Review on synthesis and applications of zinc oxide nanoparticles

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Abstract:

Background:

Boom in nanotechnology in current era has sketched unforeseen transformations in number of fields, such as medicine, health care, food, space, agriculture, etc. The synthesis of nanoparticles with different chemical compositions, sizes, shapes and controlled disparities is an important area of research in this field.

Over the last decade, the biosynthesis of metal nanoparticles has received considerable attention due to their unusual and fascinating properties, with various applications, over their bulk count erparts.

Hypothesis:

The nanoparticle can have huge application in the field of food, pharmaceutical, and cosmetic industries and thus become a major area of research. Green synthesis of zinc oxide nanoparticles (ZnO NPs) using plant extracts offers an eco-friendly and promising substitute to the conventional methods of chemical synthesis.

Conclusion:

In the arena of nanoparticle phytosynthesis, novel materials have been produced that are eco-friendly, cost-effective and stable. In the current situation, nanotechnology inspires progress in all spheres of life, and therefore the phytosynthetic path of nanoparticle synthesis has emerged as a safe and best alternative to conventional methods. This review summarizes the recent work in the field of zinc nanoparticle phytosynthesis and critically discusses the mechanism proposed behind it.

Keywords:

Zinc nanoparticles, Plant extract, Green Synthesis, Characterization, Mechanism, Applications.

Abbreviations:

XRD: X-Ray Diffraction

SEM: Scanning Electron Microscopy

FTIR: Fourier Transform Infrared

DLS: Dynamic Light Scattering

UV-Vis: Ultraviolet-Visible Spectrophotometer

TEM: Transmission Electron Microscopy

INTRODUCTION:

Nanoparticle are defined as the particles having 1-100nm of size range. Nanotechnology is one of the most common and important developments in the twenty first century, and one of the fastest growing fields of science and technology is making remarkable progress (Zhang et al., 2013). Nanoparticles are found to possess specific characteristics like size, distribution, and morphology. The physicochemical properties of nanoparticles are substantially better and help to build many new structures, processes, nanoplatforms or devices with potential applications(Mirzaei and Darroudi, 2017). In fields such as biomedical effects, electrochemistry, catalysis, sensors, biomedicine, pharmaceutics, healthcare, cosmetics, food technology, textile industry, mechanics, optics, electronics, space industry, energy science and optical devices, metal oxide nanoparticles display a very strong and widely applicable impact (Hashmi et al., 2017; Jiang et al., 2018).
Zinc is found to be an important element in humans, where various enzymes such as carbonic anhydrase, carboxy peptidase and alcohol dehydrogenase are inactive in the human system in the absence of zinc. Our body holds about 2-3 g of Zinc and has a daily need of about 10-15 mg. It is readily absorbed by the body from zinc oxide nanoparticles due to its smaller particle size, therefore it is used as a food additive. Indeed, Zinc has been found to regulates various physiological functions (Siddiqi et al., 2018).

Zinc oxide is an inorganic material that is rarely found in nature. Zinc oxide has a large ~3.37eV band gap and a high 60meV binding energy, so it exhibits semiconductor and piezoelectric properties. Zinc oxide is used potentially and in clinical purposes it is more competent for biosynthesis of nanoparticles than that of other metals(Khatami et al., 2018; Naseer et al., 2020).

In sunscreens and cosmetics, nanoparticles of zinc oxide are widely used additives that help to block UV radiation. Heiligtag et al stated that the smaller size of nanoparticles provides the skin with greater protection against UV damage. Zinc oxide has been approved by the U S Food and Drug Administration (FDA) as a 'GRAS' (generally recognised as safe) compound (Mohd Yusof et al., 2019; Shamhari et al., 2018).

Zinc oxide nanoparticles demonstrate impressive antibacterial activity across a large variety of bacterial organisms, with varying morphologies. These nanoparticles show antibacterial activity in a broad variety of gram-positive and gram-negative bacteria as well as in foodborne pathogens such as *Escherichia coli O157:H7, Salmonella, Listeria monocytogenes, Staphylococcus aureus*, etc (Sirelkhatim et al., 2015; Xie et al., 2011). Zinc oxide nanoparticles shows different bactericidal mechanism by linking with bacterial surface and bacterial core. The mechanism can be determined based on pH, temperature, area, substrate concentration stability through which associate substrate absorption in the composite surface is observed (Azizi-Lalabadi et al., 2019; Beegam et al., 2016). Zinc oxide nanoparticles fascinate greater interest towards itself due to its remarkable properties like nontoxicity, biosafety, high electron transfer rates, excellent biological compatibility, ease for fabrication, enhanced analytical performance with increased sensitivity and low cost of production (Hatamie et al., 2015).

METHOD OF SYNTHESIS:

The synthesis of zinc oxide nanoparticles was done by many synthetic methods. They are mainly divided into three types, they are

- Chemical synthesis.
- Physical synthesis.
- Biological synthesis.

2.1. Chemical synthesis:

Chemical synthesis is the method where one or more chemical reactions are carried out, here the initial materials or reactant is converted into a product. Chemical synthesis is divided into Gas phase and Liquid phase, where gas phase is sub divided into pyrolysis and gas condensation method; and liquid phase is sub divided into precipitation/co-precipitation method, colloidal method, sol-gel method, oil microemulsion method, hydrothermal method, solvothermal method (Naveed Ul Haq et al., 2017).

2.1.1. Co-precipitation method/ Precipitation method:

In this method, solution is converted into solid either by insoluble form or by super saturation. Here, zinc compounds are treated with dil. HCl and then dil. NaOH/ KOH/ NH_4OH solution is added dropwise which acts as a precursor and stirred gently, the reaction is maintained at room temperature. The addition of base solution is stopped when the pH is in between 8-10. The above mixture is constantly stirred for 6hrs at

85°C, centrifuged, cooled at room temperature and filtered. To remove impurities, precipitate with distilled water and the white powder is obtained as a product(Pergolese et al., 2016; Purwaningsih et al., 2016; Sharma et al., 2019) .

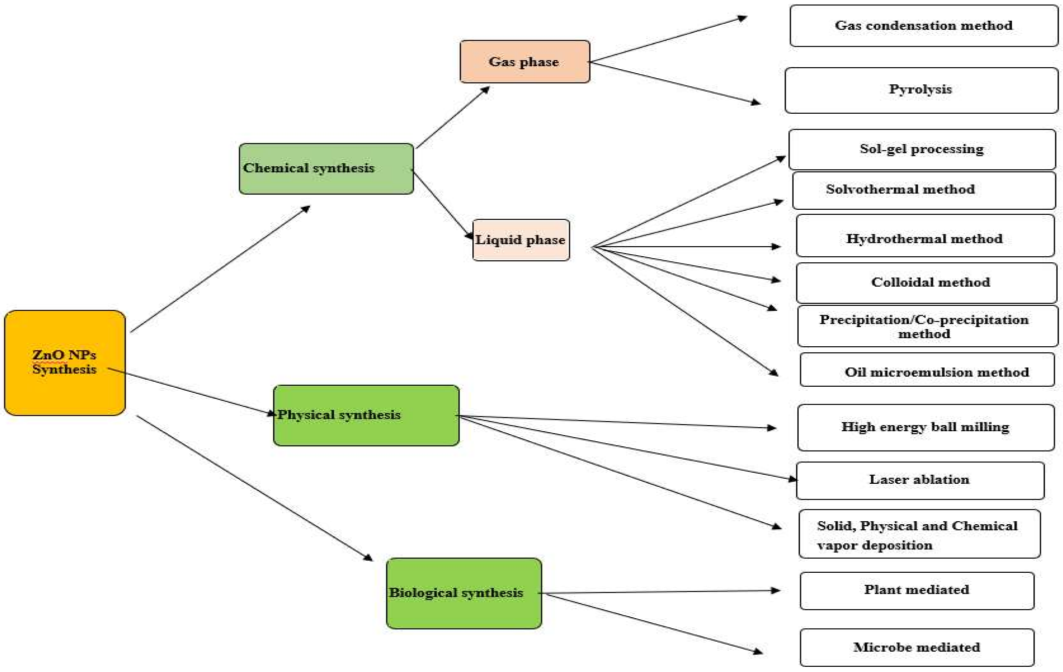

Figure 1: Methods for synthesis of zinc oxide nanoparticles.

