creation of nanoparticles with specific shapes and sizes. Looking ahead, there are promising prospects for scaling up this technology from lab settings to industrial levels, aided by the integration of bioinformatics tools to decipher the role of phytochemicals in nanoparticle synthesis. Additionally, understanding the precise mechanisms behind how these plant-based nanoparticles inhibit harmful bacteria will be crucial for their continued development. The potential applications of plant-synthesized Zinc oxide nanoparticles (ZnO NPs) are vast, spanning across industries like food, pharmaceuticals, and cosmetics. Their ability to enhance crop fertility, growth, and nutrient content makes them valuable in agriculture, while their capacity to generate reactive oxygen species (ROS) positions them as potential agents in cancer treatment and microbial infections. Environmental benefits are also significant, with ZnO NPs showing promise in waste treatment and pollution control. However, challenges remain, particularly in preserving plant extracts effectively for prolonged use in largescale nanoparticle production. Overcoming these hurdles will be key to unlocking the full potential of plant-based nanoparticles in addressing various global challenges across sectors.

References

[1] Melese, A., Wubet, W., Hussen, A., Mulate, K., & Hailekiros, A. (2024). A review on biogenic synthesized zinc oxide nanoparticles: synthesis, characterization, and its applications. *Reviews in Inorganic Chemistry*.

[2] Agarwal, H., Kumar, S. V., & Rajeshkumar, S. (2017). A review on green synthesis of zinc oxide nanoparticles–An eco-friendly approach. *Resource-Efficient Technologies*, *3*(4), 406-413.

[3] Khan, M. A., Khan, M., Naeem, R., & Hafeez, M. Synergistic effect of citrus sinensis (orange) and aloe barbadensis (aloe vera) extracts on biosynthesis and antimicrobial activities of zinc oxide nanoparticles. *Pakistan Journal of Botany*, *56*, 4.

[4] Hudlikar, M., Joglekar, S., Dhaygude, M., & Kodam, K. (2012). Latex-mediated synthesis of ZnS nanoparticles: green synthesis approach. *Journal of Nanoparticle Research*, *14*, 1-6.

[5] Alagumuthu, G., & Kirubha, R. (2012). Green synthesis of silver nanoparticles using Cissus quadrangularis plant extract and their antibacterial activity. *International Journal of Nanomaterials and Biostructures*, *2*(3), 30-33.

[6] Asghari F, Jahanshiri Z, Imani M, Shams-Ghahfarokhi M, Razzaghi-Abyaneh M (2016) Antifungal nanomaterials: synthesis properties and applications. *Nanobiomaterials in Antimicrobial Therapy: Applications of Nanobiomaterials*, 6:343–383

[7] Chen, M., Wang, S., Tan, M., & Wang, Y. (2011). Applications of nanoparticles in herbal medicine: zedoary turmeric oil and its active compound β-elemene. *The American Journal of Chinese Medicine*, *39*(06), 1093-1102.

[8] Chithra, P., Sajithlal, G. B., & Chandrakasan, G. (1998). Influence of Aloe vera on the glycosaminoglycans in the matrix of healing dermal wounds in rats. *Journal of Ethnopharmacology*, *59*(3), 179-186.

[9] Kabeerdass, N., Murugesan, K., Arumugam, N., Almansour, A. I., Kumar, R. S., Djearamane, S & Mathanmohun, M. (2022). Biomedical and textile applications of alternanthera sessilis leaf extract

Paper ID: SR24709145734 DOI: https://dx.doi.org/10.21275/SR24709145734

mediated synthesis of colloidal silver nanoparticle. *Nanomaterials*, *12*(16), 2759.

[10] Akintelu, S. A., & Folorunso, A. S. (2020). A review on green synthesis of zinc oxide nanoparticles using plant extracts and its biomedical applications. *BioNanoScience*, *10*(4), 848-863.

[11] Hischier, R., & Walser, T. (2012). Life cycle assessment of engineered nanomaterials: State of the art and strategies to overcome existing gaps. *Science of the Total Environment*, *425*, 271-282.

[12] Salieri, B., Turner, D. A., Nowack, B., & Hischier, R. (2018). Life cycle assessment of manufactured nanomaterials: where are we?. *NanoImpact*, *10*, 108-120.

