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A REVIEW STUDY OF ZINC OXIDE NANOPARTICLES SYNTHESIS FROM PLANT EXTRACTS

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Abstract

The development of nanotechnology is making the interest of researchers towards thesynthesis of nanoparticles for the bioapplication. Metal oxides such as ZnO have received increasing attentionas antibacterial materials in recent years because of their stability under harsh processing conditions, and also because they are generally regarded as safe materials for human beingsand animals. Zinc activates 300 enzymes, and it plays a role in many another phenomenon like growth, membrane stability, bone mineralization, tissue growth, and repair, wound healing and cell signaling.Many studies have shown that ZnO nanoparticles have enhanced antibacterial activity. Use of plant and plant materials for the synthesis of Zinc nanoparticles is relatively new and exciting research field. Various plants were used for the synthesis of nanoparticles using green synthesis method. Nanoparticles were synthesized from all the parts of the plant separately like stem, flower, leaf, latex, root, peel, stem bark and fruits. The prepared nanoparticles of Zinc oxide were characterized by using XRD, FTIR, UV-VIS Spectroscopy, EDAX, Particle size analyzer, TGA, and SEM. The objective of this review was to report on thesynthesis of Zinc oxide nanoparticles by using different plant extracts and their significance in different fields.

Keywords: Nanotechnology; ZnO nanoparticles; Green synthesis; Plant extracts; Characterization.

INTRODUCTION

Nanotechnology is the technological innovation of the 21st century. Research and development in this field are growing rapidly throughout the world (Vidya*et al.*, 2013). A major contribution of this field is the development of new materials in the nanometer scale (Sivakumar*et al.*, 2011). These are usually particulate materials with at least one dimension of less than 100 nanometers (nm), even the particles could be zero dimension in the case of quantum dots (Vidya*et al.*, 2013). Metal nanoparticles have been of great interest due to their distinctive features such as catalytic, optical, magnetic and electrical properties (Garima*et al.*, 2011). Nanoparticles exhibit completely new or improved properties with larger particles of the bulk materials, and these novel properties are derived due to the variation in specific characteristics such as size, distribution, and morphology of the particles (Ravindra*et al.*, 2011).

The conventional methods of synthesizing nanoparticles using chemical method were found to be more expensive and also involved the use of toxic, hazardous chemicals that were responsible for various biological risks (Geoprincy*et al.*, 2012). In order to avoid the use of toxic chemicals, scientists have developed better methods which can be done in two ways. First one is the use of microorganisms such as bacteria, fungi, and yeast (Helan*et al.*, 2013). Using microorganisms for the synthesis of nanoparticles were found to be more tedious and required more steps in maintaining cell culture, intracellular synthesis with more purification steps while the second one was with the use of plants known as 'Green synthesis' or 'Biogenic synthesis.' This type of biosynthesis shows better advancement over chemical and physical methods as it is lesser toxic, cost effective, environmental friendly (Vidya*et al.*, 2013) and also involves proteins as capping agents (Sangeetha *et al.*, 2011). Proteins are biomolecules and are advantageous by giving low toxic degradable end products (Raja *et al.*, 2014). Hence biogenic synthesis of nanoparticles was found to be more attractive for research as conventional methods were more expensive and non-ecofriendly(Raj and Jayalakshmy, 2015a). The nanoparticles synthesized using the plant system can be utilized for different commercial applications like pharmaceuticals, drugs, therapeutics, etc. (Mohanpuria*et al.*, 2008and Bhattacharya and Mukherjee, 2008).

Zinc (Zn) is an essential nutrient required by all living organisms and represents the 23rd most abundant element on earth (Broadley*et al.*, 2007) and the 2nd most abundant transition metal, subsequent to iron (Jain *et al.*, 2010). It is required in six different classes of enzymes, which include oxidoreductases, transferases, hydrolases, lyases, isomerases, and ligases (Auld, 2001). Zinc has been considered as an essential micronutrient for metabolic activities in plants and animals including humans. Zinc Nano-particles are used in various agricultural experiments to understand its effect on growth, germination, and various other properties (Fageria*et al*., 2002). The crop yield and quality of products can be affected by the deficiency of Zn (Jamali*et al*., 2011).

A novel approach of biosynthesis, Zinc oxide nanoparticles (ZnO NPs) produced using a natural source, such as plant extracts to reduce metal ions, which are readily scalable and nontoxic compared with physical and chemical methods (Jayapaul*et al*., 2011). ZnO-NPs are used in the preparation of substances processing medically as well as cosmetically. Due to its antibacterial properties, ZnOis applied on the skin irritation, diaper rash, dry skin, and blisters. ZnO-NPs can also be used for selective destruction of tumor cells and has a great potential in drug delivery applications (Rasmussen *et al*., 2010). ZnO-NPs have also been shown to exhibit strong protein adsorption properties, which can be used to modulate cytotoxicity, metabolism or other cellular responses (Horie and Nishiok, 2009). Apart from these many applications, ZnO, due to its low toxicity is listed as "Generally Recognized as Safe" (GRAS) by the US Food and Drug Administration (21, CFR 182, 8991) (Bhumi and Savithramma, 2014).