2.1.2. **Sol-gel method:**

Sol-gel method is a wet chemical process where the development of colloidal suspension i.e., sol and gelation of the sol in constant liquid phase i.e., gel to form a 3-dimensional network. Here, Zinc compound is dissolved in double distilled water and heated to 50°C. With constant stirring absolute alcohol is added slowly, further H_2O_2 is added dropwise under magnetic stirrer till the clear solution is obtained. The solution was incubated for 24hrs and dried the solution at 80°C for some hours to get white zinc oxide nanoparticles. To remove byproducts, wash several times with double distilled water and dried at 80°C in hot air oven. During the drying process the complete conversion of zinc oxide takes place (Asmatulu, 2012).

2.1.3. **Microemulsion method:**

Microemulsion are thermodynamically stable and optical isotropic liquid solution, which is the mixture of water, oil and amphiphile. Here, the synthesis of zinc oxide nanoparticles was done by reverse microemulsion system. The substances used are Dioctyl sulfosuccinate sodium, glycerol, N-heptane are used as surfactant, polar phase and non-polar phase respectively. The formulation of two microemulsion with different ratio of surfactants are prepared. Dissolve Dioctyl sulfosuccinate sodium in n-heptane at room temperature with constant stirring to get microemulsion. After dissolution, solution should be separated into two equal parts i.e., solution A and solution B.

Dissolve zinc compound in half of glycerol and added slowly to the solution A by constant stirring. Similarly, for solution B add NaOH which is dissolved in glycerol. The above two solutions were stirred continuously at room temperature until transparent solution is obtained. Then, mix solution B to Solution A slowly under constant stirring and refluxed for 24hrs at 60-70°C. White solid powder is obtained, centrifuge at 10000rpm for 20mins. Wash the product with mixture of methanol and chloroform and centrifuge for 10mins at 10000rpm, dried for 1hr at 100°C in an open-air drying oven and in a vacuum dryer for overnight at room temperature. Calcinated for 3hrs at 300°C-500°C in air atmosphere (Pantelic and Cuckovic, 2014; Yildirim and Durucan, 2010).

2.1.4 Hydrothermal method:

It is a method of preparation of single crystals that rely on the solubility of minerals with high pressure in hot water. Here, to prepare stock solutions, zinc compound is dissolved in methanol with stirring. To adjust the pH between 8 and 11, the NaOH dissolved in methanol is added to the stock solution with continuous stirring. Then, the solution was autoclaved in Teflon lined sealed stainless-steel autoclaves and the temperature is maintained for 6hrs and 12hrs at 100-200°C under autogenous pressure, it was cooled at room temperature naturally. The obtained white solid product after reaction was washed with methanol, filtered and dried at 60°C in a laboratory oven(Aneesh et al., 2007; Pan et al., 2015).

2.1.5. **Solvothermal method:**

It is the process were the solvent is added by maintaining moderate to high pressure and temperature, were interaction of precursors are made easier for the synthesis. In this preparation, ethylene glycol and ethanol were mixed and used as a solvent. Add zinc compound to the solvent system and stirred for 20mins. At desired temperature, the closed chamber is inserted into a preheated box furnace for 12hrs. At different temperature such as 200°C, 150°C and 135°C the experiment was carried out to calibrate the size of the nanoparticles. Then, collect the precipitate, wash with ethanol and water for several times and dried at atmospheric temperature in air (Ghoshal et al., 2009).

2.1.6. **Pyrolysis method:**

Pyrolysis is a method where precursor solution is atomized, evaporated and then decomposed into films and particles. Zinc compound is dissolved in distilled water to prepare precursor solution. Under the pressure of air, the solution is nebulized. Decomposition of droplets takes place in reactor under temperature 1200°C. nanoparticle is obtained and collected in cold precipitator, dried at 100°C in an oven.

By washing with water, unreacted zinc compound was removed from the product (Ghaffari-Moghaddam and Hadi-Dabanlou, 2014; Jung et al., 2014).

2.1.7. **Gas condensation method:**

Zinc compound is placed in vacuum chamber. Compound is heated using induced current by maintaining vacuum pressure and vaporized temperature, where the compound is melted and vaporized into gas. In vacuum chamber, material vapor collides with inert gas. Then, it flows to low temperature collector surface and nanoparticle is formed. Since the liquid nitrogen flows continuously inside the vacuum chamber through collector the temperature of the collector surface is increased, by maintaining ideal conditions in vacuum chamber, we can easily control the pressure and temperature. Nanoscale metal particles are nucleated and grown. By means of vaporization and condensation, the nanoparticles are collected on the surface of the collector (Chang and Tsai, 2008).

2.2. **Physical synthesis**:

It is a bottom-up process for nano structural materials to synthesize, which follows two steps, first method is to evaporate the material and second method is rapid controlled condensation to obtain particle size. Physical synthesis is divided into high energy ball milling method; solid, physical and chemical vapor deposition; and laser ablation.

2.2.1. **High energy ball milling method**:

By sustain ambient atmosphere, ZnO powder is milled using hardened steel balls in steel cells for 2-50hrs of different time range. Mechanical milling was carried out in horizontal oscillatory mill at 25Hz. The ratio of mixture i.e., ZnO powder and steel balls is 1:15 by weight percent. Without adding milling agent, the material was milled directly(Salah et al., 2011).

2.2.2. **Laser ablation**:

Prepare the solution by dissolving sodium dodecyl sulfate in double distilled water and a piece of zinc metal is irradiated by Nd:YAG lasers at 10Hz frequency for attentive output of secondary harmonics, the focal length of the lens is 250nm for 60mins and the energy is 100mJ. Zinc nanoparticles were obtained(Singh and Gopal, 2007).

2.3. **Biological synthesis**:

This method indicates to bioremediation, where degradation and metabolization of chemical substance are done by biological processes and environmental quality has been restored. Biological synthesis is divided into two types i.e., plant mediated and microbes mediated.

2.3.1. Plant mediated method:

In this method, nanoparticles are synthesized by using plants or plant parts as shown in **Table 1** for the bio reduction of metal ions to elementary form (Sharma et al., 2019).

Table 1: Synthesis of zinc nanoparticles by plant extract

S.No.	Source	Part	Shape/morphology	Size	Reference
1.	*Zingiber officinale R.*	Root	Spherical	30-50nm	(Anand Raj and Jayalakshmy, 2015)
2.	*Nigella sativa*	Seeds	Spherical and elongated rod shape	24nm	(Naseer et al., 2020)
3.	*Hibiscus subdariffa*	Leaves	Dumbbell	190-250nm	(Bala et al., 2015)
4.	*Citrus Sinensis*	Peel	Spherical	10-20nm	(Doan Thi et al., 2020)
5.	*Sambucus ebulus*	Leaves	Spherical	40-45nm	(Alamdari et al., 2020)
6.	*Catharanthus roseus (I.) G. Don.*	Leaves	Spherical	23-57nm	(Savithramma and Bhumi, 2014)
7.	*Cassia alata*	Leaves	Spherical	60-80nm	(Agarwal et al., 2019)
8.	*Coriander sativum*	Leaves	Spherical	40nm	(Pratap Goutam et al., 2017)
9.	*Trachyspermum ammi*	Seeds	Hexagonal plates	41nm	(Saravanakkumar et al., 2016)
10.	*Elettaria Cardamomum*	Seeds	Spherical	18.72nm	(Vinotha et al., 2020)
11.	*Foeniculum Vulgare*	seeds	Spherical	22-51nm	(Alsalhi et al., 2020)
12.	*Punica granatum L*	Peel	Crystal	42.87nm	(Husain, 2019)
13.	*Allium cepa*	Bulbs	-	20-100nm	(Stan et al., 2016)
14.	*Anchusa italic*	Aerial part	Hexagonal	50nm	(Azizi et al., 2016)
15.	*Ocimum tenuiflorum*	Leaves	Hexagonal	11-25nm	(Raut et al., 2013)
16.	*Artemisia annua*	Stem barks	Spherical	20nm	(Wang et al., 2020)

