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 the synthesis of nanoparticles for the bioapplication. Metal oxides such as ZnO have received increasing attention as 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 beings and 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, 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 the synthesis 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 (Sivakumaret 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 (Garimaset 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 (Geoprinreset 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 (Helanet 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. (Mohanpuriaet al., 2008 and Bhattacharyya 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 Nishioka, 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

Coriandrum sativum leaf was used for the synthesis and characterization of ZnO nanoparticles prepared by green and chemical technique. 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 the chemical 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 Ocimum tenuiflorum. Prepared ZnO nanoparticles were characterized by XRD, SEM and FTIR. The SEM image showed hexagonal shape and nanoparticle with diameterrange of 11-25 nm (Rautel et al., 2013).

Calotropis gigantea 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), whereas the 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 Calotropis gigantea plant were used in traditional Indian medicine for the treatment of painful muscular spasm, dysentery, fever, rheumatism, asthma and as an expectorant and purgative (Ravinra et al., 2011).

The synthesis of Zinc oxide nanoparticles was reported with the leaf extract of Olea europea. 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 Olea Europea 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 Catharanthus Roseus were known 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 Catharanthus Roseus. 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 aeruginosa. The highest antimicrobial activity was observed against Pseudomonas aeruginosa 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 Zn²⁺ 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 aeruginosa* and *Staphylococcus aureus*. *Adhatodavasicais* a good source for rapid reduction of metallic Zinc oxide into nanoparticles with antibacterial activity. *Adhatodavasicahas* been used as the reducing material as well as asurface stabilizing agent for the synthesis of ZnONPs (Bhumi et al., 2014a).

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\text{Zn (CH}_3\text{COO}_2\text{)}2\text{H}_2\text{O} + 2\text{NaOH} \rightarrow \text{Zn(OH)}_2 + 2\text{CH}_3\text{COONa} + 2\text{H}_2\text{O}
\]

\[
\text{Zn(OH)}_2 + \text{Biomolecules of metabolites} \rightarrow \text{ZnO} + \text{H}_2\text{O}
\]

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, 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-sized ZnO NPs, stabilized by plant metabolites had better anti-diabetic effect on streptozotocin (STZ) induced diabetic mice than that of large-sized ZnO 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 *Azadirachta indica* and *Emblica officinalis*. 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 *Azadirachta indica* and *Emblica officinalis* 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 Zinc oxide nanoparticles were confirmed by SEM, 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) whereas Shah et al., reported on green tea and synthesized Zn nanoparticles were characterized by UV-Vis Spectroscopy, Particle size analyzer, and SEM. Particle 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 oleracea* 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 oleracea* had possessed aphrodisiac activities, and it had as significant 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 the synthesis 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 *Pyrus pyrifoliwas* used for the synthesis 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 the biological method used *Pithecellobium dulce* and *Lagenaria siceraria* leaf extracts and in the chemical method using sodium hydroxide as reducing agents. In traditional medicine, the leaves of *P. dulce* was used for the treatment of fever, leprosy, peptic ulcer, toothache, venereal diseases and also showed emollient, anodyne, larvicidal (Sugumar et al., 2008) and abortifacient, and antidiabetic properties in folk medicine. Various parts of plant were used for different purposes like leaf as astringent, seed oil as spermicidal, anti-inflammatory, anti-oedema, fruit and seed as edible, bark for tannin (Mohammed et al., 2004), *Lagenaria siceraria*, which had diuretic and anti-swelling effects, was used as food (Wang and Ng, 2000). A decoction of *Lagenaria siceraria* 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 *Thevetia peruviana*. 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 (Kareruet 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 *Arachis hypogaea* 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 (Sindharuet 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 hexagonal shape with an average size of 22.18 nm. Photodegradation and antibacterial activity of the nanoparticles were studied. The antibacterial activities of synthesized nanoparticles showed sensitivity to both Gram positive and Gram negative bacteria (Varghese and George, 2015).

*Corymbiacidritiodora* 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 an average size of 64 nm. The photocatalytic activity of biosynthesized ZnO NPs has been 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 (Zhenget 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 ZNO nanoparticles (Hiremath et al., 2013).