Green synthesis of nanoparticles has gained significant importance in recent years and has become one of the most preferred methods. The biosynthesis of ZnO nanoparticles can be carried out using different plant extracts. In the plant-based synthesis, several plant parts viz., leaf, stem, bark, peel, flower, roots, fruit extracts can be used to generate nanoparticles. The ZnO nanoparticles synthesized with different plant parts and their significance is given in Table 1.

SYNTHESIS OF ZnO NANOPARTICLES FROM LEAF EXTRACTS

Coriandrumsativum leaf was used for the synthesis and characterization of ZnO nanoparticles prepared by green and chemicaltechnique. The characterization of ZnO-NPs was carried out by XRD, SEM, FTIR, and EDAX. The average size was found to be 66 nm in green synthesis method while the size was 81nm in thechemical method. The ZnO nanoparticles prepared from *Coriandrum*leaf extract were expected to have more extensive application in biotechnology, sensors, medical, catalysis, optical devices, DNA labeling, drug delivery and water remediation(Gnanasangeetha and Thambavani, 2013).

The synthesis of Zinc oxide nanoparticles was reported with the leaf extract of *Ocimumtenuiflorum*. Prepared ZnO nanoparticles were characterized byXRD, SEM and FTIR. The SEM image showed hexagonal shape and nanoparticle with diameterrange of 11-25 nm (Raut*et al*., 2013).

Calotropisgigantea leaf extract was used for the synthesis of Zinc oxide nanoparticles. The synthesized Zinc nanoparticles were characterized using SEM and XRD. The synthesized nano crystallites of ZnO were in the range of 30-35 nm (Vidya*et al*., 2013), whereasthe synthesis of leaf extract of *Calotropis procera* was reported by Poovizhi and Krishnaveni and FTIR and SEM characterized the synthesized ZnO-NPs. The size of the particles ranged from 100 to 200 nm. The antibacterial activity towards human bacterial and plant pathogens showed good sensitivity towards the green synthesized ZnO-NPs at all concentrations. The study indicated that the *C. procera*ZnO nanoparticles had strong antimicrobial activity against the tested human and plant bacterial pathogens along with the fungal pathogens (Poovizhi and Krishnaveni, 2015). The different parts of the *Calotropisgigantea* plant were used in traditional Indian medicine for the treatment of painful muscular spasm, dysentery, fever, rheumatism, asthma and as an expectorant and purgative (Ravindra*et al*., 2011).

The synthesis of Zinc oxide nanoparticles was reported with the leaf extract of *Oleaeuropea*. Prepared ZnO nanoparticles were characterized by UV-Vis Spectroscopy, FTIR, XRD and SEM, The average size of particles was found to be 500 nm and the thicknesses was about 20 nm by SEM studies.FT-IR analysis of aqueous *OleaEuropea*leaf extract indicated the presence of phytoconstituents such as amines, aldehydes, phenols and alcohols which were the surface active molecules stabilizing the Zinc oxide nanosheets (Awwad *et al*., 2014).

Chemotherapeutic agents from *CatharanthusRoseus* wereknown for their pain relieving property in cancer treatment. It is cultivated mainly for its alkaloids, which are having anticancer activities (Jaleel *et al*., 2009). The Zinc oxide nanoparticles were synthesized with the leaf extract of *Catharanthusroseus*. The synthesized Zinc oxide nanoparticles were characterized using XRD, SEM, EDAX and FT-Raman Spectroscopy. The SEM results showed that the particles were spherical in shape with an average size of 23 to 57 nm. The synthesized ZnO-NPs were evaluated for the antibacterial activity against *Bacillus thuringiensis*, *Escherichia coli*, *Staphylococcus aureus*and *Pseudomonas aeuroginosa*. The highest antimicrobial activity was observed against *Pseudomonas aeuroginosa*followed by *Staphylococcus aureus*(Bhumi and Savithramma, 2014b).

The synthesis of Zinc oxide nanoparticles was reported with the leaf extract of *Adhatodavasica*. The Synthesized ZnO-NPs were characterized by UV-Vis Spectroscopy, SEM, EDAX, XRD, and FT- Raman Spectroscopy. The Synthesized ZnO-NPs were found to be discoid in shape with an average size of 19 - 60 nm. Phytochemicals present in the plant were responsible for the quick reduction of Zn^{+} ion to metallic Zinc Oxide nanoparticles. The synthesized ZnO-NPs had the potential to mitigate the bacterial cell proliferation particularly *Escherichia coli*, *Bacillus thuringiensis*, *Pseudomonas aeurogonisa*and *Staphylococcus aureus*. *Adhatodavasica*is a good source for rapid reduction of metallic Zinc oxide into nanoparticles with antibacterial activity.*Adhatodavasica*has been used as the reducing material as well as asurface stabilizing agent for the synthesis of ZnONPs(Bhumi*et al*., 2014a).