17.	*Syzgium aromaticum Linn*	Buds	Hexagonal	50nm	(Anvarinezhad et al., 2020)
18.	*Crocus sativus*	Flowers	Spherical	75nm	(Shashanka, 2020)
19.	*Strychnos nux-vomica L.*	Leaves	Quasi-spherical	10-20nm	(Steffy et al., 2018)
20.	*Camellia sinensis*	Leaves	-	30-40nm	(Irshad et al., 2018)
21.	*Senna alata*	Leaves	Needle	412nm	(Adebayo-Tayo et al., 2020)
22.	*Aleo Barbadensis*	Leaves	Hexagonal	10.35nm	(Parthasarathy G et al., 2017)
23.	*Mentha spicata*	Leaves	Spherical	11-80nm	(Abdelkhalek and Al-Askar, 2020)
24.	*Daucus carota*	Roots	polyhedral	16-21nm	(Luque et al., 2018)
25.	*Ipomoea pes-caprea L.*	Leaves	-	10-100nm	(Venkateasan et al., 2017)
26.	*Azadirachta indica A.Juss.*	Leaves	Spherical	20-40nm	(Singh et al., 2019)
27.	*Boerhavia diffusa*	Leaves	Spherical	140nm	(Joseph et al., 2016)
28.	*Lycopersicon esculentum*	Fruit	Spherical	40-100nm	(Sutradhar and Saha, 2016)
29.	*Mangifera indica*	Leaves	-	26nm	(Narayan, 2018)
30.	*Andrographis paniculata*	Leaves	Hexagonal	20.23nm	(Kavitha et al., 2017)
31.	*Lawsonia inermis*	Leaves	Hexagonal	75-100nm	(Kiruba Daniel et al., 2013)
32.	*Trifolium pratense*	Flower	-	100-190nm	(Dobrucka and Długaszewska, 2016)
33.	*Carica papaya*	Leaves	Spherical	50nm	(Rathnasamy et al., 2017)
34.	*Solanum nigrum*	Leaves	Spherical	20-30nm	(Ramesh et al., 2015)
35.	*Plectranthus amboinicus*	Leaves	Spherical and Hexagonal	20-50nm	(Vijayakumar et al., 2015)
36.	*Rosa Canina*	Fruit	Spherical	<50nm	(Jafarirad et al., 2016)
37.	*Terminalia chebula*	Fruit	Spherical	20nm	(Rana et al., 2016)
38.	*Pongamia pinnata*	Leaves	Spherical	100nm	(Sundrarajan et al., 2015)
39.	*Boswellia ovalifoliolata*	Stem barks	Spherical	20nm	(Supraja et al., 2016)

2.3.2. **Microbes mediated**:

Nutrition broth is prepared and sterilized by autoclave. Then bacterial strains are inoculated under aseptic condition, allow it for overnight maintaining temperature. The emergence of turbidity confirms the bacterial growth and then centrifuged at 5000rpm, then separate the supernatant and pellet and examined under SEM, UV spectrometer, XRD and FTIR(Gunalan et al., 2012).

3. MECHANISM OF ZINC OXIDE NANOPARTICLES:

Zinc oxide nanoparticles have peak affect on the cell surface and initiated when subject to UV-Visible light to produce ROS, such as hydroxyl radicals, superoxide anion, and hydrogen peroxide. They penetrate the cell body where O_2^{2-}, ROS Species carrying negative charge remain on cell surface. Zn^{2+} release when it is triggered by the assemble zinc oxide nanoparticles in cytoplasm or outer membrane of bacterial cells, which might cause disintegration of cell membrane, damage of membrane protein and genomic instability which leads to death of bacterial cells (Jiang et al., 2018; Siddiqi et al., 2018).

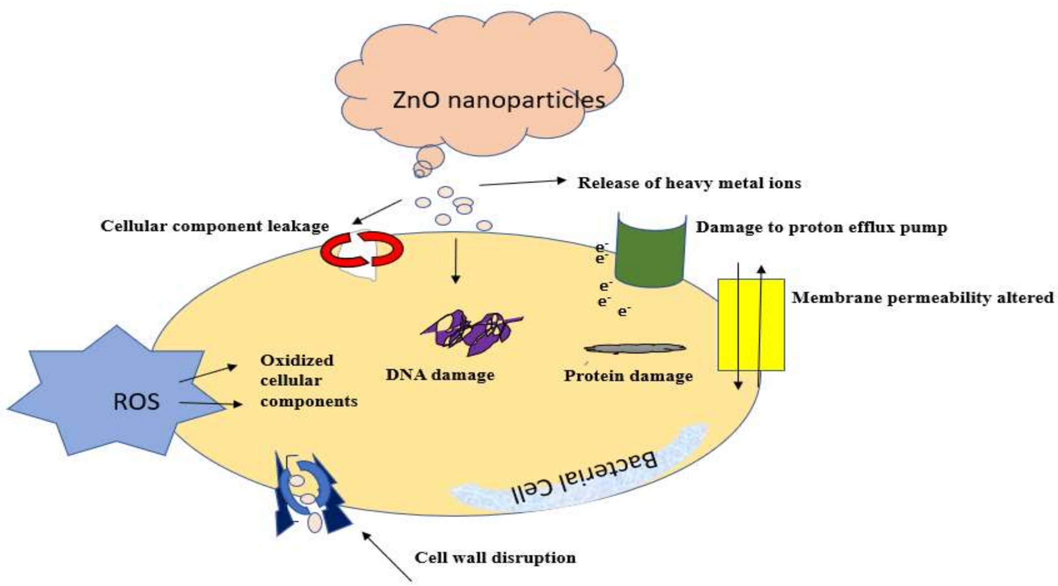

Figure 2: Schematic representation of mechanism of zinc nanoparticles

4. CHARACTERIZATION OF ZINC NANOPARTICLES:

4.1. **Spectroscopic analysis (UV- visible):**

It is used to measure the maximum absorbance of the particle in certain wavelength. It is an absorption spectroscopy where light gets absorbed by the particles which shows excitation of the electrons from the ground state to excitation state ((Klotz, 1945; Rocha et al., 2018).

4.2. **Scanning Electron Microscopy**:

It reveals microstructure of coated surface of the particle, photocatalyst distribution over substrate surface, homogeneity, and morphology of the particles. It determines the secondary electrons which gets emitted when the impinging electron beam interacts with the sample(Faraldos and Bahamonde, 2018; Modena et al., 2019).

4.3. **Field Emission Scanning Electron Microscopy:**

It works with electron rather than light. The electron is discharged from the field emission source and they are scanned in a zig-zag pattern. It envisions fractioned or entire or details on the surface objects. It gives information about smaller structures of 1nm (Semnani, 2017).

4.4. **Transmission Electron Microscopy**:

It elucidates characteristics dimensions of fine particles, which are lesser than 100nm in size. This provide both bright field and dark field images of nanoparticles size. It gives information about morphology, crystalline structure and elemental information (Senthil Kumar et al., 2019; Tang and Yang, 2017).

4.5. **Fourier Transform Infrared Spectroscopy:**

FTIR utilizes the mathematical process which gets converted into actual spectrum by raw data. It is used to detect the functional groups and molecular bonds present in chemical compounds. It identifies organic and inorganic compounds present in the sample (Abbasi et al., 2013).

4.6. **X-Ray Diffraction**:

It is a powerful non-destructive technique which gives information about characteristics of crystalline nature, structure, average size. XRD works on constructive inference of crystalline sample and monochromatic x-ray (Bunaciu et al., 2015).

4.7. **Energy-Dispersive X-Ray**:

It detects the chemical characterization and elemental composition of the desired sample. It depends on the interaction of the sample and X-ray excitation (Qi and Wang, 2005).