The stem extract of *Rutagraweolens* 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 *Rutagraweolens* 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 bacterialidal activity against Gram –ve bacterial strains such as *Klebsiella aerogenes*, *Pseudomonas aeruginosa*, *Escherichia coli* and Gram +ve *Staphylococcus aureus* (Lingaraju 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 Javalaksmy, 2015). *Tinosporacordifolia*
was rich in bioactive components such as alkaloids, phenolics, steroids such as tiosiprine, tinosporide, columbine, etc., that were responsible for its medicinal activities (Pandey et al., 2012 and Shanthi and Nelson, 2013).

*Boswellia* *a* *v* *a* *l* *i* *f* *i* *o* *l* *i* *o* *l* *a* *t* *a* 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* ZnNPs were 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 (Supraja et al., 2015).

The root extract of *Zingiber officinalis* was used in the synthesis of Zinc oxidonanoparticles. 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, terpineol, 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 oxidonanoparticles 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 extract 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 *Emblica* *O* *f* *f* *i* *c* *i* *n* *a* *l* *i* *s* 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, *Aspergillus* *n* *i* *g* *e* *r* *a* and *candida albicans*. The results concluded that the green synthesized Zinc oxide nanoparticles from *E. officinalis* might serve as an effective antibacterial agent in traditional medicine (Anbukkarasiet al., 2015).

The biosynthesis of Zinc 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 ZnO nanoparticles 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 *Punica granatum*. The synthesized Zinc oxide nanoparticles were characterized by using UV-Visible Spectroscopy and SEM. The particles were spherical and square in shape with the diameters ranging from 50-100 nm (Mishra and Sharma, 2015).

The flower extract of *Trifolium pratense* 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 *Calotropis procera*. 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 Morindapubescent. Zinc oxide nanoparticles were characterized using the UV-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 spectrophotometric 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 the formation 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 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.) Bentham 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 Couroupitgualanensis Aubl. were reported. UV-Visible spectral studies were conducted for the characterization and confirmation of synthesized ZnO nanoparticles and the absorbance peaks 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. (Biset et al., 2009 and Pradhan et al., 2009).

Plant aqueous extracts + Zinc nitrate 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).

Durantaarctica gained horticultural and medicinal importance due to its various biological activities (Ravindranet al., 2016). This plant also exhibits antioxidant, antibacterial and antimicrobial activities against human pathogens (Bangouet al., 2012and Prabhakaret al., 2015). The biosynthesis of Zinc oxide nanoparticles using aqueous extracts of leaves, stem, root, flowers and fruit extract of DurantaarcticaL. 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 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 (Ravindranet al., 2016).

CONCLUSIONS

The synthesis of nanoparticles 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 consumption, non-toxic by-products and large-scale synthesis. The objective of thereview was to report on the synthesis 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 the synthesis of nanoparticles as eco-friendly approach.

