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Biosynthesis Of Zirconia (ZrO_2) Nanoparticles Using Plant Extract: A Review

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Abstract: Zirconia (ZrO_2) nanoparticles have wide range of applications in various fields. The green synthesis of metal oxide nanoparticles provides an advantage over the chemical synthesis approach. Researchers are working on synthesis methods of plant extracts to produce cost-effective and eco-friendly nanoparticles. Plant tissues contains various phytochemicals i.e. phenolic compounds, flavonoids, alkaloids, saponins, and amino acids. These compounds act as reducing, capping and stabilizing agent during the formation of ZrO_2 nanoparticles. In this review, we focus on the biosynthesis of ZrO_2 nanoparticles using different parts of plant extracts. This review article has summarized research papers from 2018-2023 which describe the process of ZrO_2 nanoparticles biosynthesis, characterization and their application in different fields.

Keywords: Metal oxide, Zirconia, Green synthesis, Phytochemical, Nanoparticles.

Introduction:

Nanotechnology is the control of matter at the nanoscale, in range between 1 to 100 nm, their unique phenomenon provides novel applications. Nanoparticles (NP's) possess physical, chemical, and biological properties due to their high surface area and nanoscale size, differing in important ways from the properties of bulk materials, single atoms, and molecules.[1]

Green synthesis of nanoparticles is a bottom-up approach where the nanoparticles are synthesized through the oxidation/reduction process of metallic ions by the organic moieties from the biological resources.[2]

Biosynthesis shows an advantage over chemical and physical methods because it is simple, cost-effective and reproducible, and it gives more stable materials. Microbial synthesis method is also used for nanoparticle production but the synthesis rate is slow and only few number of sizes and shapes are amenable to the method compared to other process involving plant extracts. High pressure, energy, temperature, or toxic chemicals are not required in biosynthesis. Plants produce more stable nanoparticles compared to other methods and it is easy to scale up. There is low risk of contamination in green synthesis. In recent years due to these advantages, green synthesis is gaining extreme importance in all the fields focusing on a greener environment.[3]

Recently, metal oxide nanoparticles are of special importance due to the increasing demand in industries and medical sectors such as fillers, disinfectants, optics, antimicrobial agents, drug delivery, and catalytic products. Metal oxide nanoparticles such as ZnO, CuO, CeO_2, and ZrO_2 NPs have been mainly focused for their biological and biomedical uses. Zirconia (ZrO_2), also known as zirconia, is widely used as a photocatalyst. It has enhanced thermal, mechanical, catalytic, and corrosion properties. Different methods have been studied for synthesizing ZrO_2 nanoparticles for various applications.[4]

Zirconium (Zr) is s a chemical element with the symbol Zr and the atomic number 40. Zr is a very strong, malleable, ductile, lustrous silver-gray metal and its chemical and physical properties are similar to titanium. Zr is highly resistant to corrosion by alkalis, acids, salt water and other agents. Zr does not basically capture neutrons, offering a potential metallic cladding for the fuel rods in the nuclear reactors (Cazado et al. 2021). Zirconium dioxide (ZrO_2) or zirconia is classified as a transition metal, Zirconium is a solid at room temperature and one of the highly stable oxides, created by thermalizing zirconium compounds (Hassan and Jalil 2022).[5]

Zirconia nanoparticles have been used for various synthesis because of its high strength, high fracture toughness and hardness. Zirconia powder exist in three forms i.e. monoclinic, tetragonal and cubic. The monoclinic phase is stable at room temperature but above 1170^{o}C it transforms to the tetragonal form and cubic form which is thermodynamically stable up to a temperature 2370^{o}C.[6]

Zirconia nanoparticles can be synthesized using different methods such as ultrasonic assisted, microwave irradiation, hydrothermal, thermal decomposition, sol-gel, laser ablation, aqueous precipitation method, polyacrylamide gel method, template method, low temperature hydrolysis, two phase approach, solvothermal, spray pyrolysis, ball-mill aided precipitation, microwave plasma, sonochemical method, emulsion precipitation, pulsed plasma in liquid, thermal plasma route, electric arc discharge, freeze drying and propellent chemical combustion method.[7]

This review gives detailed description of the new findings in the research area of green synthesis of zirconia nanoparticles (ZrO_2) using different plants and their various applications covering the literature since 2018.