4.8. **Dynamic Light Scattering:**

It is used to determine the particle size and distribution of the particles. Using Brownian motion, DLS estimates light interference. It measures both turbid and dilute system with the lower concentration (Kumar and Dixit, 2017).

4.9. **Zeta Potential**:

The stationary layer and dispersion medium of the fluid bonded with particles gives the potential difference between them and it is called as Zeta potential. It detects the dispersion stability of the solution (Sathishkumar et al., 2009).

5. APPLICATIONS:

5.1. **Antibacterial activity:**

Zinc oxide nanoparticles shows diverse morphologies and it shows impressive antibacterial activity around wide ranges of bacteria (Sirelkhatim et al., 2015). Previous reports revealed by decreasing particle size, the antibacterial activity of zinc oxide nanoparticles increases and also increases with increasing powder concentration (Zarrindokht Emami-Karvani, 2012). The large surface area to volume ratio of nanoparticles shows high antibacterial property, where it binds a greater number of ligands on its surface (Agarwal et al., 2019). The mechanism of zinc oxide nanoparticles towards antibacterial activity is based on induced oxidative stress. The oxidative stress is formed in bacterial cell because of the interaction between Zn^{+} ion and thiol group of bacterial respiratory enzyme, where increase in the reactive oxygen species (ROS) causes bacterial cell damage and death (Fontecha-Umaña et al., 2020). Zinc oxide nanoparticles shows potent antibacterial activity towards both gram-positive and gram-negative bacteria. Zinc oxide nanoparticles inhibits food borne and most dangerous pathogens as an antibacterial agent (De Souza et al., 2019).

5.2. **Antimicrobial activity:**

Zinc oxide nanoparticles shows good antimicrobial activity because it produces the free radical, especially on the oxide surface(Akbar et al., 2019). Inorganic oxides show advantage over organic antimicrobial agents because of their properties like stability on pressure, higher temperature, long shelf life, robustness etc. Zinc oxide nanoparticles reveal higher antimicrobial property due to its smaller size, higher porosity and larger specific area (Pasquet et al., 2014). In cosmetics, personal care products and functional textile fabrics, the principle involved for the designing was the antimicrobial effects of zinc oxide nanoparticles (Popescu et al., 2020). Zinc oxide nanoparticles interact with water, which gives numerous reactive oxygen species, singlet oxygen or superoxide anion (O_2^-), primarily hydroxyl radicals (OH^-) and hydrogen peroxide (H_2O_2), which has important role in showing antimicrobial activity by the nanoparticles.

5.3. **Antioxidant activity:**

Zinc oxide nanoparticles exhibit antioxidant property because of the electron density transfer at oxygen and property rely on structural configuration of oxygen atom (Stan et al., 2016). The naturally obtained substance shows high protective activity of natural antioxidant from higher plants against chronic disorder which originated from oxidative process. Zinc behaves as an antioxidant because of its free radicals to decrease cell membrane damage. It also acts as a cofactor or component of many enzymes which effect oxidative process. The increased sensitivity of certain oxidative stress is due to the chronic effect of antioxidant. Removal of peroxide from the body is due to the antioxidant enzyme catalase and the destruction of structure of the mitochondrial membrane is been protected (Zhao et al., 2014).

5.4. **Anticancer activity:**

Zinc oxide nanoparticles shows good anticancer activity due to its good solubility, effective delivery to the cells and higher toxicity than the individual agents. When concentration of the zinc oxide nanoparticles increases, it also increases cell viability levels and inhibition (Jiang et al., 2018). Zinc oxide nanoparticles reduces ROS production over the cells which destroys mitochondrial membrane and causes death of cancer tissue (Medina Cruz et al., 2020). Zinc oxide nanoparticles are able to induce notable selective toxicity against cancer cells without damaging normal cells (Akintelu and Folorunso, 2020). Zinc oxide nanoparticles shows various types of surface charge behavior since chemisorption of neutral hydroxyl groups over its surface. At higher pH, protons move towards aqueous medium from the particles surface and allows behind partially bonded oxygen atom with negatively charged surface. Transfer of protons takes place from environment to the particle surface at lower pH, which gives positively charged surface. Zinc nanoparticles exhibits isoelectric point at 9-10, under physiological conditions nanoparticles shows strong positive surface charge(Mishra et al., 2017; Rasmussen et al., 2010).

5.5. **Anti-inflammatory activity:**

Zinc oxide nanoparticles shows wide ratio of surface area to volume, which is good at blocking inflammation-enhancers such as inflammation and cytokines than that of bulk counter parts (Agarwal et al., 2019). Zinc oxide nanoparticles mechanism involves nitric oxide synthase enzyme inhibition, inhibition of myeloperoxidase, pro-inflammatory cytokines inhibition, NF-κβ pathway inhibition, mast cell degranulation inhibition (Agarwal and Shanmugam, 2020). In auto-regulating inflammatory process, macrophages play a very important role. There are two types i.e., Pro-inflammatory M_1 macrophages, which promotes the production of inflammation and M_2 macrophages, where it is alternately activated as the response for anti-inflammatory reaction and remodel the process of the affected organs and tissues.

5.6. **Antidiabetic activity:**

Zinc oxide nanoparticles exhibits remarkable antidiabetic effect especially glucose tolerance improvement, blood glucose reduction, higher serum insulin, non-esterified fatty acid reduction and reduced triglycerides(Raguraman et al., 2020). Zinc is well familiar to hold on the structure of insulin and it plays an essential role in biosynthesis of insulin secretion and storage. It has been demonstrated that various zinc transporters in β-cell of pancreas like zinc transporter-8 shows potent role in secretion of insulin. The mechanism is followed by various ways like increased phosphorylation of insulin receptor, increase in phosphoinositide 3-kinase, insulin signaling is also been improved by zinc. Thus, zinc and diabetic has very complex inter relationship between them. The significant reduction in fasted blood glucose levels by Zinc oxide nanoparticles to diabetic is seen (Siddiqui et al., 2020).

5.7. **Photocatalytic activity:**

The photocatalytic activity of zinc oxide nanoparticles shows the greater electron mobility which increases the migration rate of zinc oxide electron is photogenerated, which block the recombination of photogenerated holes and electrons, therefore the photogenerated charge carriers shows increase in the lifetime. There are many methods possible for the photocatalytic reaction rate to increase, which also indicates the decrease in the bandgap, increases in the defect concentration and increases in the surface area (Hanif et al., 2019). The increase in concentration of the pollutant shows the decrease of the photocatalytic activity, because of which the tendency of the illuminated light beam to reach the catalyst particles will decrease. Zinc oxide nanoparticles has the greater surface area, narrow bandgap, and smaller particle size, which intensify the UV light absorption and the photodecomposition. Therefore, the synthesis of smaller sized nanoparticles is increased through the photocatalytic activity(Munshi et al., 2018).

5.8. **Wound healing:**

Wound healing is an active process, where replacement of injured tissue to its initial state exactly after the injury and the depletion of injured area in a clear-cut indication of healing(Khalid et al., 2017). The reactive oxygen species is generated by metal oxide nanoparticles which considerably helps in fibroblast proliferation. The interlinkage of the fibroblast cells and zinc oxide nanoparticles was impacted by the surface area and the particle size of nanoparticles. The increased particle size increases the membrane integrity and cell proliferation (Kaushik et al., 2019). Wound contraction is caused by activity of myofibroblasts which reduces wound area. The hydrogel based wound dressing integrates in increasing contact time and further follows keratinocyte migration and enhances re-epithelialization (Mihai et al., 2019). Zinc oxide nanoparticles dressing increases apoptosis, bacteria clearance, platelet activation, tissue necrosis, re-epithelialization, tissue scar formation, debris removal, angiogenesis and stem cell activation through wound healing (Batool et al., 2020).