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REFERENCES

1. Amrta, R., Reena, S. L., Mohammad, J. and Kapil, L., 2015, Antibacterial activity of Zinc oxide nanoparticles prepared from Brassica oleracea leaves extract. Int. J. Adv. Res., 3(11): 322-328.
2. Anandh, B., Muthuvel, A. and Emayavaramban, M., 2014, Bio synthesis and characterization of silver nanoparticles using Lagerariasisceraria leaf extract and their antibacterial activity. Int. Lett. Chem. Phys. Astron., 19(1): 35-45.
3. Anbukkarasi, V., Srinivasan, R. and Elangovan, N., 2015, Antimicrobial activity of green synthesized Zinc oxide nanoparticles from Emblicaofficinalis. Int. J. Pharm. Sci. Rev. Res., 33(2): 110-115.
4. Arumugam, N., Sasikumar, K., Malipeddi, H.andSekar, M., 2011, Antifungal activity of Hybanthusneespermuon wet clothes. Int. J. Res. Ayurveda. Pharm., 2(4): 1184–1185.
5. Auld, D. S., 2001, Zinc coordination sphere in biochemical Zinc sites. Biometals., 14(3): 271-313.
6. Awwad, A. M., Albiss, B. and Ahmad, A. L., 2014, Green synthesis, characterization and optical properties of Zinc oxide nanosheets using Olea europaea leaf extract. Adv. Mat. Lett.,5(9): 520-524.
7. Bala, N., Saha, S., Chakraborty, M. Maiti, M., Das, S., Basu, R. and Nandy, P., 2015, Green synthesis of Zinc oxide nanoparticles using Hibiscus sabdariffa leaf extract: effect of temperature on synthesis, anti-bacterial activity and anti-diabetic activity. RSC Adv., 5(7): 4993–5003.
8. Bangou, M. J., Meda, N. T. R., Thiombiano, A. M. E., Kiendrebeogo, M. and Zeba, B., 2012, Curr. Res. J. Biol. Sci., 4(6): 665-672.
9. Bhattacharya, R. and Mukherjee, P., 2008, Biological properties of naked nanoparticles. Adv.Drug Deliv. Rev., 60(11): 1289–1306.
10. Bhumi, G., Raju, Y.R. and Savithramma, N., 2014a, Screening of Zinc oxide nanoparticles for cell prolifertain synthesized through Adhatodavascicanees. Int. J. Drug Dev. Res., 6 (2): 97-104.
11. Bhumi, G. and Savithramma, N., 2014b, Biological Synthesis of Zinc oxide Nanoparticles from Catharanthusserosus( I.) G.Don. Leaf extract and validation for antibacterial activity. Int. J. Drug Dev. Res., 6 (1): 208-214.
12. Biset, J. S., Cruz, J. C., Mirbel, A., Rivera, E. and Canigueral, S., 2009. J. Ethnopharmacology., 122: 333-362.
13. Boominathan, R., Parimaladevi, B., Mandal, S. C. and Ghoshal, S. K., 2004, Anti-inflammattory evaluation of IonidiumsulfurificumGing. in rats. J. Ethnopharmacol., 91: 367–370.
14. Broadley, M. R., White, P.J., Hammond, J. P., Zelko, I. and Lux, A., 2007, Zinc in plants. New Phytol., 173(4): 677-702.
15. Devi, R. S. and Gayathri, R., 2014, Green synthesis of Zinc oxide nanoparticles by using Hibiscus rosa–sinensis. Int. J. Curr. Eng. Technol., 4(4): 2444-2446.

16. Dobrucka, R. and Dugaszewska, J., 2015, Biosynthesis and antibacterial activity of ZnO nanoparticles using Trifolium pratense flower extract. Saudi. J. Biol. Sci., 1-7.

17. Fageria, N. K., Baligar, V. C. and Clark, R. B., 2002, Micronutrients in crop production. Adv. Agron., 77: 189-272.

18. Garima, S., Bhavesh, R., Kasariya, K. R., Sharma, A. R. and Singh, R. P., 2011, Biosynthesis of Silver nanoparticles using Ocimum sanctum (Tulasi) leaf extract and screening its antimicrobial activity. J. Nanoparticle. Res., 13(7): 2981–2988.

19. Geoprinicy, G., Vidyha, S. B. N., Poonguzhalii, U., Nagendra, G. N. and Renganathan, S., 2012, A Review on green synthesis of Silver nanoparticles. Asian. J. Pharm. Clin. Res., (6): 1: 8-12.

20. Ghosh, A. K., Banerjee, S., Mullick, H. I. and Banerjee, J., 2011, Zingiber officinale: A Natural Gold. Int. J. Bioeng. Sci., 2: 283-294.

21. Gnanasangeetha, D. and Thambavani, S. D., 2013, One pot synthesis of Zinc oxide nanoparticles via chemical and green method. Res. J. Mater. Sci., 1(7): 1-8.

22. Gnanasangeetha, D. and Thambavani, S. D., 2014, Facile and eco-friendly method for the synthesis of Zinc oxide nanoparticles using Azadirachta indica and Emblica. Int. J. Pharm. Sci. Res., 5(7): 2866-2873.