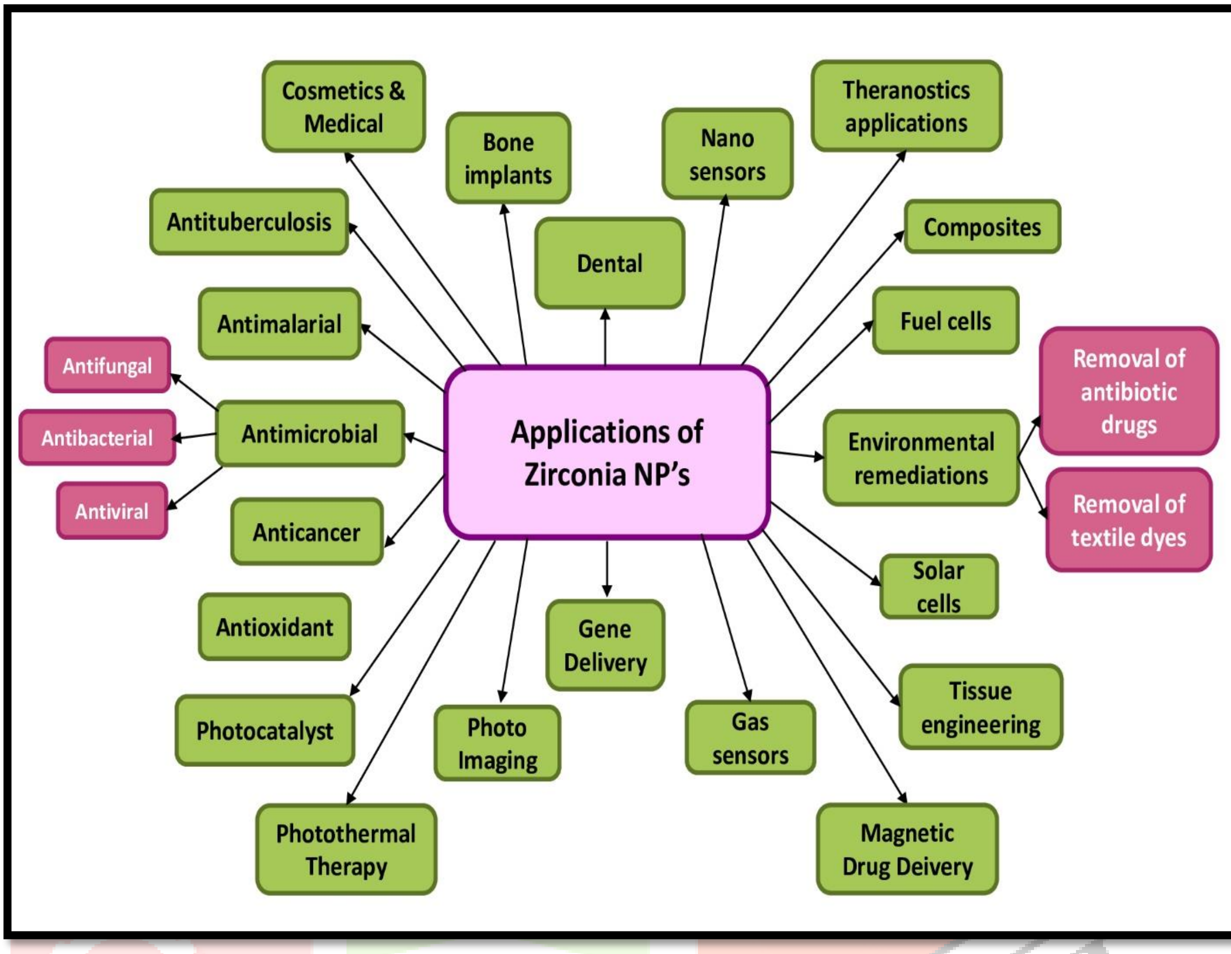

Figure 1: The applications of Zirconia NP's

Green synthesis of Zirconia (ZrO_2) Nanoparticles using Plants:

Various parts of plant such as leaves, roots, flowers, fruits, rhizomes etc., have been successfully utilized for the biosynthesis of zirconia nanoparticles (ZrO_2). Shinde et al. (2018) studied the green synthesis of ZrO_2 nanoparticles using *Ficus benghalensis* leaf extract for photocatalytic activity.[8] Davar et al. (2018) synthesized zirconia nanoparticles using *Rosmarinus officinalis* (Leaves).[9] Vennila et al. (2018) biosynthesized zirconia nanoparticles using *Glorisa superba* and studied its natural dye sensitized solar cell.[10] Silva et al. (2019) green synthesized zirconia nanoparticles using *Euclea natalensis* plant extract.[11] Jeyasakthy et al. (2019) studied the synthesis and characterization of zirconia nanoparticles using *Averrhoa bilimbi.*[12] Annu et al. (2020) studied the synthesis and characerization of ZrO_2 nanoparticle by *Moringa oleifera* leaf extract bio reduction process for its antibacterial and *in vitro* antioxidant activity.[13] Isacfranklin et al. (2020) synthesized highly active biocompatible ZrO_2 nanorods using a *Nephelium lappaceum* bioextract and studied its anticancer activity.[14] Parsa Rasheed *et al.* (2020) studied biosynthesis of vanadium oxide-zirconium oxide using *Daphne alpine* nanocomposite for the degradation of methyl orange and picloram. [15] Joshi et al. (2021) *Tinospora cordifolia* plant leaves extract based synthesis, characterisations and antimicrobial Activities of ZrO_2 Nanoparticles (ZrO_2 NPs) and their antibacterial and antifungal activity was studied.[16] Al-Zaqri et al. (2021) described biosynthesis of zirconium oxide nanoparticles using *Wrightia tinctoria* leaf extract and studied their photocatalytic degradation and antibacterial activities.[17] Chau et al. (2021) demonstrated the synthesis of zirconia nanoparticles using *Laurus nobilis* for use as an antimicrobial agent.[18] Goyal et al. (2021) studied the green synthesis of zirconium oxide nanoparticles using *Helianthus annuus* seed and their antimicrobial effects.[19] Whangchai etal. (2021) evaluated antimicrobial activity of *Thespesia populnea*-coated nanozirconium on cotton gauze fabrics.[20] Alagarsamy et al. (2022) synthesis and characterization of zirconium oxide (ZrO_2) nanoparticles using *Sapindus mukorossi* for adsorptive removal of methylene blue dye was demonstrated.[21] Chau et al. (2022) synthesized zirconium nanoparticles using *Punica granatum* peel extract and studied their antimicrobial and antioxidant potency.[22] Kumari et al. (2022) synthesized low-band gap porous zirconia nanoparticles using green tea leaves and evaluated their applications photocatalytic and antimicrobial activity.[23] Yuan et al. (2022) biosynthesized zirconium nanoparticles by *Phyllanthus niruri* extract and studied its photocatalytic dye degradation activity, antimicrobial and bioremediation efficiency.[24] Kazi et al. (2022) Synthesized zirconium nanoparticles using the dried biomass of *Sphagneticola trilobata* plant leaf and evaluated their antifungal activity, antituberculosis activity, antimalarial activity.[25] Selvam et al. (2022) studied photocatalytic degradation of malachite green and antibacterial potential of biomimetic-synthesized zirconium oxide nanoparticles using *Annona reticulata* leaf extract.[26] Chowdhury et al. (2022) described green synthesis and characterization of zirconium nanoparticle using Ginger and Garlic extract for dental implant application.[27] Muthulakshmi et al. (2022) fabricated zirconia nanoparticles using *Guettarda speciosa* leaves extract.[28] Chelliah et al. (2023) biosynthesized ZrO_2 NPs studied photocatalytic organic contaminant degradation of *Murraya koenigii* and evaluated their antibacterial activities.[29]

A simple process of Biosynthesis of Zirconia Nanoparticles:

A simple and easy procedure is followed for zirconia nanoparticle biosynthesis. The different plant materials such as leaves, fruits, tuber and flowers, are collected from different sources and thoroughly washed with distilled water to remove other unwanted entities. The plant parts are either dried or grinded to form the fine powder. Nagaraj Muthulakshmi et al. (2022) described the detailed procedure of green synthesis of zirconia nanoparticles by *G. speciosa* leaves extract. For the synthesis of zirconia nanoparticles different concentrations of aqueous solution were prepared using *G. speciosa* leaves extract. The reaction mixture was heated on a hot plate with a magnetic stirrer. The off-white precipitate was formed and this precipitate was washed with distilled water several times. Then, the precipitate was collected and dried in a hot air oven. The precipitate was then calcinated in muffle furnace. Finally, zirconia nanoparticles were obtained and stored in an airtight container for further studies.