CONCLUSION:

Nanoparticles are an imminent area of research due to their limited size of less than 100nm. The preparation of metallic nanoparticles using a green method is cheap, environmentally friendly and easily scaled up compared to other methods. New developments in nanoparticles can be observed in various fields such as biomedicine, biosensors, bio-nanotechnology due to its different properties compared to the bulk of the same materials due to its small size. Among various metals, Zinc oxide nanoparticles are therefore considered as a potential platform for biomedical research due to their anticancer, anti-inflammatory, antioxidant, antibacterial, antidiabetic, antimicrobial, photocatalytic and wound healing properties. Hence, the enigmas gleaned from nature have contributed to the progress of biomimetic approaches to the growth of advanced nanomaterials.

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CONFLICT OF INTEREST

No conflict of interest was reported by authors

REFERENCE:

Abbasi, T., Anuradha, J., Ganaie, S.U., Khandelwal, S.R., 2013. Development of biogenic silver nano particle from pelargonium graveolens leaf extract and their antibacterial activity. Colloids Surfaces B Biointerfaces 4, 194–198. https://doi.org/10.1016/j.colsurfa.2013.01.059

Abdelkhalek, A., Al-Askar, A.A., 2020. Green synthesized ZnO nanoparticles mediated by Mentha spicata extract induce plant systemic resistance against Tobacco mosaic virus. Appl. Sci. 10. https://doi.org/10.3390/app10155054

Adebayo-Tayo, B.C., Borode, S.O., Olaniyi, O.A., 2020. Phytosynthesis of zinc oxide nanoparticles using methanol extract of Senna alata leaf: Characterization, optimization, antimicrobial properties, and its application in cold cream formulation. Polim. Med. 50, 5–19. https://doi.org/10.17219/pim/122901

Agarwal, H., Nakara, A., Shanmugam, V.K., 2019. Anti-inflammatory mechanism of various metal and metal oxide nanoparticles synthesized using plant extracts: A review. Biomed. Pharmacother. 109, 2561–2572. https://doi.org/10.1016/j.biopha.2018.11.116

Agarwal, H., Shanmugam, V.K., 2020. A review on anti-inflammatory activity of green synthesized zinc oxide nanoparticle: Mechanism-based approach. Bioorg. Chem. 94, 103423. https://doi.org/10.1016/j.bioorg.2019.103423

Akbar, A., Sadiq, M.B., Ali, I., Muhammad, N., Rehman, Z., Khan, M.N., Muhammad, J., Khan, S.A., Rehman, F.U., Anal, A.K., 2019. Synthesis and antimicrobial activity of zinc oxide nanoparticles against foodborne pathogens Salmonella typhimurium and Staphylococcus aureus. Biocatal. Agric. Biotechnol. 17, 36–42. https://doi.org/10.1016/j.bcab.2018.11.005

Akintelu, S.A., Folorunso, A.S., 2020. A Review on Green Synthesis of Zinc Oxide Nanoparticles Using Plant Extracts and Its Biomedical Applications. Bionanoscience 10, 848–863. https://doi.org/10.1007/s12668-020-00774-6

Alamdari, S., Ghamsari, M.S., Lee, C., Han, W., Park, H.H., Tafreshi, M.J., Afarideh, H., Ara, M.H.M., 2020. Preparation and characterization of zinc oxide nanoparticles using leaf extract of sambucus ebulus. Appl. Sci. 10, 1–19. https://doi.org/10.3390/app10103620

Alsalhi, M.S., Devanesan, S., Atif, M., Alqahtani, W.S., Nicoletti, M., Del Serrone, P., 2020. Therapeutic potential assessment of green synthesized zinc oxide nanoparticles derived from fennel seeds extract. Int. J. Nanomedicine 15, 8045–8057. https://doi.org/10.2147/IJN.S272734

Anand Raj, L.F.A., Jayalakshmy, E., 2015. Biosynthesis and characterization of zinc oxide nanoparticles using root extract of Zingiber officinale. Orient. J. Chem. 31, 51–56. https://doi.org/10.13005/ojc/310105

Aneesh, P.M., Vanaja, K.A., Jayaraj, M.K., 2007. Synthesis of ZnO nanoparticles by hydrothermal method. Nanophotonic Mater. IV 6639, 66390J. https://doi.org/10.1117/12.730364

Anvarinezhad, M., Javadi, A., Jafarizadeh-Malmiri, H., 2020. Green approach in fabrication of photocatalytic, antimicrobial, and antioxidant zinc oxide nanoparticles - Hydrothermal synthesis using clove hydroalcoholic extract and optimization of the process. Green Process. Synth. 9, 375–385. https://doi.org/10.1515/gps-2020-0040

Asmatulu, R., 2012. Nanocoatings for corrosion protection of aerospace alloys, Corrosion Protection and Control Using Nanomaterials. Woodhead Publishing Limited. https://doi.org/10.1533/9780857095800.2.357

Azizi-Lalabadi, M., Ehsani, A., Divband, B., Alizadeh-Sani, M., 2019. Antimicrobial activity of Titanium dioxide and Zinc oxide nanoparticles supported in 4A zeolite and evaluation the morphological characteristic. Sci. Rep. 9, 1–10. https://doi.org/10.1038/s41598-019-54025-0

Azizi, S., Mohamad, R., Bahadoran, A., Bayat, S., Rahim, R.A., Ariff, A., Saad, W.Z., 2016. Effect of annealing temperature on antimicrobial and structural properties of bio-synthesized zinc oxide nanoparticles using flower extract of Anchusa italica. J. Photochem. Photobiol. B Biol. 161, 441–449. https://doi.org/10.1016/j.jphotobiol.2016.06.007

Bala, N., Saha, S., Chakraborty, M., Maiti, M., Das, S., Basu, R., Nandy, P., 2015. Green synthesis of zinc oxide nanoparticles using Hibiscus subdariffa leaf extract: Effect of temperature on synthesis, anti-bacterial activity and anti-diabetic activity. RSC Adv. 5, 4993–5003. https://doi.org/10.1039/c4ra12784f

Batool, M., Khurshid, S., Qureshi, Z., Daoush, W.M., 2020. Adsorption, antimicrobial and wound healing activities of biosynthesised zinc oxide nanoparticles. Chem. Pap. https://doi.org/10.1007/s11696-020-01343-7

Beegam, A., Prasad, P., Jose, J., Oliveira, M., Costa, F.G., Soares, A.M.V.M., Gonçalves, P.P., Trindade, T., Kalarikkal, N., Thomas, S., Pereira, M. de L., 2016. Environmental Fate of Zinc Oxide Nanoparticles: Risks and Benefits. Toxicol. - New Asp. to This Sci. Conundrum. https://doi.org/10.5772/65266

Bunaciu, A.A., Udriştioiu, E. gabriela, Aboul-Enein, H.Y., 2015. X-Ray Diffraction: Instrumentation and Applications. Crit. Rev. Anal. Chem. 45, 289–299. https://doi.org/10.1080/10408347.2014.949616

Chang, H., Tsai, M.H., 2008. Synthesis and characterization of ZnO nanoparticles having prism shape by a novel gas condensation process. Rev. Adv. Mater. Sci. 18, 736–745.