23. Helan, J. C., Anand, R. L. F. A., Namiasiavayam, S. K. R. and Bharani, R. S. A., 2013, Improved pesticidal activity of fungal metabolite from Nomureaerileyi with chitosan nanoparticles, ICANMEET, IEEE: 387-390.

24. Hiremath, S., Vidya, C., Antonyraj, M. A. L., Chandraprabha, M. N., Gandhi, P., Jain, A. and Anand, K., 2013, Biosynthesis of ZnOnano particles assisted by Euphorbia tirucalli (Pencil Cactus). Int. J. Curr. Eng. Technol., (1): 176-179.

25. Horie, M. and Nishiok, F. K., 2009, Protein adsorption of ultra fine metal oxide and its influence on cytotoxicity toward cellular culture. Chem. Res.Toxicol., 22(3): 543-53.

26. Jain, R., Srivastava, S., Solomon, S., Shrivastava, A.K. and Chandra, A., 2010, Impact of excess Zinc on growth parameters, cell division, nutrient accumulation, photosynthetic pigments and oxidative stress of sugarcane (Saccharumppp.). ActaPhysiol Plant., 32(5): 979-986.

27. Jaleel, C. A., Gopi, R. and Paneerselvam, R., 2009, Alterations in non-enzymatic antioxidant components of Catharanthus roseusexposed to paclobutrazol, gibberellic acid and Pseudomonas fluorescens. Plant. Omics. J., 2(1): 30-40.

28. Jamali, G., Enteshari, S. H. and Hosseini, S. M., 2011, Study effect adjustment drought stress apperwering and Seed Productivity in Onion. Int. J. Curr. Microbiol. App. Sci., 3(7): 874-881.

29. Jayapaul, J., Hodenius, M. and Arms, S., 2011, FMN-coated fluorescent iron oxide nanoparticles for RCP-mediated targetting and labeling of metabolically active cancer and endothelial cells. Biomaterials., 32(25): 5863–5871.

30. Jeyachandran, R. and Bastin, M., 2013, An efficient protocol for in vitro flowering and fruiting in Micrococcamercruisulci (L.) Benth. Int. J. Nat. Appl. Sci., 2(1): 18-22.

31. Karem, P. G., Keriko, J. M., Kenji, G. M. and Gachanja, A. N., 2010, Anti-Micrococcamercurialis (L.) Benth. Oil extract. Afr. J. Pharm. Pharmacol., 4(2): 087-089.

32. Kumar, B., Smita, K., Cumbal, L. and Debut, A., 2014, Green approach for fabrication and applications of Zinc oxide nanoparticles. Bioinorg. Chem. Appl., 1-7.

33. Lingaraju, K., Naika, H. R., Manjunath, K., Basavaraj, R. B., Nagabhushana, H., Nagaraju, G. and Suresh, D., 2015, Biogenic synthesis of Zinc oxide nanoparticles using Rutagraweolens (L) and their antibacterial and antioxidant activities. Appl. Nanosci., 6(5): 703-710.

34. Manokari, M. and Shekhawat, M. S., 2015, Biogenesis of Zinc oxide nanoparticles using aqueous extracts of Hemidesmusindiculus (L) R.Br. Int. J. Res. Stud. Microbiol, Biotechnol., 1(1): 20-24.

35. Manokari, M. and Shekhawat, M. S., 2016b, Biogenesis of Zinc oxide nanoparticles using Couroupitaguanensisaulubl. extracts - a green approach. World. Sci. News., 29: 135-145.

36. Manokari, M., Ravindra, C. P. and Shekhawat, M. S., 2016a, Biosynthesis of Zinc oxide nanoparticles using Meliaazedarach L. extracts and their characterization. Int. J. Pharm. Sci. Res., 1(1): 31-36.

37. Manokari, M., Ravindra, C. P. and Shekhawat, M. S., 2016b, Production of Zinc oxide nanoparticles using aqueous extracts of a medicinal plant Micrococcamercruisulci (L) Benth. World. Sci. News., 30: 117-128.