[13] Antunes Filho, S., Dos Santos, M. S., Dos Santos, O. A. L., Backx, B. P., Soran, M. L., Opriş, O., ... & Bououdina, M. (2023). Biosynthesis of nanoparticles using plant extracts and essential oils. *Molecules*, *28*(7), 3060.

[14] Goutam, S. P., Saxena, G., Roy, D., Yadav, A. K., & Bharagava, R. N. (2020). Green synthesis of nanoparticles and their applications in water and wastewater treatment. *Bioremediation of Industrial Waste for Environmental Safety: Volume I: Industrial Waste and Its Management*, 349-379.

[15] Missoum, A. (2018). An update review on Hibiscus rosa sinensis phytochemistry and medicinal uses. *Journal of ayurvedic and herbal medicine*, *4*(3), 135-146.

[16] Devi, R. S., & Gayathri, R. (2014). Green synthesis of zinc oxide nanoparticles by using Hibiscus rosa-sinensis. *International Journal of Current Engineering Technology*, *4*(4), 2444-2446.

[17] Pavithra, S., Sudha, P., Kalaiselvi, V., Ramya, V., & Vidhya, N. (2020). Green Synthesis and Characterization of ZnO Nanoparticles using Hibiscus rosa-sinensis Leaf Extract. *Journal of Environmental Nanotechnology*, *9*(3), 07-12.

[18] Bala, N., Saha, S., Chakraborty, M., Maiti, M., Das, S., Basu, R., & Nandy, P. (2015). Green synthesis of zinc oxide nanoparticles using Hibiscus subdariffa leaf extract: effect of temperature on synthesis, anti-bacterial activity and anti-diabetic activity. *RSC Advances*, *5*(7), 4993-5003.

[19] Lanka, S. (2018). A review on Aloe vera-The wonder medicinal plant. *Journal of Drug Delivery and Therapeutics*, *8*(5-s), 94-99.

[20] Subramani, K., Kolathupalayam Shanmugam, B., Rangaraj, S., Palanisamy, M., Periasamy, P., & Venkatachalam, R. (2018). Screening the UV-blocking and antimicrobial properties of herbal nanoparticles prepared from Aloe vera leaves for textile applications. *IET nanobiotechnology*, *12*(4), 459-465.

[21] Xu, J., Huang, Y., Zhu, S., Abbes, N., Jing, X., & Zhang, L. (2021). A review of the green synthesis of ZnO nanoparticles using plant extracts and their prospects for application in antibacterial textiles. *Journal of Engineered Fibers and Fabrics*, *16*, 15589250211046242

[22] Batool, M., Khurshid, S., Qureshi, Z., & Daoush, W. M. (2021). Adsorption, antimicrobial and wound healing activities of biosynthesised zinc oxide nanoparticles. *Chemical Papers*, *75*, 893-907.

[23] Mondal, M. I. H., & Saha, J. (2019). Antimicrobial, UV resistant and thermal comfort properties of chitosan-and Aloe vera-modified cotton woven fabric. *Journal of Polymers and the Environment*, *27*, 405-420.

[24] Shanmugapriya, J., Monisha, P., Nandhini, A., & Praveena, K. (2019). Synthesis of zinc oxide nanoparticles from Aloe barbadensis for medical application. *nternational Journal of Advanced Research and Technology* , *7*, 1-10.

[25] Sharma, V. (2018). A review on medicinal properties of neem (Azadirachta indica). *Journal of Pharmaceutical Innovation***,** *7*, 648-650.

[26] Sharma, J., Sweta, S., Thakur, C., Vats, M., & Sharma, S. K. (2020, May). Green synthesis of zinc oxide nanoparticles using neem extract. In *AIP Conference Proceedings* (Vol. 2220, No. 1). AIP Publishing.

[27] Sagar, D. S., & Biradar, D. P. (2021). Green synthesis and characterization of zinc oxide nanoparticles from leaf extracts of Hibiscus rosa-sinensis and Azadirachta indica. *Environment and Ecology*, *40*, 395–403.

[28] Kar, T. R., Samanta, A. K., Sajid, M., & Kaware, R. (2019). UV protection and antimicrobial finish on cotton khadi fabric using a mixture of nanoparticles of zinc oxide and poly-hydroxy-amino methyl silicone. *Textile Research Journal*, *89*(11), 2260-2278.