De Souza, R.C., Haberbeck, L.U., Riella, H.G., Ribeiro, D.H.B., Carciofi, B.A.M., 2019. Antibacterial activity of zinc oxide nanoparticles synthesized by solochemical process. Brazilian J. Chem. Eng. 36, 885–893. https://doi.org/10.1590/0104-6632.20190362s20180027

Doan Thi, T.U., Nguyen, T.T., Thi, Y.D., Ta Thi, K.H., Phan, B.T., Pham, K.N., 2020. Green synthesis of ZnO nanoparticles using orange fruit peel extract for antibacterial activities. RSC Adv. 10, 23899–23907. https://doi.org/10.1039/d0ra04926c

Dobrucka, R., Długaszewska, J., 2016. Biosynthesis and antibacterial activity of ZnO nanoparticles using Trifolium pratense flower extract. Saudi J. Biol. Sci. 23, 517–523. https://doi.org/10.1016/j.sjbs.2015.05.016

Faraldos, M., Bahamonde, A., 2018. Multifunctional photocatalytic coatings for construction materials, Nanotechnology in Eco-efficient Construction: Materials, Processes and Applications. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102641-0.00023-2

Fontecha-Umaña, F., Ríos-Castillo, A.G., Ripolles-Avila, C., Rodríguez-Jerez, J.J., 2020. Antimicrobial activity and prevention of bacterial biofilm formation of silver and zinc oxide nanoparticle-containing polyester surfaces at various concentrations for use. Foods 9. https://doi.org/10.3390/foods9040442

Ghaffari-Moghaddam, M., Hadi-Dabanlou, R., 2014. Plant mediated green synthesis and antibacterial activity of silver nanoparticles using Crataegus douglasii fruit extract. J. Ind. Eng. Chem. 20, 739–744. https://doi.org/10.1016/j.jiec.2013.09.005

Ghoshal, T., Biswas, S., Paul, M., De, S.K., 2009. Synthesis of ZnO nanoparticles by solvothermal method and their ammonia sensing properties. J. Nanosci. Nanotechnol. 9, 5973–5980. https://doi.org/10.1166/jnn.2009.1290

Gunalan, S., Sivaraj, R., Rajendran, V., 2012. Green synthesized ZnO nanoparticles against bacterial and fungal pathogens. Prog. Nat. Sci. Mater. Int. 22, 693–700. https://doi.org/10.1016/j.pnsc.2012.11.015

Hanif, M.A., Lee, I., Akter, J., Islam, M.A., Zahid, A.A.S.M., Sapkota, K.P., Hahn, J.R., 2019. Enhanced photocatalytic and antibacterial performance of ZnO nanoparticles prepared by an efficient thermolysis method. Catalysts 9. https://doi.org/10.3390/catal9070608

Hashmi, M.U., Khan, F., Khalid, N., Shahid, A.A., Javed, A., Alam, T., Jalal, N., Hayat, M.Q., Abbas, S.R., Janjua, H.A., 2017. Hydrogels incorporated with silver nanocolloids prepared from antioxidant rich Aerva javanica as disruptive agents against burn wound infections. Colloids Surfaces A Physicochem. Eng. Asp. 529, 475–486. https://doi.org/10.1016/j.colsurfa.2017.06.036

Hatamie, A., Khan, A., Golabi, M., Turner, A.P.F., Beni, V., Mak, W.C., Sadollahkhani, A., Alnoor, H., Zargar, B., Bano, S., Nur, O., Willander, M., 2015. Zinc Oxide Nanostructure-Modified Textile and Its Application to Biosensing, Photocatalysis, and as Antibacterial Material. Langmuir 31, 10913–10921. https://doi.org/10.1021/acs.langmuir.5b02341

Husain, W.M., 2019. Green Synthesis of Zinc Oxide Nanoparticles from (Punica granatum L) Pomegranate Aqueous Peel Extract. Iraqi J. Vet. Med. 43, 6–14. https://doi.org/10.30539/iraqijvm.v43i2.524

Irshad, S., Salamat, A., Anjum, A.A., Sana, S., Saleem, R.S., Naheed, A., Iqbal, A., 2018. Green tea leaves mediated ZnO nanoparticles and its antimicrobial activity. Cogent Chem. 4. https://doi.org/10.1080/23312009.2018.1469207

Jafarirad, S., Mehrabi, M., Divband, B., Kosari-Nasab, M., 2016. Biofabrication of zinc oxide nanoparticles using fruit extract of Rosa canina and their toxic potential against bacteria: A mechanistic approach. Mater. Sci. Eng. C 59, 296–302. https://doi.org/10.1016/j.msec.2015.09.089

Jiang, J., Pi, J., Cai, J., 2018. The Advancing of Zinc Oxide Nanoparticles for Biomedical Applications[1] J. Jiang, J. Pi, and J. Cai, "The Advancing of Zinc Oxide Nanoparticles for Biomedical Applications," vol. 2018, 2018. Bioinorg. Chem. Appl. 2018, 18.

Joseph, B., Chacko, M., Rebello, S., Rishad, K.S., Ramesh Babu, N.G., Karthikeyan, S., 2016. Molecular taxonomic identification, biosynthesis and in vitro antibacterial activity of ZNO nanoparticles using boerhavia diffusa against MRSA. Int. J. Toxicol. Pharmacol. Res. 8, 40–44.

Jung, D.S., Ko, Y.N., Kang, Y.C., Park, S. Bin, 2014. Recent progress in electrode materials produced by spray pyrolysis for next-generation lithium ion batteries. Adv. Powder Technol. 25, 18–31. https://doi.org/10.1016/j.apt.2014.01.012

Kaushik, M., Niranjan, R., Thangam, R., Madhan, B., Pandiyarasan, V., Ramachandran, C., Oh, D.H., Venkatasubbu, G.D., 2019. Investigations on the antimicrobial activity and wound healing potential of ZnO nanoparticles. Appl. Surf. Sci. 479, 1169–1177. https://doi.org/10.1016/j.apsusc.2019.02.189

Kavitha, S., Dhamodaran, M., Prasad, R., Ganesan, M., 2017. Synthesis and characterisation of zinc oxide nanoparticles using terpenoid fractions of Andrographis paniculata leaves. Int. Nano Lett. 7, 141–147. https://doi.org/10.1007/s40089-017-0207-1

Khalid, A., Khan, R., Ul-Islam, M., Khan, T., Wahid, F., 2017. Bacterial cellulose-zinc oxide nanocomposites as a novel dressing system for burn wounds. Carbohydr. Polym. 164, 214–221. https://doi.org/10.1016/j.carbpol.2017.01.061

Khatami, M., Alijani, H.Q., Heli, H., Sharifi, I., 2018. Rectangular shaped zinc oxide nanoparticles: Green synthesis by Stevia and its biomedical efficiency. Ceram. Int. 44, 15596–15602. https://doi.org/10.1016/j.ceramint.2018.05.224

Kiruba Daniel, S.C.G., Mahalakshmi, N., Sandhiya, J., Nehru, K., Sivakumar, M., 2013. Rapid Synthesis of Ag Nanoparticles Using Henna Extract for the Fabrication of Photoabsorption Enhanced Dye Sensitized Solar Cell (PE-DSSC). Adv. Mater. Res. 678, 349–360. https://doi.org/10.4028/www.scientific.net/AMR.678.349

Klotz, I.M., 1945. Ultraviolet absorption spectroscopy. J. Chem. Educ. 22, 328–336. https://doi.org/10.1021/ed022p328

Kumar, A., Dixit, C.K., 2017. Methods for characterization of nanoparticles. Adv. Nanomedicine Deliv. Ther. Nucleic Acids 44–58. https://doi.org/10.1016/B978-0-08-100557-6.00003-1

Luque, P.A., Nava, O., Soto-Robles, C.A., Vilchis-Nestor, A.R., Garrafa-Galvez, H.E., Castro-Beltran, A., 2018. Effects of Daucus carota extract used in green synthesis of zinc oxide nanoparticles. J. Mater. Sci. Mater. Electron. 29, 17638–17643. https://doi.org/10.1007/s10854-018-9867-5

Medina Cruz, D., Mostafavi, E., Vernet-Crua, A., Barabadi, H., Shah, V., Cholula-Díaz, J.L., Guisbiers, G., Webster, T.J., 2020. Green nanotechnology-based zinc oxide (ZnO) nanomaterials for biomedical applications: a review. J. Phys. Mater. 3, 034005. https://doi.org/10.1088/2515-7639/ab8186

Mihai, M.M., Dima, M.B., Dima, B., Holban, A.M., 2019. Nanomaterials for wound healing and infection control. Materials (Basel). 12, 1–16. https://doi.org/10.3390/ma12132176

Mirzaei, H., Darroudi, M., 2017. Zinc oxide nanoparticles: Biological synthesis and biomedical applications. Ceram. Int. 43, 907–914. https://doi.org/10.1016/j.ceramint.2016.10.051