38. Misra, V. and Sharma, R., 2015, Green synthesis of Zinc oxide nanoparticles using fresh peels extract of Punicagranatum and its antimicrobial activities. Int. J. Pharm. Res. Health. Sci., 3(3): 694-699.

39. Mohammed, S., Kasera, P. K. and Shukla, J. K., 2004, Exported plants of potential medicinal value from the Indian Thar desert. Nat. Prod. Radiance., 3: 69-74.
40. Mohanpuria, P., Rana, N. K., Yadav, S.K., 2008, Biosynthesis of nanoparticles: technological concepts and future applications. J. Nanoparticle. Res., 10(3): 507-517.
41. Noorjahan, C. M., Shahina, S. K. J., Deepika, T. and Rafiq, S., 2015, Green synthesis and characterization of Zinc oxide nanoparticles from Neem (Azadirachta indica). Int. J. Sci. Eng. Technol. Res., 4(30): 5751-5753.
42. Pandey, M., Surendra, K., Chikara, Manoj, K. V., Rohit, S. and Thakur, S. G., 2012, Tinospora cordifolia: A climbing shrub in health care management. Int. J. Pharm. Biol. Sci. 3: 612–28.
43. Parthiban, C. and Sundaramurthy, N., 2015, Biosynthesis, characterization of ZnO nanoparticles by using Pyrus malus leaf extract and their photocatalytic activity. Int. J. Innov. Res. Sci. Eng. Technol., 4(10): 9710-9718.
44. Patel, D. K., Kumar, R., Prasad, S. K., Sairam, K. and Hemalatha, S., 2011, Antidiabetic and in vitro antioxidant potential of Hybanthus enneaspermus (Linn.) Muell in streptozotocin-induced diabetic rats. Asian. Pac. J. Trop. Biomed., 1(4): 316–322.
45. Poovizhi, J. and Krishnaveni, B., 2015, Synthesis, characterization and antimicrobial activity of Zinc oxide nanoparticles synthesized from Calotropis procera. Int. J. Pharm. Sci. Drug. Res., 7(5): 425-431.
46. Prabhakar, G., Kamalakar, P., Ashok, V. T. and Shailaja, K., 2015, Eur. J. Pharm. Med. Res., 2: 411-419.
47. Pradhan, D., Panda, P. K. and Tripathy, G., 2009, National Product Radiance., 8: 37-42.
48. Prakash, M. J. and Kalyanasundharam, S., 2015, Biosynthesis and characterisation of Zinc oxide nanoparticles produced by Cassia auriculata. J. NanoSci. NanoTechnol., 1(1): 41-45.
49. Ramesh, P., Rajendran, A. and Meenakshisundaram, M., 2014a, Green synthesis of Zinc oxide nanoparticles using flower extract Cassia auriculata. J. NanoSci. NanoTechnol., 1(1): 41-45.
50. Ramesh, P., Rajendran, A. and Subramanian, A., 2014b, Synthesis of Zinc oxide nanoparticle from fruit of Citrus aurantiifolia by chemical and green method. Asian. J. Phytomedicine. Clin. Res., 2(4): 189 - 195.
51. Rasmussen, J. W., Martinez, E., Louka, P. and Wingett, D. G., 2010, Zinc oxide nanoparticles for selective destruction of tumour cells and potential for Drug delivery applications. Pubmed., 7(9): 1063-1077.
52. Raut, S., Thorat, P. V. and Thakre, R., 2013, Green synthesis of Zinc oxide (ZnO) nanoparticles using Ocimumtenuiflorum leaves. Int. J. Sci. Res., 4(5): 1225-1228.
53. Sahoo, S., Kar, D. M., Mohapatra, S., Rout, S. P. and Dash, S. K., 2006, Antibacterial activity of Hybanthus enneaspermus against selected urinary tract pathogens. Indian. J. Pharm. Sci. 68(5): 653–655.
54. Samat, N. A. and Nor, R. M., 2012, Sol-gel synthesis of Zinc oxide nanoparticles using Citrus aurantiifolia extracts. Ceram. Int., 39: 545-548.
55. Sangeetha, G., Rajeshwari, S. and Venkatesh, R., 2011, Green synthesis of Zinc oxide nanoparticles by Aloe barbadensis miller leaf extract: Structure and optical properties. Mater. Res. Bull., 46: 2560–2566.
56. Satheesh, S. K. and Kottai, M. A., 2012, Comparative evaluation of flavone from Mucuna pruriens and coumarin from Iondiumsaurfruticosum for hypolipidemic activity in rats fed with high Fat diet. Lipids. Health. Dis. 11: 126.
57. Senthilkumar, S. R. and Sivakumar, T., 2014, Green Tea (Camellia Sinensis) Mediated synthesis of Zinc oxide (ZnO) nanoparticles and studies on their antimicrobial activities. Int. J. Pharm. Pharm. Sci., 6(6): 461-465.
58. Shah, R. K., Boruah, F. and Parween, N., 2015, Synthesis and characterization of ZnO nanoparticles using leaf extract of Camellia sinensis and evaluation of their antimicrobial efficacy. Int. J. Curr. Microbiol. App. Sci., 4(8): 444-450.
59. Shanthi, V. and Nelson, R., 2013, Anitbacterial activity of Tinospora cordifolia (Wild) Hook. F. Thomson urinary tract pathogens. Int. J. Curr. Microbiol. App. Sci., 2: 190-4.
60. Shekhawat, M. S. and Manokari, M., 2014a, Biogenesis of Zinc oxide nanoparticles using Morindapubescens I.E. Smith extracts and their characterization. Int. J. BioEng. Technol., 5(1): 1-6.
66. Shekhawat, M. S., Ravindran, C. P. and Manokari, M., 2014b, A biomimetic approach towards synthesis of Zinc oxide nanoparticles using *Hybanthusenemuspermus (L.) F.Muell.* Trop. Plant. Res., 1(2): 55-59.