[29] Asim, F., & Naeem, F. (2023). Investigation of self-cleaning attributes of denim fabric modified with naturally synthesized ZnO nanoparticles. *Pigment & Resin Technology*, *52*(6), 738-746.

[30] Geetha, A., Sakthivel, R., Mallika, J., Kannusamy, R., & Rajendran, R. (2016). Green synthesis of antibacterial zinc oxide nanoparticles using biopolymer Azadirachta indica Gum. *Oriental journal of Chemistry*, *32*(2), 955-963.

[31] Srabana, M, & Kshitju, S. (2017). Pharmacological Study of *Symplocos racemosa* Roxb. *International journal of Pharmacy & Pharmaceutical research*, *9*(1), 106-113.

[32] Princeton, B., Cecil, A., & Rajeshkumar, S. (2022). antifungal activity of *Symplocos racemosa* (lodhra) and *Cinnamomum verum* (cinnamon) bark formulation mediated zinc oxide nanoparticles against candida albicans. *Annals of Forest Research*, *65*(1), 4120-4124..

[33] Cecil, A., & Rajeshkumar, S. (2022). biofabrication of zinc oxide nanoparticles using cinnamon and lodhra bark formulation and its anti inflammatory activity. sowbaraniya sm Saveetha Dental College and hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai-600077, Tamil Nadu, India, Email. id: 151801094. sdc@ saveetha. com. *Annals of Forest Research*, *65*(1), 4125-4130.

[34] Chattopadhyay, R. R., & Bhattacharyya, S. K. (2007). PHCOG REV: Plant review. Terminalia chebula: An update. *Pharmacognosy reviews*, *1*(1), 151-156.

[35] Ramesh Kumar, P., Balaprakash, V., Sudha, S., & Gowrisankar, P. (2017). Microwave Assisted, Eco

friendly - Biosynthesis and Characterization of Alumina Zinc Oxide (AZO) Nanoparticles using Myrobalan fruit extract. Journal of Advances in Science and Technology, 14(2) 1 - 4 (4).

[36] Amritkar, S., Chavan, J., Kakad, A. & Shaikh, M. (2023). Phytochemical and pharmacological review of cynodon dactylon grass with its potential effects. *Journal of Pharmaceutical and Biological Sciences*. 3;11(2):112-116.

[37] Meenatchi, T., Palanimurugan, A., Dhanalakshmi, A., Maheshkumar, V., & Natarajan, B. (2020). Green synthesis of Cynodon Dactylon capped concentrations on ZnO nanoparticles for antibacterial activity, ROS/ML-DNA treatment and compilation of best controlling microbes by mathematical comparisons. Chemical Physics Letters, 749, 137429.

[38] Heer, A. S. K. (2017). Spectral characterization and anti-fungal activity of zinc oxide (zno) nanoparticles synthesized using cynodon dactylon leaf extract. World Journal of Pharmaceutical Research, 6, 16.

[39] Anuforo, H. U., Ogbulie, T. E., Udebuani, A. C., & Ezeji, E. U. (2023). Synthesis of Zinc Oxide Nanoparticles using Extract of Cynodon dactylon and Assessment of their Biological Activity against *Staphylococcus aureus* and *Escherichia coli*. UMYU Journal of Microbiology Research, 8(2), 74-85.

[40] Acharya, R., Tettey, F., Gupta, A., Sharma, K. R., Parajuli, N., & Bhattarai, N. (2024). Bioinspired synthesis and characterization of zinc oxide nanoparticles and assessment of their cytotoxicity and antimicrobial efficacy. Discover Applied Sciences, 6(3), 1-17.

[41] Pooja, P., & Kumar, A. (2023). A systemic review of Tulsi (*Ocimum tenuiflorum* or *Ocimum sanctum*): Phytoconstituents, ethnobotanical and pharmacological profile. Research Journal of Pharmacognosy and Phytochemistry, 15(2), 179-188.

[42] Bala Chennaiah, M., Kumar, K. D., Kumar, B. S., & Tanneeru, S. R. (2022). Characterisation of zinc oxide nanoparticles–herbal synthesised coated with Ocimum tenuiflorum. Advances in Materials and Processing Technologies, 8(sup2), 466-477.