Mishra, P.K., Mishra, H., Ekielski, A., Talegaonkar, S., Vaidya, B., 2017. Zinc oxide nanoparticles: a promising nanomaterial for biomedical applications. Drug Discov. Today 22, 1825–1834. https://doi.org/10.1016/j.drudis.2017.08.006

Modena, M.M., Rühle, B., Burg, T.P., Wuttke, S., 2019. Nanoparticle Characterization: What to Measure? Adv. Mater. 31, 1–26. https://doi.org/10.1002/adma.201901556

Mohd Yusof, H., Mohamad, R., Zaidan, U.H., Abdul Rahman, N.A., 2019. Microbial synthesis of zinc oxide nanoparticles and their potential application as an antimicrobial agent and a feed supplement in animal industry: A review. J. Anim. Sci. Biotechnol. 10, 1–22. https://doi.org/10.1186/s40104-019-0368-z

Munshi, G.H., Ibrahim, A.M., Al-Harbi, L.M., 2018. Inspired preparation of zinc oxide nanocatalyst and the photocatalytic activity in the treatment of methyl orange dye and paraquat herbicide. Int. J. Photoenergy 2018. https://doi.org/10.1155/2018/5094741

Narayan, A., 2018. Synthesis and Characterization of Zinc Oxide (Zno) Nanoparticles Using Mango (Mangifera Indica) Leaves 5, 17–23.

Naseer, M., Aslam, U., Khalid, B., Chen, B., 2020. Green route to synthesize Zinc Oxide Nanoparticles using leaf extracts of Cassia fistula and Melia azadarach and their antibacterial potential. Sci. Rep. 10, 1–10. https://doi.org/10.1038/s41598-020-65949-3

Naveed Ul Haq, A., Nadhman, A., Ullah, I., Mustafa, G., Yasinzai, M., Khan, I., 2017. Synthesis Approaches of Zinc Oxide Nanoparticles: The Dilemma of Ecotoxicity. J. Nanomater. 2017.

https://doi.org/10.1155/2017/8510342

Pan, Z., Wang, Y., Huang, H., Ling, Z., Dai, Y., Ke, S., 2015. Recent development on preparation of ceramic inks in ink-jet printing. Ceram. Int. 41, 12515–12528. https://doi.org/10.1016/j.ceramint.2015.06.124

Pantelic, I., Cuckovic, B., 2014. Alkyl Polyglucosides: An emerging class of sugar surfactants, Alkyl Polyglucosides: From Natural-Origin Surfactants to Prospective Delivery Systems. Woodhead Publishing Limited. https://doi.org/10.1533/9781908818775.1

Parthasarathy G, Saroja M, Venkatachalam M, 2017. Bio-Synthesized Nano-Formulation of Zinc Oxide-Aloe Vera and To Study Their Characterization and Antibacterial Activities Against Multiple Pathogens. Int. J. Pharm. Sci. Res. 8, 900–907. https://doi.org/10.13040/IJPSR.0975-8232.8(2).900-07

Pasquet, J., Chevalier, Y., Pelletier, J., Couval, E., Bouvier, D., Bolzinger, M.A., 2014. The contribution of zinc ions to the antimicrobial activity of zinc oxide. Colloids Surfaces A Physicochem. Eng. Asp. 457, 263–274. https://doi.org/10.1016/j.colsurfa.2014.05.057

Pergolese, B., Muniz-Miranda, M., Bigotto, A., 2016. Optimization of process variables for the biosynthesis of silver nanoparticles by *Aspergillus wentii* using statistical experimental design. Langmuir 18, 287–294. https://doi.org/10.1007/s00604-012-0928-9

Popescu, T., Matei, C.O., Vlaicu, I.D., Tivig, I., Kuncser, A.C., Stefan, M., Ghica, D., Miclea, L.C., Savopol, T., Culita, D.C., Moisescu, M.G., 2020. Influence of surfactant-tailored Mn-doped ZnO nanoparticles on ROS production and DNA damage induced in murine fibroblast cells. Sci. Rep. 10. https://doi.org/10.1038/s41598-020-74816-0

Pratap Goutam, S., Kumar Yadav, A., Jyoti Das, A., 2017. Coriander Extract Mediated Green Synthesis of Zinc Oxide Nanoparticles and Their Structural , Optical and Antibacterial ... J. Nanosci. Technol. 3, 249–252.

Purwaningsih, S.Y., Pratapa, S., Triwikantoro, T., Darminto, 2016. Nano-sized ZnO powders prepared by co-precipitation method with various pH. AIP Conf. Proc. 1725, 1–7. https://doi.org/10.1063/1.4945517

Qi, W.H., Wang, M.P., 2005. Size and shape dependent lattice parameters of metallic nanoparticles. J. Nanoparticle Res. 7, 51–57. https://doi.org/10.1007/s11051-004-7771-9

Raguraman, V., Jayasri, M.A., Suthindhiran, K., 2020. Magnetosome mediated oral Insulin delivery and its possible use in diabetes management. J. Mater. Sci. Mater. Med. 31, 1–9. https://doi.org/10.1007/s10856-020-06417-2

Ramesh, M., Anbuvannan, M., Viruthagiri, G., 2015. Green synthesis of ZnO nanoparticles using Solanum nigrum leaf extract and their antibacterial activity. Spectrochim. Acta - Part A Mol. Biomol. Spectrosc. 136, 864–870. https://doi.org/10.1016/j.saa.2014.09.105

Rana, N., Chand, S., Gathania, A.K., 2016. Green synthesis of zinc oxide nano-sized spherical particles using Terminalia chebula fruits extract for their photocatalytic applications. Int. Nano Lett. 6, 91–98. https://doi.org/10.1007/s40089-015-0171-6

Rasmussen, J.W., Martinez, E., Louka, P., Wingett, D.G., 2010. Zinc oxide nanoparticles for selective destruction of tumor cells and potential for drug delivery applications. Expert Opin. Drug Deliv. 7, 1063–1077. https://doi.org/10.1517/17425247.2010.502560

Rathnasamy, R., Thangasamy, P., Thangamuthu, R., Sampath, S., Alagan, V., 2017. Green synthesis of ZnO nanoparticles using Carica papaya leaf extracts for photocatalytic and photovoltaic applications. J. Mater. Sci. Mater. Electron. 28, 10374–10381. https://doi.org/10.1007/s10854-017-6807-8

Raut, S., Thorat, P. V, Thakre, R., 2013. Green Synthesis of Zinc Oxide (ZnO) Nanoparticles Using Ocimum Tenuiflorum Leaves. Int. J. Sci. Res. ISSN (Online Index Copernicus Value Impact Factor 14, 2319–7064.

Rocha, F.S., Gomes, A.J., Lunardi, C.N., Kaliaguine, S., Patience, G.S., 2018. Experimental methods in chemical engineering: Ultraviolet visible spectroscopy—UV-Vis. Can. J. Chem. Eng. 96, 2512–2517. https://doi.org/10.1002/cjce.23344

Salah, N., Habib, S.S., Khan, Z.H., Memic, A., Azam, A., Alarfaj, E., Zahed, N., Al-Hamedi, S., 2011. High-energy ball milling technique for ZnO nanoparticles as antibacterial material. Int. J. Nanomedicine 6, 863–869. https://doi.org/10.2147/ijn.s18267

Saravanakkumar, D., Sivaranjani, S., Umamaheswari, M., Pandiarajan, S., Ravikumar, B., 2016. Green synthesis of ZnO nanoparticles using Trachyspermum ammi seed extract for antibacterial investigation. Der Pharma Chem. 8, 173–180.

Sathishkumar, M., Sneha, K., Won, S.W., Cho, C.W., Kim, S., Yun, Y.S., 2009. Cinnamon zeylanicum bark extract and powder mediated green synthesis of nano-crystalline silver particles and its bactericidal activity. Colloids Surfaces B Biointerfaces 73, 332–338. https://doi.org/10.1016/j.colsurfb.2009.06.005

Savithramma, N., Bhumi, G., 2014. Biological Synthesis of Zinc oxide Nanoparticles from C atharanthus roseus (l.) G. Don. Leaf extract and validation for antibacterial activity. Int. J. Drug Dev. Res. 6, 208–214.