67. Shekhawat, M. S., Ravindran, C. P. and Manokari, M., 2015a, A green approach to synthesize the Zinc oxide nanoparticles using aqueous extracts of *Ficusbenghalensis L.* Int. J. BioSci. Agr. Technol., 6(1): 1-5.

68. Shekhawat, M. S., Ravindran, C. P. and Manokari, M., 2015b, An ecofriendly method for the synthesis of Zinc oxide nanoparticles using *Lawsoniainermis L.* aqueous extracts. Int. J. Innov., 5(1): 1-4.

69. Sindhura, K. S., Prasad, T. N. V. K. V., Selvam, P. and Hussain, O. M., 2015, Biogenic synthesis of Zinc nanoparticles from *Thevetiapervuviana* and influence on soil exo-enzyme activity and growth of peanut plants. Int. J. Appl. Pure Sci. Agr., 1(2): 19-32.

70. Singh, K., Agrawal, K. K., Mishra, V., Uddin, S. M. and Shukla, A., 2012, A review on *Thevetiapervuviana*. Int. Res. J. Pharm., 3(4): 74-77.

71. Sivakumar, J., Premkumar, C., Santhanam, P. and Saraswathi, N., 2011, Biosynthesis of Silver nanoparticles using *Calotropis gigantea* leaf. Afr. J. Basic. Appl. Sci., 3(6): 265-270.

72. Sugumaran, M., Vetrichelvan, T. and Quine, S. D., 2008, Locomotor activity of leaf extracts of *Pithecellobium dulce* Benth. Ethanolot. Leaflet., 12: 490-493.

73. Supraja, N., Prasad, T. N. V. K. V., Krishna, T. G. and David, E., 2015, Characterization and evaluation of the antimicrobial efficacy of *Boswelliaovalifoliolata* stem bark-extract-mediated Zinc oxide nanoparticles. *ApplNanosci.*, 6(4): 581-590.

74. Varghese, E. and George, M., 2015, Green synthesis of Zinc oxide nanoparticles. *Int. J. Adv. Res. Sci. Eng.*, 4(1): 307-314.

75. Vidya, C., Hiremath, S., Chandraprabha, M. N., Antonyraj, L.M.A., Gopal, I.V., Jain, A. and Bansal, K., 2013, Green synthesis of ZnO nanoparticles by *Calotropisgigantea* Int. J. Curr. Eng. Technol., 1: 118-120.