[43] Khan, M. A., Anwar, M. F., & Ahmad, M. (2023). Ocimum sanctum L water extract: In-situ green synthesis of zinc oxide nanoparticles for treatment of rheumatoid arthritis: Preclinical study. Journal of Trace Elements in Medicine and Biology, 79, 127212.

[44] Yasotha, P., Kalaiselvi, V., Vidhya, N., & Ramya, V. (2020). Green synthesis and characterization of zinc oxide nanoparticles using Ocimum tenuiflorum. International Journal on Advanced Science, Engineering, 2020, 1584-1588.

[45] Sagar Raut, D. P., & Thorat, R. (2015). Green synthesis of zinc oxide (ZnO) nanoparticles using OcimumTenuiflorum leaves. International Journal of Science and Research, 4, 1225-1228.

[46] Kumar, M. S., Bhuvaneshwari, S., Santhoshkumar, M., Arunnesh, A., Ameen, M. M., Sathiyapriya, K., & Astalakshmi, N. A Comprehensive Review on–Acalypha indica Linn.

[47] Karthik, S., Siva, P., Balu, K. S., Suriyaprabha, R., Rajendran, V., & Maaza, M. (2017). Acalypha indica–mediated green synthesis of ZnO nanostructures under differential thermal treatment: Effect on textile coating, hydrophobicity, UV resistance, and antibacterial activity. Advanced Powder Technology, 28(12), 3184-3194.

[48] Kamarajan, G., Anburaj, D. B., Porkalai, V., Muthuvel, A., & Nedunchezhian, G. (2022). Green synthesis of ZnO nanoparticles using Acalypha indica leaf extract and their photocatalyst degradation and antibacterial activity. Journal of the Indian Chemical Society, 99(10), 100695

[49] Chaudhary, A., Kumar, N., Kumar, R., & Salar, R. K. (2019). Antimicrobial activity of zinc oxide nanoparticles synthesized from Aloe vera peel extract. SN Applied Sciences, 1, 1-9.

[50] Hussain, A., Oves, M., Alajmi, M. F., Hussain, I., Amir, S., Ahmed, J., Rehman, M. T.; El-Seedi, H. R & Ali, I. (2019). Biogenesis of ZnO nanoparticles using Pandanus odorifer leaf extract: anticancer and antimicrobial activities. RSC advances, 9(27), 15357-15369.

[51] AlSalhi, M. S., Devanesan, S., Atif, M., AlQahtani, W. S., Nicoletti, M., & Serrone, P. D. (2020). Therapeutic potential assessment of green synthesized zinc oxide nanoparticles derived from fennel seeds extract. International Journal of Nanomedicine, 8045-8057.

[52] Mydeen, S. S., Kumar, R. R., Sambathkumar, S., Kottaisamy, M., & Vasantha, V. S. (2020). Facile synthesis of ZnO/AC nanocomposites using Prosopis juliflora for enhanced photocatalytic degradation of methylene blue and antibacterial activity. Optik, 224, 165426.

[53] Pillai, A. M., Sivasankarapillai, V. S., Rahdar, A., Joseph, J., Sadeghfar, F., Rajesh, K., & Kyzas, G. Z. (2020). Green synthesis and characterization of zinc oxide nanoparticles with antibacterial and antifungal activity. Journal of Molecular Structure, 1211, 128107.

[54] Alamdari, S., Sasani Ghamsari, M., Lee, C., Han, W., Park, H. H., Tafreshi, M. J., ... & Ara, M. H. M. (2020). Preparation and characterization of zinc oxide nanoparticles using leaf extract of Sambucus ebulus. Applied Sciences, 10(10), 3620.

[55] Rajashekara, S., Shrivastava, A., Sumhitha, S., & Kumari, S. (2020). Biomedical Applications of Biogenic Zinc Oxide Nanoparticles Manufactured from Leaf Extracts of Calotropis gigantea (L.) Dryand. BioNanoScience, 10, 654-671.

[56] Sukri, S. N. A. M., Shameli, K., Wong, M. M. T., Teow, S. Y., Chew, J., & Ismail, N. A. (2019). Cytotoxicity and antibacterial activities of plant-mediated synthesized zinc oxide (ZnO) nanoparticles using Punica granatum (pomegranate) fruit peels extract. Journal of Molecular Structure, 1189, 57-65.