$$Zn\ (CH_3COO_2)2H_2O + 2NaOH \longrightarrow Zn(OH_2) + 2CH_3COONa + 2H_2O$$

$$Zn(OH)_2 + \text{Biomolecules of metabolites} \longrightarrow ZnO + H_2O$$

The leaf extract of *Hibiscus rosa -sinensis*was used for the synthesis of Zinc oxide nanoparticles.The particle size and morphology of the synthesized nanoparticles were characterized by using SEM and XRD.The SEM image showed relatively spongy shape nanoparticles and size were found to be in the range of 30-35 nm. Bala et al. reported the synthesis of Zinc oxide nanoparticles from the leaf extract of Hibiscus subdariffa.,and the formation of synthesized ZnO nanoparticles was confirmed by UV-Vis Spectroscopy, FTIR, XRD, HRTEM, EDX and FESEM. The synthesized ZnO nanoparticles had potential anti-bacterial agents which have been studied on *Escherichia coli* and *Staphylococcus aureus*. Another study has indicated that the small-sizedZnO NPs, stabilized by plant metabolites had better anti-diabetic effect on streptozotocin (STZ) induced diabetic mice than that of large-sizedZnO particles (Bala*et al*., 2015). The flowers of *Hibiscus rosa-sinensis* are edible and are used in salads in the Pacific Islands. The flower is additionally used in hair care as a preparation (Devi and Gayathri, 2014).

The synthesis of Zinc oxide nanoparticles was reported with the leaf extracts of *AzadirachtaIndica* and *Emblicaofficinalis*. The formed nanoparticles were characterized by SEM, XRD, FTIR, and EDAX for their morphology, size, crystallinity and percentage composition. The synthesized nanoparticles were found to be in the range of 100-200 nm by SEM results. The qualitative examination of the aqueous extracts of the leaf samples of *Azadirachtaindica*and *Emblicaofficinalis*showed the presence of phytochemical constituents such as Alkaloids, Carbohydrates, Glycosides, Steroids, Flavonoids, Terpenoids, Tannins, and Steroids (Gnanasangeetha and Thambavani, 2014).

The Zinc oxide nanoparticles were synthesized from the leaf extract of Tanners cassia (*Cassia auriculata*). The synthesized Zincoxide nanoparticles were confirmedbySEM, UV- Vis Spectrophotometer and FTIR. The SEM studies revealed that the synthesized ZnO-NPs were spherical in shape(Ramesh *et al*., 2014a).

The Zinc oxide nanoparticles were synthesized with the leaf extract of green tea (*Camellia sinensis)*. The synthesized Zinc oxide nanoparticles were characterized using XRD, UV–VIS spectrum and FTIR. The average size of the nanoparticles calculated using XRD data was 16 nm (Senthilkumar and Sivakumar, 2014)whereasShah *et al*., reported on green tea and synthesized Zn nanoparticles were characterized by UV-Vis Spectroscopy, Particle size analyzer, and SEM. Particles size analyzer determined the size of the particles and was found to be 853 nm in diameter. The synthesized Zn nanoparticles showed significant antimicrobial activity against Gram positive and Gram negative bacteria as well as against a fungal strain. The study also suggested that the green synthesized Zn nanoparticles could be used as an alternative to existing antimicrobial agents.(Shah *et al*., 2015). The synthesized ZnO NPs showed better and comparable antimicrobial activities concerning the activities of synthetic drugs (Senthilkumar and Sivakumar, 2014).

The plant leaf extract of *Brassica oleraceae*was used for the synthesis of Zinc oxide nanoparticles. The characterization of the synthesized nanoparticles was examined by UV- Vis spectrum and SEM. The particles were spherical and sheet shape. The experimental results showed that the diameters of prepared nanoparticles in the solution had sizes between 1 and 100 nm. The whole plant body of *Brassica oleraceae*had possessed aphrodisiac activities, and it had asignificant role in maintaining maleness. Siddha medicine explained it as rejuvenating herb, and it was known to possess coumarin, which was responsible for the hypolipidemic activity. The nanoparticles showed antibacterial activity against both Gram-positive and negative bacteria. The antibacterial activities increased as the concentration of Zinc oxide nanoparticles increased (Amrita *et al*., 2015).

The plant leaf extract of neem (*Azadirachta indicia)* was used for thesynthesis of Zinc oxide nanoparticles. The synthesized ZnO nanoparticles were characterized using FTIR spectroscopy and SEM analysis. The SEM results revealed that the particles were spindle-shaped and their size were 50 µm(Noorjahan*et al*., 2015).

The leaf extract of *Pyruspyrifolia*was used for thesynthesis of Zinc oxide nanoparticles. The structural, morphological and optical properties of the synthesized nanoparticles have been characterized by using UV–Vis spectrophotometer, XRD, FTIR, AFM, and FE – SEM with EDX analysis. The synthesized ZnONPS were found to be almost spherical in shape with aparticle size of around 45 nm. The photocatalytic study concluded that the bio – ZnO NPs had the efficiency to dye degrade methylene blue under solar irradiation. Therefore, the study could find application in water treatment plants and textile industries(Parthiban and Sundaramurthy, 2015).