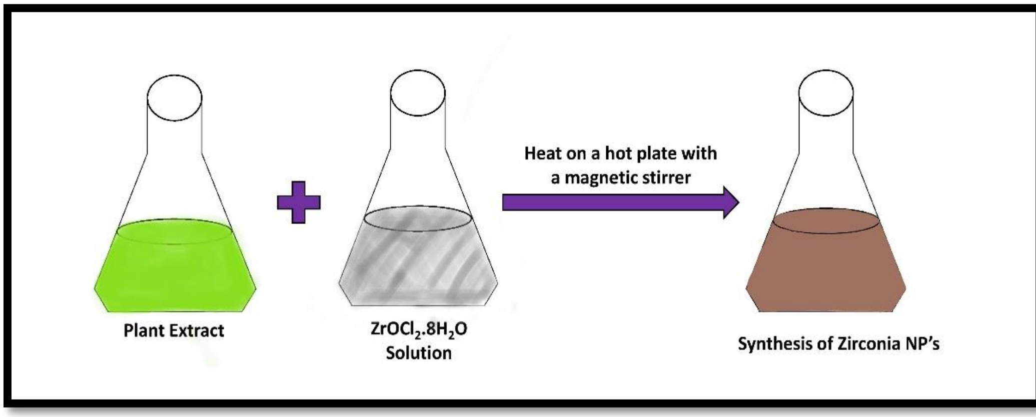

Figure 2: Biosynthesis of Zirconia (ZrO_2) nanoparticles using Plant extract

Characterization of Zirconia Nanoparticles:

The characterization is done to study the confirmation of nanoparticles formation. Different characterization techniques are used to study their shape, size, dispersity, morphology, surface area, chemical composition and crystal structure, Surface chemistry and charge, etc.