[57] Mthana, M. S., Mthiyane, D. M., Onwudiwe, D. C., & Singh, M. (2022). Biosynthesis of ZnO nanoparticles

using Capsicum chinense fruit extract and their in vitro cytotoxicity and antioxidant assay. Applied Sciences, 12(9), 4451.
[58] Faisal, S., Jan, H., Shah, S. A., Shah, S., Khan, A., Akbar, M. T., ... & Syed, S. (2021). Green synthesis of zinc oxide (ZnO) nanoparticles using aqueous fruit extracts of Myristica fragrans: their characterizations and biological and environmental applications. ACS omega, 6(14), 9709-9722.
[59] Sudha, K. G., Ali, S., Karunakaran, G., Kowsalya, M., Kolesnikov, E., & Rajeshkumar, M. P. (2020). Eco-friendly synthesis of ZnO nanorods using Cycas pschannae plant extract with excellent photocatalytic, antioxidant, and anticancer nanomedicine for lung cancer treatment. Applied Organometallic Chemistry, 34(4), e5511.
[60] Demissie, M. G., Sabir, F. K., Edossa, G. D., & Gonfa, B. A. (2020). Synthesis of zinc oxide nanoparticles using leaf extract of lippia adoensis (koseret) and evaluation of its antibacterial activity. Journal of Chemistry, 2020, 1-9.
[61] Vijayakumar, S., Mahadevan, S., Arulmozhi, P., Sriram, S., & Praseetha, P. K. (2018). Green synthesis of zinc oxide nanoparticles using Atalantia monophylla leaf extracts: Characterization and antimicrobial analysis. Materials Science in Semiconductor Processing, 82, 39-45.
[62] Naseer, M., Aslam, U., Khalid, B., & Chen, B. (2020). Green route to synthesize Zinc Oxide Nanoparticles using leaf extracts of Cassia fistula and Melia azadarach and their antibacterial potential. Scientific Reports, 10(1), 9055.
[63] Vijayakumar, S., Vaseeharan, B., Sudhakaran, R., Jeyakandan, J., Ramasamy, P., Sonawane, A., Padhi, A.; Velusamy, P.; Anbu, P. & Faggio, C. (2019). Bioinspired zinc oxide nanoparticles using Lycopersicon esculentum for antimicrobial and anticancer applications. Journal of cluster science, 30, 1465-1479.
[64] Mahendra, C., Chandra, M. N., Murali, M., Abhilash, M. R., Singh, S. B., Satish, S., & Sudarshana, M. S. (2020). Phyto-fabricated ZnO nanoparticles from Canthium dicoccum (L.) for antimicrobial, anti-tuberculosis and antioxidant activity. Process biochemistry, 89, 220-226.
[65] Loganathan, S., Manimaran, K., Mutamimurugan, K., Prakash, D. G., & Subashini, R. (2022). Green Synthesis of Zinc Oxide Nanoparticles (ZnO-NPs) by Pterolobium hexapetalum (Roth) Santapau & Wagh Aqueous Leaf Extract and Its Assessment of Biocompatible, Antibacterial, DPPH Radical Scavenging, Anticancer and Larvicidal Activities: An Effective Eco-Friendly Approach.
[66] Abdelbaky, A. S., Abd El-Mageed, T. A., Babalghith, A. O., Selim, S., & Mohamed, A. M. (2022). Green synthesis and characterization of ZnO nanoparticles using Pelargonium odoratissimum (L.) aqueous leaf extract and their antioxidant, antibacterial and anti-inflammatory activities. Antioxidants, 11(8), 1444.
[67] Patil, B. N., & Taranath, T. C. (2016). Limonia acidissima L. leaf mediated synthesis of zinc oxide nanoparticles: A potent tool against: Mycobacterium tuberculosis. The International Journal of Mycobacteriology, 5(2), 197-204.
[68] Sharma, A., Nagraik, R., Sharma, S., Sharma, G., Pandey, S., Azizov, S., Chauhan, P. K. & Kumar, D. (2022). Green synthesis of ZnO nanoparticles using Ficus palmata: Antioxidant, antibacterial and antidiabetic studies. Results in Chemistry, 4, 100509.
[69] Abomuti, M. A., Danish, E. Y., Firoz, A., Hasan, N., & Malik, M. A. (2021). Green synthesis of zinc oxide nanoparticles using salvia officinalis leaf extract and their photocatalytic and antifungal activities. Biology, 10(11), 1075.
[70] Al Awadh, A. A., Shet, A. R., Patil, L. R., Shaikh, I. A., Alshahrani, M. M., Nadaf, R., ... & Kumbar, V. (2022). Sustainable synthesis and characterization of zinc oxide nanoparticles using Raphanus sativus extract and its biomedical applications. Crystals, 12(8), 1142.
[71] Awan, S. S., Khan, R. T., Mehmood, A., Hafeez, M., Abass, S. R., Nazir, M., & Raffi, M. (2023). Ailanthus altissima leaf extract mediated green production of zinc oxide (ZnO) nanoparticles for antibacterial and antioxidant activity. Saudi Journal of Biological Sciences, 30(1), 103487.
[72] Kazempour, P., Yaghoubi, H., & Mohammadi-Aloucheh, R. (2021). Green Synthesis of ZnO Nanoparticles Using Eryngium Billardieri Leaf Extract: Characterization and Its Anti-Diabetic Properties. Biochem. Mol. Biol, 7, 18.
[73] Mekonnen, G., Negash, A., Gashu, M., & Belachew, N. (2022). Echinops kebericho aqueous root extract assisted green synthesis of zinc oxide nanoparticles for photocatalytic degradation of methylene blue. Letters in Applied NanoBioScience. 2023, 12 (3).
[74] Bayrami, A., Parvinroo, S., Habibi-Yangjeh, A., & Rahim Pouran, S. (2018). Bio-extract-mediated ZnO nanoparticles: microwave-assisted synthesis, characterization and antidiabetic activity evaluation. Artificial cells, nanomedicine, and biotechnology, 46(4), 730-739.
[75] Dulta, K., Koşarsoy Ağçeli, G., Chauhan, P., Jasrotia, R., & Chauhan, P. K. (2022). Ecofriendly synthesis of zinc oxide nanoparticles by Carica papaya leaf extract and their applications. Journal of Cluster Science, 1-15.
[76] Rehman, H., Ali, W., Khan, N. Z., Aasim, M., Khan, T., & Khan, A. A. (2023). Delphinium uncinatum mediated biosynthesis of zinc oxide nanoparticles and in-vitro evaluation of their antioxidant, cytotoxic, antimicrobial, anti-diabetic, anti-inflammatory, and anti-aging activities. Saudi Journal of Biological Sciences, 30(1), 103485.
[77] Kundu, S., Haydar, M. S., & Mandal, P. (2021). Zinc Oxide Nanoparticles: Different synthesis approaches and applications. Journal of Plant Science. 13, 42-64.
[78] Becheri, A., Dürr, M., Lo Nostro, P., & Baglioni, P. (2008). Synthesis and characterization of zinc oxide nanoparticles: application to textiles as UV-absorbers. Journal of Nanoparticle Research, 10, 679-689.