The synthesis of Zinc oxide nanoparticles was done by using biological and chemical reducing agents. The synthesized nanoparticles in thebiologicalmethod used *Pithecellobiumdulce*and *Lagenariasiceraria*leaf extracts and in thechemical method using sodium hydroxide as reducing agents. In traditional medicine, the leaves of *P. dulce*was used for the treatment offearache, leprosy, pepticulcer, toothache, venereal diseases and also showed emollient, anodyne, larvicidic(Sugumaran*et al.*, 2008) and abortifacient, and antidiabetic properties in folk medicine. Various parts of plantwere used for different purposes like aleaf as astringent, seed oil as spermicidal, anti-inflammatory, anti-oedemia, fruit and seed as edible, bark for tannin (Mohammed *et al*., 2004).*Lagenariasiceraria*, which had diuretic and anti-swelling effects, was used as food (Wang and Ng, 2000). A decoction of *Lagenariasiceraria*was employed in the treatment of anasarca, ascites, and beriberi (Anandh*et al.*, 2014). The biologically synthesized ZnO Nanoparticles showed better antimicrobial activities with respect to the activities of synthetic drugs than chemical method (Prakash and Kalyanasundharam, 2015).

The synthesis of Zinc nanoparticles was reported with the leaf extract of *Thevetiaperuviana*. The plant contained a poisonous toxin called thevetin, which was used as a heart stimulant (Singh *et al*., 2012). These plant toxins were also used as biological pest controls (Kareru*et al.*, 2010). The synthesized Zinc oxide nanoparticles were characterized using UV-Visible Spectroscopy, FTIR, Particle size analyzer, XRD, SEM, TEM, Inductively Coupled Plasma-Optical Emission Spectrophotometer. The average particle size of synthesized Zinc nanoparticles was found to be 53 nm. SEM and TEM data revealed the presence of triangular shaped and poly-dispersed zinc nanoparticles with a grain size of 50 ± 5 nm. The synthesized Zinc nanoparticles were applied on *Arachishypogaea*L (peanut) pot-culture to estimate soil microbial population, soil exo-enzyme activities and physiological growth parameters of the peanut plants.Zinc nanoparticles applied to the peanut pot-culture exhibited good soil microbial and enzyme activities by showing significant variations compared to the control and enhanced the physiological growth parameters of peanut plants.(Sindhura*et al.*, 2015).

The Zinc oxide nanoparticles were synthesized with the leaf extract of *Aloe vera*. XRD, SEM, UV-Vis Spectroscopy, PL, BET, and TGA were used for characterization of synthesized ZnO nanoparticles. The particles were ahexagonal shape with anaverage size of 22.18 nm.Photodegradation and antibacterial activity of the nanoparticles were studied. The antibacterial studies of synthesized nanoparticles showed sensitivity to both Gram positive and Gram negative bacteria (Varghese and George, 2015).

Corymbiacitriodora leaf extract was used for the synthesis of Zinc oxide nanoparticles. SEM, EDX, XRD, UV–VIS spectroscopy, Raman spectroscopy and TGA had been used for characterizing the biosynthesized ZnO NPs. The synthesized nanoparticles exhibited polyhedron shape with a size range between 20 and 120 nm and showed excellent dispersibility with anaverage size of 64 nm. The photocatalytic activity of biosynthesized ZnO NPs hasbeen evaluated by the photodegradation of methylene blue. The results showed that the biosynthesized ZnO NPs had higher photocatalytic performance than normal hydrothermally prepared ZnO NPs due to the smaller size (Zheng*et al.*, 2015).

SYNTHESIS OF ZnO NANOPARTICLES FROM STEM AND ROOT EXTRACTS

The stem extract of *Euphorbia tirucalli*was used for the synthesis of Zinc oxide nanoparticles.The particle size, topography, and morphology of the synthesized ZnO nanoparticles were characterized using XRD and SEM. The particles obtained were spherical in nature and were agglomerates of nanocrystallites of 20 nm. Branches (stems) of *Euphorbia tirucalli* provided capping and reducing agents for the synthesis of ZNOnano particles(Hiremath*et al.*, 2013).

The stem extract of *Rutagraveolens*was used for the synthesis of Zinc oxide nanoparticles. Formation of ZnO nanoparticles was characterized by PXRD, UV- Visible Spectroscopy, SEM, and TEM. SEM results showed that the particles were spherical in shape and the average crystallite size was found to be 28 nm. The ingredient of *Rutagraveolens*was used in herbal veterinary medicine. The ZnO nanoparticles were found to inhibit the antioxidant activity of 1,1-diphenyl- 2-picrylhydrazyl free radicals effectively. ZnONPS exhibited significant bactericidal activity against Gram –ve bacterial strains such as *Klebsiellaaerogenes*, *Pseudomonas aeruginosa,Escherichia coli* and Gram +ve*Staphylococcus aureus*(Lingarraju*et al.*, 2015).

Zinc Oxide nanoparticles were synthesized by a biological method using the stem extract of *Tinosporacordifolia*. The synthesized Zinc Oxide nanoparticles were characterized using SEM, EDX, and FTIR. The average size of ZnO nanoparticles was found to be 37 nm having a spherical shape as determined by SEM. EDX results confirmed the presence of Zinc and Oxygen in the synthesized ZnO nanoparticles. FTIR studies clearly indicated the presence of reducing and capping biomolecules that were responsible for the production of ZnO nanoparticles (Raj and Jayalaksmy, 2015). *Tinosporacordifolia* was rich in bioactive components such as alkaloids, phenolics, steroids such as tiospirone, tinosporide, columbine, etc., that were responsible for its medicinal activities (Pandey *et al.*, 2012 and Shanthi and Nelson, 2013).