76. Wang, H. X. and Ng, T. B., 2000, *Lagenin*, a noble ribosome-inactivating protein with ribonucleolytic activity from bottle gourd *Lagenariasiceraria* seeds. *Life Sci.*, 67(21): 2631-2638.

77. Zheng, Y., Fu, L., Han, F., Wang, A., Wen, C., Jinping, Y., Yang, J. and Peng, F., 2015, Green biosynthesis and characterization of Zinc oxide nanoparticles using *Corymbiacitriodora* leaf extract and their photocatalytic activity. *Green. Chem. Lett. Rev.*, 8(2): 59–63.

**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 |
|-------|------------|----------------|----------------|--------------|-----------|
| *Corriandrum sativum* | Leaf extract | XRD, SEM, FTIR and EDAX | 66 and 81 nm | Phyto constituents | Ganasangheetha and Thambuvani, 2013 |
| *Ocimum tenuiflorum* | Leaf extract | XRD, SEM, and FTIR | Hexagonal and 11-25 nm | Characterization with various techniques | Rautet et al., 2013 |
| *Calotropis Gigantea* | Leaf extract | SEM and XRD | Spherical and 11-25 nm | Characterization with various techniques | Vidya et al., 2013 |
| *Calotropis procera* | Leaf extract | FTIR and SEM | 100-200nm | Antimicrobial activity | Poovizhi and Krishnaveni, 2015 |
| *Olea europaea* | Leaf extract | UV-Vis Spectroscopy, FTIR, XRD, and SEM | 500 nm | Phyto constituents | Awwad et al., 2014 |
| *Catharanthus roseus* (L.) G.Don. | Leaf extract | XRD, SEM, EDAX and FT-Raman Spectroscopy | Spherical and 23 to 57 nm | Antibacterial activity | Bhuminet al., 2014 |
| *Adhatoda vasica* | Leaf extract | UV-Vis Spectroscopy, SEM, EDAX, XRD, and FT-Raman | Discoid and 19 - 60 nm | Antibacterial activity | Bhuminet al., 2014 |
| Species                        | Methodology                                                                 | Characterization      | Activity/Effect                                                                 | Reference                                      |
|-------------------------------|-----------------------------------------------------------------------------|-----------------------|---------------------------------------------------------------------------------|-----------------------------------------------|
| *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                                        | Balaat 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 sinensis*           | 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 indica*          | Leaf extract, FTIR and SEM                                                | Spindle and 50 μm     | leaf extract acts as a promoter, stabilizer and template                        | Noorjahanat et al., 2015                     |
| *Pyrus pyrifolia*             | Leaf extract, UV-Vis Spectrophotometer, XRD, FTIR, AFM, FE-SEM, and EDX   | Spherical and 45 nm   | Photocatalytic activity                                                          | Parthiban and Sundaramurthy, 2015            |
| *Pithecellobium dulce* and *Lagenaria sicera* | Leaves extract, FTIR, SEM, EDX, TEM, and XRD                             | Spherical and 4.3, 34.7, and 120 nm | Antimicrobial activity                                                          | Prakash and Kalyanasundharam, 2015           |
| *Thevetiaperviana*            | 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                            | Sindhuraet al., 2015                         |
| *Aloe vera*                   | Leaf extract, XRD, 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                                                          | Zhenget al., 2015                            |
| *Euphorbia tirucalli*         | Stem (branches) extract, SEM and XRD                                      | Spherical and 20 nm   | Reducing and stabilizing agent                                                   | Hiremathet et al., 2013                      |
| *Rutagraveolens (L.)*         | Stem, PXRD, UV-                                                           | Spherical             | Antibacterial and                                                              | Lingarajuuet al.,                            |