[79] Sabir, S., Arshad, M., & Chaudhari, S. K. (2014). Zinc oxide nanoparticles for revolutionizing agriculture: synthesis and applications. The Scientific World Journal, 2014, 925494.
[80] Kaushik, M., Niranjan, R., Thangam, R., Madhan, B., Pandiyarasan, V., Ramachandran, C.,... & Venkatasubbu, G. D. (2019). Investigations on the antimicrobial activity and wound healing potential of ZnO nanoparticles. Applied Surface Science, 479, 1169-1177.

Author Profile

Mona Sadasivam, Completed M.Sc. Microbiology from Bharathidasan University in 2008 with university rank. Received doctorate degree in Biomass-Bioenergy-Microbiology from University of Madras in 2019 with DST-INSPIRE Fellowship. Recently (2021-2024) completed DST-SYST project as Principal Investigator in reviving traditional dyeing practices. Passionate in research with microbes and plants.

Viyaanchi I.S is a fresher candidate in Biotechnology field, She holds a Master's degree in Biotechnology from Bharathidasan University, Does research include Eco friendly nanoparticle synthesis, the application in nanoparticle textiles and the antimicrobial properties of plant based nanoparticles.She was worked on the development of Zinc Oxide nanoparticles using medicinal plant extracts for applications in UV protection and antibacterial textiles.