Boswelliaovalifoliolata stem bark extract was used for the synthesis of Zinc oxide nanoparticles. The synthesized Zinc oxide nanoparticles were characterized by using UV-Visible Spectroscopy, FTIR, TEM, XRD, DLS and Zeta potential. Zeta potential determined the size of particles and was found to be 20.3 nm. *Boswellia*ZnNPswere evaluated against pathogenic fungi and bacteria isolated from the biofilm formed in drinking water PVC pipelines by *in vitro* using disk diffusion method. *Boswellia*ZnNPs showed good antibacterial activity compared to antifungal activity (Suprajа*et al.*, 2015).

The root extract of *Zingiberofficinale*was used in the synthesis of Zinc oxidenanoparticles. The synthesized Zinc Oxide nanoparticles were characterized by SEM, EDX, and FTIR. The average size of the nanoparticles was found to be 30-50 nm and had spherical shape (Raj and Jayalaksmy, 2015). Chemically, ginger was rich in flavonoids and polyphenolic compounds such as gingerols, shagols, zingerone, paradol, terphineol, terpenes, borneol, geraniol, limonene, linalool, alphazingiberene, etc.(Ghosh *et al.*, 2011).

SYNTHESIS OF ZnO NANOPARTICLES FROM FRUIT, PEEL, FLOWER AND LATEX EXTRACTS

Citrus aurantifolia fruits were used for the synthesis of Zinc oxide nanoparticles. The morphology structure and stability of the synthesized ZnO nanoparticles were studied using SEM, UV- Spectrophotometer, and FTIR. The particles were spherical in shape, and the size ranged from 9 to 10 nm in diameter. *Citrus aurantifolia*extract revealed the presence of phytoconstituents like alcohols, aldehydes, and amines (Ramesh *et al.*, 2014b).

Zinc oxidenanoparticles were synthesized using the fruit extract of *Citrus aurantifolia*. The synthesized Zinc Oxide nanoparticles were characterized by FE-SEM, XRD and PL spectroscopy. FESEM imaging showed the formation of nanoparticles in size range of 50–200 nm and was spherical in shape. The synthesis of zinc oxide nanoparticles using the citrus extracts were found to be comparable to those obtained from conventional reduction methods using hexamethylenetetramine or cetyltrimethylammonium bromide and could be an excellent alternative for the synthesis of ZnO nanoparticles using biomaterials(Samat and Nor, 2012).

The fruit extract of *EmblicaOfficinalis*was used for the synthesis of Zinc oxide nanoparticles. The antimicrobial activity tests were performed against six bacterial pathogens namely, *Bacillus subtilis, Streptococcus pneumonia, Staphylococcus epidermidis, Klebsiella pneumonia, Salmonella typhi*and *Escherichia coli*, and two fungal pathogens namely, *Aspergillusniger*and *candidaalbicans*. The results concluded that the green synthesized Zinc oxide nanoparticles from *E. officinalis*might serve as an effective antibacterial agent in traditional medicine (Anbukkarasi*et al.*, 2015).

The biosynthesis ofZinc oxide nanoparticles from grapefruit (*Citrus paradise)* peel extract was reported. Structural, morphological, and optical properties of the synthesized nanoparticles have been characterized by using UV-Vis spectrophotometer, TEM, DLS, and FTIR analysis. The particles were spherical in shape and size ranged from 12 to 72 nm. The study showed the green approach for fabrication of ZnOnanoparticles and it was responsible for significant photocatalytic and antioxidant activity. The formed ZnO-NPs were highly stable and exhibited more than 56% degradation of methylene blue in sunlight for 6.0 h. In addition, the study clearly demonstrated that the ZnO-NPs were responsible for significant antioxidant activity (≥80% for 1.2mM)(Kumar *et al.*, 2014).

The green synthesis of Zinc oxide nanoparticles were done by using peel extract of *Punicagranatum*. The synthesized Zinc oxide nanoparticles were characterized by using UV-Visible Spectroscopy and SEM.The particles were spherical and square in shape with adiameter range of 50-100 nm(Mishra and Sharma, 2015).

The flower extract of *Trifoliumpratense*was used for the synthesis of Zinc oxide nanoparticles. The synthesized Zinc Oxide nanoparticles were characterized by UV-Visible Spectroscopy, XRD, FTIR, SEM, and EDX. The synthesized ZnO nanoparticles were agglomerated with a particle size ranging from below 100 to 190 nm. ZnO nanoparticles synthesized from *T. pratense* flower extract showed effective antibacterial activity against all tested strains (Dobruckaand Dugaszewska, 2015).

The Zinc oxide nanoparticles were synthesized with the milky latex extract of *Calotropisprocera.*The synthesized Zinc oxide nanoparticles were characterized by using XRD, TEM, SEM and UV-Vis Spectroscopy. The morphology of ZnO NPs embedded in *calotropis*matrix with little agglomeration having sizes about 5 nm throughout the carbon coated copper grid, and average particle size was in the range of 5 - 40 nm. Photoluminescence (PL) studies were performed to emphasize ZnONps emission properties (Ravindra*et al.*, 2011).