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| Plant Name                                      | Extract Type       | Techniques                              | Shape/Size and Characteristics                      | Year | Description                                      |
|------------------------------------------------|--------------------|-----------------------------------------|----------------------------------------------------|------|--------------------------------------------------|
| Tinospora cordifolia                           | Stem extract       | SEM, EDX, and FTIR                      | Spherical and 37 nm                                | 2015 | Characterization with various techniques         |
| Boxwellia ovalifoliolata                       | Stem bark extract  | UV-Visible Spectroscopy, FTIR, TEM, XRD, DLS and Zeta potential | 20.3 nm | Antimicrobial activity                           | Supraja et al., 2015 |
| Zingiber officinale                            | Root extract       | SEM, EDX, and FTIR                      | Spherical and 30-50 nm                              | 2015 | Flavonoids                                       | Raj and Jayalaksmy, 2015 |
| Citrus aurantifolia                            | Fruit extract      | FE-SEM, XRD and PL spectroscopy         | Spherical and 50-200 nm                             | 2015 | Sol-gel synthesis                               | Samat and Nor, 2012 |
| Citrus aurantifolia                            | Fruit extract      | SEM, UV-Spectrophotometer, and FTIR     | Spherical and 9-10 nm                               | 2015 | Phytochemical analysis                          | Ramesh et al., 2014 |
| Emblica officinalis                            | Fruit extract      | -                                       | -                                                  | 2015 | Antimicrobial activity                          | Anbukkarasiet et al., 2015 |
| Citrus paradise                                | Peel extract       | UV-Visible Spectrophotometer, TEM, DLS and FTIR | Spherical and 12-72 nm                             | 2014 | Photocatalytic and antioxidant activity         | Kumar et al., 2015 |
| Punicagranatum                                 | Peel extract       | UV-Visible Spectroscopy and SEM          | Spherical and square and 50-100 nm                 | 2015 | Antimicrobial activity                          | Mishra and Sharma, 2015 |
| Trifolium pretense                             | Flower extract     | UV-Visible Spectroscopy, XRD, FTIR, SEM, and EDX | 100-190 nm | Antibacterial activity                          | Dobrcka and Dugaszewska, 2015 |
| Calotropis procera                             | Latex              | XRD, TEM, SEM and UV-Vis Spectroscopy   | 5 - 40 nm | Photoluminescence (PL) studies                  | Ravindra et al., 2011 |
| Morinda pubescens 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 |
| Hybanthusus elegans (L.) F.Muell.              | Leaf, stem and root extract | UV-Visible Spectroscopy | - | Aphrodisiac activities                          | Shekhawat et al., 2014 |
| Hemidesmus indicus (L.) R.Br.                  | Leaf, stem and root | UV-Visible Spectroscopy | - | Primary and secondary metabolites               | Manokari and Shekhawat, 2015 |
| Ficus benghalensis L.                          | Leaf, stem, root, aerial | UV-Visible Spectroscopy | - | Aphrodisiac Properties                          | Shekhawat et al., 2015 |
| Plant                        | Part Used                          | Extraction Method                  | Analytical Method | Application                                      | Reference                  |
|-----------------------------|------------------------------------|------------------------------------|-------------------|-------------------------------------------------|----------------------------|
| *Lawsonia inermis* L.       | Leaf, stem, roots, fruits and bark | UV-Visible Spectrophotometer        | -                 | Medical and cosmetic purpose                     | Shekhawat *et al.*, 2015   |
| *Micrococcusmercurialis* (L.) Benth. | Leaf, stems, roots and fruit extract | UV-Visible Spectrophotometer        | -                 | Primary and secondary metabolites               | Manokari *et al.*, 2016    |
| *Couroupitaguianensis* Aubl | Leaves, stem, flowers and bark     | UV-Visible Spectrophotometer        | -                 | Phytochemicals                                   | Manokari and Shekhawat, 2016 |
| *Melia azedarach* L.        | Leaf, stems, roots, flowers and fruits | UV-Vis Spectrophotometer            | -                 | Primary and secondary metabolites               | Manokari *et al.*, 2016    |
| *Duranta erecta* L.         | Leaf, stem, root, flower and fruits | UV-Visible Spectroscopy             | -                 | Biomolecules, bioreducing agents and phytomolecules | Ravindranet *et al.*, 2016 |