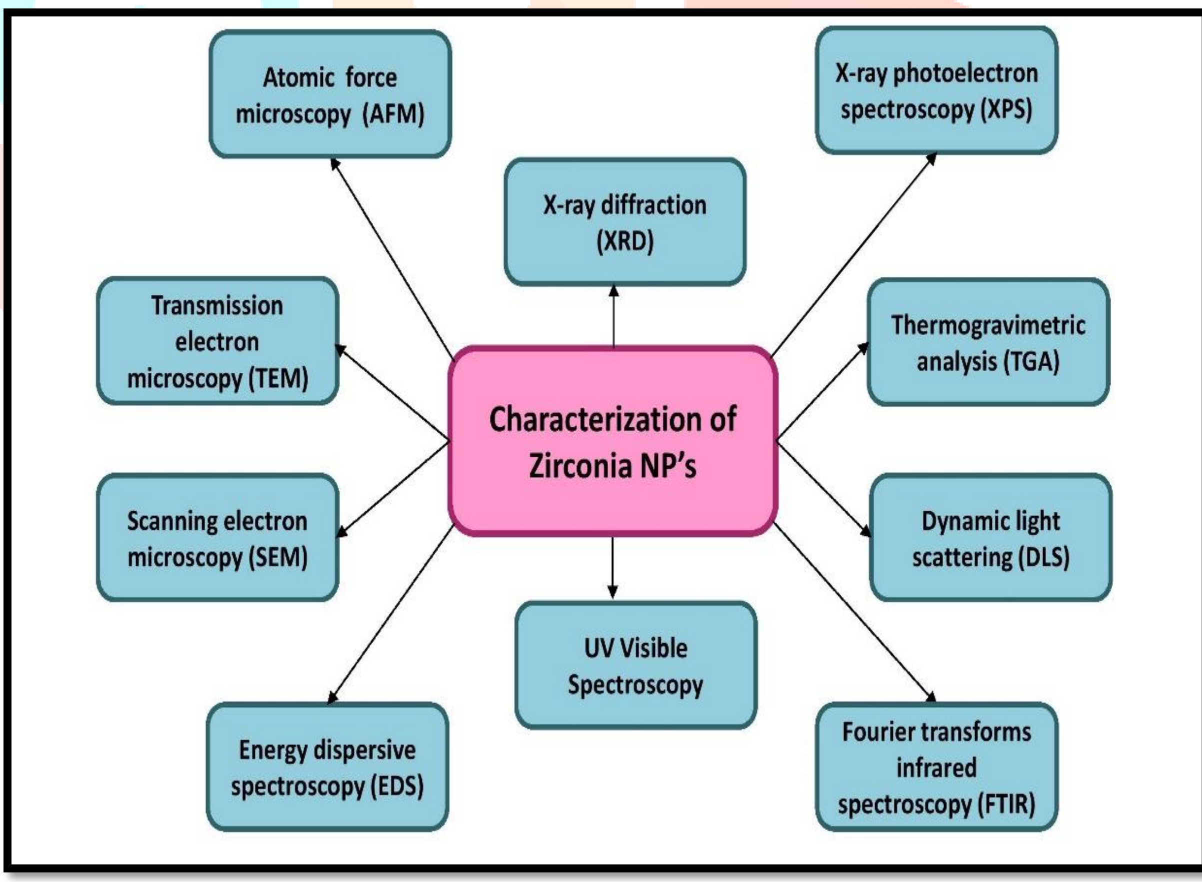

Figure 3: Characterization of Zirconia NP's

Results and Discussion:

Various plant extracts have been used as a green stabilizing agent in the synthesis of ZrO_2 NPs as shown in the table no. 1

Plant	Size of zirconia	Applications	References
Ficus benghalensis	-	Photo catalytic activity	Shinde et al. (2018)
Rosmarinus officinalis	12–17 nm	-	Davar et al. (2018)
Glorisa superba	-	Solar Cell	Vennila et al. (2018)
Euclea natalensis	5.90 to 8.54 nm	-	Silva et al. (2019)
Averrhoa bilimbi	10 to 50 nm	-	Jeyasakthy et al. (2019)
Moringa oleifera	<10 nm	Antibacterial and *in vitro* antioxidant activity	Annu et al. (2020)
Nephelium lappaceum	50 nm	Anticancer activity	Isacfranklin et al. (2020)
Daphne alpine	45–80 nm	Photocatalytic degradation	Parsa Rasheed et al. (2020)
Tinospora cordifolia	73 nm	Antibacterial and antifungal activity	Joshi et al. (2021)
Wrightia tinctoria	17 nm	Photocatalytic degradation and antibacterial activity	Al-Zaqri et al. (2021)
Laurus nobilis	20-100 nm	Antimicrobial activity	Chau et al. (2021)
Helianthus annuus	~331 nm	Antimicrobial activity	Goyal et al. (2021)
Thespesia populnea	10 nm	Antimicrobial activity	Whangchai et al. (2021)
Sapindus mukorossi	5-10 nm	-	Alagarsamy et al. (2022)
Punica granatum	20–60 nm	Antimicrobial and antioxidant activity	Chau et al. (2022)
Green tea leaves	~7 nm	Photocatalytic and antimicrobial activity	Kumari et al. (2022)
Phyllanthus niruri	121.5-125.4 nm	Antimicrobial and bioremediation efficiency	Yuan et al. (2022)
Sphagneticola trilobata	20 –100 nm	Antifungal activity, antituberculosis activity, antimalarial activity	Kazi et al. (2022)
Annona reticulata leaf	13–20 nm	Photocatalytic degradation and antibacterial potential	Selvam et al. (2022)
Ginger and Garlic	-	Dental implant	Chowdhury et al. (2022)
G. speciosa leaves extract.	4 to 9 nm	Antibacterial activity	Muthulakshmi et al. (2022)
Murraya koenigii	27 nm	Photocatalyst and antibacterial agent	Chelliah et al. (2023)

Conclusion:

This review has summarized the current research work in the area of biosynthesis of zirconia nanoparticles by using some plant parts extract. This literature shows that very few works are done for the biosynthesis of zirconia using plants extract. Hence, scientists need to give special attention to synthesize zirconia nanoparticles and explore this simple, non-toxic, environment friendly and commercially viable method for synthesis of zirconia nanoparticles through this green chemistry bottom to top approach. Among some biological method of zirconia nanoparticle synthesis, the use of microorganisms for biosynthesis is not feasible due to the requirements of special aseptic environment. Therefore, the use of plant material extracts for fabrication of zirconia nanoparticles is potentially effective over the use of microorganisms. Furthermore, much more plant species are in way to be exploited and reported in future era towards simple and rapid green synthesis of metal oxide nanoparticles. Because, use of plant material extracts is also cost effective but the use of microorganisms is very expensive. Further research is required to study new applications and to study the exact mechanism of zirconia nanoparticles synthesis using plant parts.

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