SYNTHESIS OF ZnO NANOPARTICLES FROM WHOLE PLANT EXTRACTS

Zinc oxide nanoparticles were synthesized from the aqueous extracts of mature leaves, stems, stem bark, dried bark of stem, roots, flower petals, immature and ripened fruits of *Morindapubescens.* Zinc oxide nanoparticles were characterized using theUV-Visible Spectroscopic method. The nanoparticle suspension gave the maximum UV-Vis absorbance peak at 290 nm to 300 nm.(Shekhawat and Manokari, 2014a).

The synthesis of Zinc oxide (ZnO) nanoparticles from the aqueous extracts of leaves, stem and root extracts of *Hybanthusenneaspermus(L.) F. Muell*was reported.UV-Vis spectrophotometeric analysis characterized the synthesized ZnO nanoparticles.(Shekhawat*et al.*, 2014b). The ethnobotanical herb *Hybanthus enneaspermus* has been reported to have anti-inflammatory, antitussive, antiplasmodial, anticonvulsant, anti-bacterial, anti-oxidant, antifungal, hypolipidemic and free radical scavenging activities (Boominathan *et al.*, 2004, Sahoo *et al.*, 2006, Satheesh and Kottai, 2012, Patel *et al.*, 2011 and Arumugam *et al.*, 2011).

The biosynthesis of Zinc oxide nanoparticles from the leaves, stem and root extracts of *Hemidesmusindicus*were reported.Leaves, stem and root aqueous extracts contained various primary and secondary metabolites responsible for the synthesis of nanoparticles.UV-Visible spectrophotometer characterized the Zinc oxide nanoparticles and the absorption peaks were reported between 29 nm and 310 nm, which proved the formation of Zinc oxide nanoparticles in the reaction mixture(Manokari and Shekhawat, 2015).

The biosynthesis of Zinc oxide nanoparticles using aqueous extracts of leaves, stem, root, aerial root, fruits, and fresh and dried bark extracts of *Ficusbenghalensis*were reported. Zinc nanoparticles were characterized using UV-Visible Spectroscopic method. The nanoparticle suspension showed maximum UV-Vis absorbance peak in between 290 nm and 300 nm which indicated theformation of Zinc oxide nanoparticles. Whole plant (*Ficusbenghalensis*) was used in traditional systems of medicines in India to cure various disorders like ulcers, leprosy, syphilis, diabetes, biliousness, dysentery, skin diseases, inflammation, etc. Its milky latex was reported to possess aphrodisiac properties (Shekhawat*et al.*, 2015a).

The biological synthesis of Zinc oxide nanoparticles using henna (*LawsoniainermisL.)* plant extracts was reported. The synthesized nanoparticles were confirmed by color changes from brown to pale green and characterized by UV-Visible spectrophotometer. Absorption peaks in between 296 nm and 302 nm and were observed to confirm the presence of Zinc oxide nanoparticles in the solution. Henna is known to be a traditional product with religious associations and widely used over the centuries for medical and cosmetic purposes. (Shekhawat*et al.*, 2015b).

The synthesis of Zinc oxide (ZnO) nanoparticles using the aqueous extracts of leaves, stem, roots and fruits of *Micrococcamercurialis (L.) Benth*were reported. UV-Visible spectrophotometer performed the characterization and confirmation of synthesized ZnO nanoparticles. The reaction mixtures showed significant and sharp UV absorbance peaks at 305 nm, 299 nm, 311 nm and 302 nm. The plant (*Micrococcamercurialis*) was found to be rich in primary and secondary metabolites such as proteins, steroids, and alkaloids, which were responsible for enhancing the biogenic synthesis of ZnO nanoparticles (Manokari *et al.*, 2016b). This plant was reported to possess purgative and anticancer activities (Jeyachandran and Bastin, 2013).

The synthesis of Zinc oxide (ZnO) nanoparticles using the aqueous extracts of leaves, stem, flower petals and bark of*Couroupitaguianensis*Aubl. were reported. UV- Visible spectral studies were conducted for the characterization and confirmation of the synthesized ZnO nanoparticles and the absorbance peak were reported in the range of 290 nm to 302 nm (Manokari and Shekhawat, 2016b). The whole plant is used to diagnose cold, stomach ache, toothache, throat infection, tumor, etc. (Bise*et al.*, 2009 and Pradhan *et al.*, 2009).

Plant aqueous extracts + Zinc nitrate $\xrightarrow{}$ ZnO nanoparticles + byproducts

The synthesis of Zinc oxide (ZnO) nanoparticles using the aqueous extracts of leaves, stem, roots, flowers, and fruits of *Meliaazedarach L.* were reported. UV- Visible spectral studies were conducted for the characterization and confirmation of the synthesized ZnO nanoparticles and the absorbance peak were reported in the range of 290-330 nm. The plant (*Meliaazedarach*) is enriched with alkaloids, sterols, glycosides, phenolic compounds, tannins, flavonoids, saponins and other biologically active phytocompounds (Manokari *et al.*, 2016a).