Semnani, D., 2017. Geometrical characterization of electrospun nanofibers, Electrospun Nanofibers. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-100907-9.00007-6

Senthil Kumar, P., Grace Pavithra, K., Naushad, M., 2019. Characterization techniques for nanomaterials, Nanomaterials for Solar Cell Applications. Elsevier Inc. https://doi.org/10.1016/B978-0-12-813337-8.00004-7

Shamhari, N.M., Wee, B.S., Chin, S.F., Kok, K.Y., 2018. Synthesis and characterization of zinc oxide nanoparticles with small particle size distribution. Acta Chim. Slov. 65, 578–585. https://doi.org/10.17344/acsi.2018.4213

Sharma, G., Kumar, A., Sharma, S., Naushad, M., Prakash Dwivedi, R., ALOthman, Z.A., Mola, G.T., 2019. Novel development of nanoparticles to bimetallic nanoparticles and their composites: A review. J. King Saud Univ. - Sci. 31, 257–269. https://doi.org/10.1016/j.jksus.2017.06.012

Shashanka, R., 2020. Investigation of optical and thermal properties of CuO and ZnO nanoparticles prepared by Crocus Sativus (Saffron) flower extract. J. Iran. Chem. Soc. https://doi.org/10.1007/s13738-020-02037-3

Siddiqi, K.S., ur Rahman, A., Tajuddin, Husen, A., 2018. Properties of Zinc Oxide Nanoparticles and Their Activity Against Microbes. Nanoscale Res. Lett. 13. https://doi.org/10.1186/s11671-018-2532-3

Siddiqui, S.A., Rashid, M.M.O., Uddin, M.G., Robel, F.N., Hossain, M.S., Haque, M.A., Jakaria, M., 2020. Biological efficacy of zinc oxide nanoparticles against diabetes: A preliminary study conducted in mice. Biosci. Rep. 40, 1–8. https://doi.org/10.1042/BSR20193972

Singh, A., Neelam, Kaushik, M., 2019. Physicochemical investigations of zinc oxide nanoparticles synthesized from Azadirachta Indica (Neem)leaf extract and their interaction with Calf-Thymus DNA. Results Phys. 13, 102168. https://doi.org/10.1016/j.rinp.2019.102168

Singh, S.C., Gopal, R., 2007. Zinc nanoparticles in solution by laser ablation technique. Bull. Mater. Sci. 30, 291–293. https://doi.org/10.1007/s12034-007-0048-z

Sirelkhatim, A., Mahmud, S., Seeni, A., Kaus, N.H.M., Ann, L.C., Bakhori, S.K.M., Hasan, H., Mohamad, D., 2015. Review on zinc oxide nanoparticles: Antibacterial activity and toxicity mechanism. Nano-Micro Lett. 7, 219–242. https://doi.org/10.1007/s40820-015-0040-x

Stan, M., Popa, A., Toloman, D., Silipas, T.D., Vodnar, D.C., 2016. Antibacterial and antioxidant activities of ZnO nanoparticles synthesized using extracts of Allium sativum, Rosmarinus officinalis and Ocimum basilicum. Acta Metall. Sin. (English Lett. 29, 228–236. https://doi.org/10.1007/s40195-016-0380-7

Steffy, K., Shanthi, G., Maroky, A.S., Selvakumar, S., 2018. Synthesis and characterization of ZnO phytonanocomposite using Strychnos nux-vomica L. (Loganiaceae) and antimicrobial activity against multidrug-resistant bacterial strains from diabetic foot ulcer. J. Adv. Res. 9, 69–77. https://doi.org/10.1016/j.jare.2017.11.001

Sundrarajan, M., Ambika, S., Bharathi, K., 2015. Plant-extract mediated synthesis of ZnO nanoparticles using Pongamia pinnata and their activity against pathogenic bacteria. Adv. Powder Technol. 26, 1294–1299. https://doi.org/10.1016/j.apt.2015.07.001

Supraja, N., Prasad, T.N.V.K.V., Krishna, T.G., David, E., 2016. Synthesis, characterization, and evaluation of the antimicrobial efficacy of Boswellia ovalifoliolata stem bark-extract-mediated zinc oxide nanoparticles. Appl. Nanosci. 6, 581–590. https://doi.org/10.1007/s13204-015-0472-0

Sutradhar, P., Saha, M., 2016. Green synthesis of zinc oxide nanoparticles using tomato (Lycopersicon esculentum) extract and its photovoltaic application. J. Exp. Nanosci. 11, 314–327. https://doi.org/10.1080/17458080.2015.1059504

Tang, C.Y., Yang, Z., 2017. Transmission Electron Microscopy (TEM), Membrane Characterization. Elsevier B.V. https://doi.org/10.1016/B978-0-444-63776-5.00008-5

Venkateasan, A., Prabakaran, R., Sujatha, V., 2017. Phytoextract-mediated synthesis of zinc oxide nanoparticles using aqueous leaves extract of Ipomoea pes-caprae (L).R.br revealing its biological properties and photocatalytic activity. Nanotechnol. Environ. Eng. 2, 1–15. https://doi.org/10.1007/s41204-017-0018-7

Vijayakumar, S., Vinoj, G., Malaikozhundan, B., Shanthi, S., Vaseeharan, B., 2015. Plectranthus amboinicus leaf extract mediated synthesis of zinc oxide nanoparticles and its control of methicillin resistant Staphylococcus aureus biofilm and blood sucking mosquito larvae. Spectrochim. Acta - Part A Mol. Biomol. Spectrosc. 137, 886–891. https://doi.org/10.1016/j.saa.2014.08.064

Vinotha, V., Yazhiniprabha, M., Raj, D.S., Mahboob, S., Al-Ghanim, K.A., Al-Misned, F., Govindarajan, M., Vaseeharan, B., 2020. Biogenic synthesis of aromatic cardamom-wrapped zinc oxide nanoparticles and their potential antibacterial and mosquito larvicidal activity: An effective eco-friendly approach. J. Environ. Chem. Eng. 8, 104466. https://doi.org/10.1016/j.jece.2020.104466

Wang, D., Cui, L., Chang, X., Guan, D., 2020. Biosynthesis and characterization of zinc oxide nanoparticles from Artemisia annua and investigate their effect on proliferation, osteogenic differentiation and mineralization in human osteoblast-like MG-63 Cells. J. Photochem. Photobiol. B Biol. 202, 111652. https://doi.org/10.1016/j.jphotobiol.2019.111652

Xie, Y., He, Y., Irwin, P.L., Jin, T., Shi, X., 2011. Antibacterial activity and mechanism of action of zinc oxide nanoparticles against Campylobacter jejuni. Appl. Environ. Microbiol. 77, 2325–2331. https://doi.org/10.1128/AEM.02149-10

Yildirim, Ö.A., Durucan, C., 2010. Synthesis of zinc oxide nanoparticles elaborated by microemulsion method. J. Alloys Compd. 506, 944–949. https://doi.org/10.1016/j.jallcom.2010.07.125

Zarrindokht Emami-Karvani, 2012. Antibacterial activity of ZnO nanoparticle on Gram-positive and Gram-negative bacteria. African J. Microbiol. Res. 5. https://doi.org/10.5897/ajmr10.159

Zhang, Yongqiang, Cheng, X., Zhang, Yucang, Xue, X., Fu, Y., 2013. Biosynthesis of silver nanoparticles at room temperature using aqueous aloe leaf extract and antibacterial properties. Colloids Surfaces A Physicochem. Eng. Asp. 423, 63–68. https://doi.org/10.1016/j.colsurfa.2013.01.059

Zhao, C.Y., Tan, S.X., Xiao, X.Y., Qiu, X.S., Pan, J.Q., Tang, Z.X., 2014. Effects of dietary zinc oxide nanoparticles on growth performance and antioxidative status in broilers. Biol. Trace Elem. Res. 160, 361–367. https://doi.org/10.1007/s12011-014-0052-2