Durantaerecta gained horticultural and medicinal importance due to its various biological activities (Ravindran*et al.*, 2016). This plant also exhibits antioxidant, antibacterial and antimicrobial activities against human pathogens (Bangou*et al.*, 2012and Prabhakar*et al.*, 2015). The biosynthesis of Zinc oxide nanoparticles using aqueous extracts of leaves, stem, root, flowers and fruit extract of *DurantaerectaL.* were reported. The synthesized ZnO nanoparticles were characterized by UV-

Vis spectrophotometric analysis. The leaf extract showed strong absorbance peak at 302 nm, stem and flower peaks were located at 299 nm, roots at 293 nm and fruit extract solution peak was observed at 317 nm. The study ascertained the value of *D. erecta*in nano-field, which could be of considerable interest to the development of new drugs in medical field and production of pesticides and nano-bio-fertilizers in revolutionizing agriculture (Ravindran*et al.*, 2016).

CONCLUSIONS

The synthesis ofnanoparticles by conventional physical and chemical methods has some adverse effects like critical conditions of temperature and pressure, expensive and toxic chemicals, long reflux time of reaction, toxic by-products, etc. Green synthesis of nanoparticles has gained significant importance in recent years and has become one of the most preferred methods. Green synthesis procedures have several merits such as simple, inexpensive, good stability of nanoparticles, less time consumption, non-toxic byproducts and large-scale synthesis. The objective of thereview was to report on thesynthesis of Zinc oxide nanoparticles by using different plant extracts and their significance in different fields. In the plant-based synthesis several extracts (leaves, stem, bark, peel, flower, roots, fruit) were used to generate nanoparticles. Therefore it is concluded that plants and their extracts are important in thesynthesis of nanoparticles as eco-friendly approach.

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Table 1: Zinc oxide nanoparticles synthesized from different plant and plant part extracts and their significance

Plant	Plant part	Equipment used	Shape and size	Significance	Reference
Corriandrumsativum	Leaf extract	XRD, SEM, FTIR and EDAX	66 and 81 nm	Phyto constituents	Gnanasangeetha and Thambavani, 2013
Ocimumtenuiflorum	Leaf extract	XRD, SEM, and FTIR	Hexagonal and 11-25 nm	Characterization with various techniques	Raut*et al.*, 2013
CalotropisGigantea	Leaf extract	SEM and XRD	Spherical and 11-25 nm	Characterization with various techniques	Vidya*et al.*, 2013
Calotropisprocera	Leaf extract	FTIR and SEM	100-200nm	Antimicrobial activity	Poovizhi and Krishnaveni, 2015
Oleaeuropea	Leaf extract	UV-Vis Spectroscopy, FTIR, XRD, and SEM,	500 nm	Phyto constituents	Awwad *et al.*, 2014
Catharanthusroseus (I.) G.Don.	Leaf extract	XRD, SEM, EDAX and FT-Raman Spectroscopy	Spherical and 23 to 57 nm	Antibacterial activity	Bhumi and Savithramma, 2014
Adhatodavasica	Leaf extract	UV-Vis Spectroscopy, SEM, EDAX, XRD, and FT-Raman	Discoid and 19 - 60 nm	Antibacterial activity	Bhumi*et al.*, 2014

		Spectroscopy			
Hibiscus rosa –sinensis	Leaf extract	SEM and XRD	Spongy and 30-35 nm	Reducing and surface stabilizing agent	Devi and Gayathri, 2014
Hibiscus subdariffa	Leaf extract	UV-Vis Spectroscopy, FTIR, XRD, HRTEM, EDX, and FESEM	-	Anti-bacterial and anti-diabetic activity	Bala*et al.*, 2015
*Azadirachtaindica*and *Emblicaofficinalis*	Leaf extract	SEM, XRD, FTIR, and EDAX	100-200 nm	Phytochemical constituents	Gnanasangeetha and Thambavani, 2014
Cassia auriculata (Tanners cassia)	Leaf extract	SEM, UV- Vis Spectrophotometer and FTIR	Spherical	Characterization with various techniques	Ramesh *et al.*, 2014
Camellia sinensis	Leaf extract	XRD, FTIR and UV-Visible Spectrum	16 nm	Antimicrobial activity	Senthilkumar and Sivakumar, 2014
Camellia sinesis	Leaf extract	UV-Vis Spectroscopy, Particle size analyzer, and SEM	853 nm	Antimicrobial activity	Shah *et al.*, 2015
Brassica oleraceae	Leaf extract	UV-Visible Spectroscopy and SEM	Spherical and 1-100 nm	Antibacterial activity	Amrita *et al.*, 2015
Azadirachta indicia	Leaf extract	FTIR and SEM	Spindle and 50 μm	leaf extract acts as a promoter, stabilizer and template	Noorjahan*et al.*, 2015
Pyruspyrifolia	Leaf extract	UV- Vis Spectrophotometer, XRD, FTIR, AFM, FE-SEM, and EDX	Spherical and 45 nm	Photocatalytic activity	Parthiban and Sundaramurthy, 2015
*Pithecellobiumdulce*and*Lagenariasiceraria*	Leaves extract	FTIR, SEM, EDX, TEM, and XRD	Spherical and 4.3, 34.7 and 120 nm	Antimicrobial activity	Prakash and Kalyanasundharam, 2015
Thevetiaperuviana	Leaf extract	UV-Visible Spectroscopy, FTIR, Particle size analyzer, XRD, SEM, TEM and Inductively Coupled Plasma-Optical Emission Spectrophotometer	Triangular and 53 nm	soil exo-enzyme activity and growth of peanut plants	Sindhura*et al.*, 2015
Aloe vera	Leaf extract	XRD, SEM, UV-Vis Spectroscopy, PL, BET and TGA	Hexagonal and 22.18 nm	Photodegradation and antibacterial activity	Varghese and George, 2015
Corymbiacitriodora	Leaf extract	SEM, EDX, XRD, UV-VIS Spectroscopy, Raman Spectroscopy and TGA	Polyhedron and 20-120 nm	Photocatalytic activity	Zheng*et al.*, 2015
Euphorbia tirucalli	Stem (branches) extract	SEM and XRD	Spherical and 20 nm	Reducing and stabilizing agent	Hiremath*et al.*, 2013
Rutagraveolens (L.)	Stem	PXRD, UV-	Spherical	Antibacterial and	Lingaraju*et al.*,

	extract	Visible Spectroscopy, SEM, and TEM,	and 28 nm	antioxidant activity	2015
Tinosporacordifolia	Stem extract	SEM, EDX, and FTIR	Spherical and 37 nm	Characterization with various techniques	Raj and Jayalaksmy, 2015
Boswelliaovalifoliolata	Stem bark extract	UV-Visible Spectroscopy, FTIR, TEM, XRD, DLS and Zeta potential	20.3 nm	Antimicrobial activity	Suprajaet *al.*, 2015
Zingiberofficinale	Root exract	SEM, EDX, and FTIR	Spherical and 30-50 nm	Flavonoids	Raj and Jayalaksmy, 2015
Citrus aurantifolia	Fruit extract	FE-SEM, XRD and PL spectroscopy	Spherical and 50-200 nm	Sol-gel synthesis	Samat and Nor, 2012
Citrus aurantifolia	Fruit extract	SEM, UV-Spectrophotometer, and FTIR	Spherical and 9-10 nm	Phytochemical analysis	Ramesh *et al.*, 2014
Emblicaofficinalis	Fruit extract	-	-	Antimicrobial activity	Anbukkarasi*et al.*, 2015
Citrus paradise	Peel extract	UV-Visible Spectrophotometer, TEM, DLS and FTIR	Spherical and 12-72 nm	Photocatalytic and antioxidant activity	Kumar *et al.*, 2014
Punicagranatum	Peel extract	UV-Visible Spectroscopy and SEM	Spherical and square and 50-100 nm	Antimicrobial activity	Mishra and Sharma, 2015
Trifolium pretense	Flower extract	UV-Visible Spectroscopy, XRD, FTIR, SEM, and EDX	100–190 nm	Antibacterial activity	Dobrucka and Dugaszewska, 2015
Calotropisprocera	Latex	XRD, TEM, SEM and UV-Vis Spectroscopy	5 - 40 nm	Photoluminescence (PL) studies	Ravindra*et al.*, 2011
*Morindapubescens*J.E.Smith	Mature leaves, stem, stem bark, dried bark of stem, roots, flower petals, immature and ripened fruits	UV-Visible Spectrophotometer	-	Phytochemicals	Shekhawat and Manokari, 2014
Hybanthusenneaspermus (L.) F.Muell.	Leaf, stem and root extract	UV-Visible Spectroscopy	-	Aphrodisiac activities	Shekhawat*et al.*, 2014
Hemidesmusindicus (L.) R.Br.	Leaf, stem and root	UV-Visible Spectrophotometer	-	Primary and secondary metabolites	Manokari and Shekhawat, 2015
Ficusbenghalensis L.	Leaf, stem, root, aerial	UV-Visible Spectroscopy	-	Aphrodisiac Properties	Shekhawat*et al.*, 2015

	root, fruits and fresh and dried bark extract				
Lawsoniainermis L.	Leaf, stem and root aqueous extract	UV-Visible Spectrophotometer	-	Medical and cosmetic purpose	Shekhawat*et al.*, 2015
Micrococcamercurialis (L.) Benth.	Leaf, stems, roots and fruit extract	UV-Visible Spectrophotometer	-	Primary and secondary metabolites	Manokari*et al.*, 2016
Couroupitaguianensis Aubl	leaves, stem, flower petals and bark	UV-Visible Spectrophotometer	-	Phytochemicals	Manokari and Shekhawat, 2016
Meliaazedarach L.	Leaf, stems, roots, flowers and fruits	UV- Vis Spectrophotometer	-	Primary and secondary metabolites	Manokari *et al.*, 2016
Durantaerecta L.	Leaf, stem, root, flower and fruits	UV-Visible Spectroscopy	-	Biomolecules, bioreducing agents and phytomolecules	Ravindran*et al.*, 2016