A Review on Synthesis, Characterisation and Application of Zinc and Iron Oxide Nanoparticles

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Abstract

Nanotechnology is a manipulation of matter on an atomic, molecular, supramolecular scale. Nanotechnology may be able to create many new materials and devices with a vast range of applications in nanomedicine, nanoelectronics and biomaterials, energy production, etc. Nanoscience identifies the unique properties and characteristics of matter at the molecular level. The synthesis of metallic nanoparticles has been increased and the purpose is to minimize the negative impacts of synthetic procedures, their accompanying chemicals and derivative compounds. Surface functionalized magnetic iron oxide nanoparticles (NPs) are a kind of novel functional materials, which have been widely used in the biotechnology and catalysis. This review focuses on the recent development and various strategies in preparation, structure, and magnetic properties of naked and surface functionalized iron oxide NPs and their corresponding applicationbriefly.

Keywords: Zinc oxide nanoparticles, Iron oxide nanoparticles, Green Synthesis, antibacterial activity, nanotechnology.

DOINumber:10.48047/nq.2022.20.22.NQ10466 **NeuroQuantology2022;20(22):4632-4638**

Introduction

In modern science, nanotechnology is an ablaze field for the researchers. The synthesis of metallic nanoparticles has been increased and the purpose is to minimize the negative impacts of synthetic procedures, their accompanying chemicals and derivative compounds (Fawcett *et al*.,2017).Zinc oxide nanoparticles, in particular, have gained prominence due to their impressive properties and wide range of applications. Zinc oxide nanoparticles are essential metal oxides that have become popular in biological applications due to their excellent biocompatibility and low toxicity. These nanoparticles have found use in industries like rubber, paint, coating, and cosmetics (Jiang *et al*., 2018). Antibacterial activity of Zinc oxide nanoparticles has received significant interest worldwide. Many microorganisms exist in the range from hundreds of nanometres to tens of micrometres. Nanoparticles have been integrated into various industrial, health, food, space, chemical, and cosmetics industry which calls for a green and environment-friendly approach to their synthesis. Zinc oxide (ZnO) exists within the earth crust as a mineral zincite; while most of it thatis used commercially is produced through syntheticmethods.

Iron oxides are chemical compounds which have different polymorphic forms, including γ-Fe_2O_3 (maghemite), Fe_3O_4 (magnetite), and FeO (wurtzite). Among them, the most studied are γ-Fe_2O_3 and Fe_3O_4, as they possess extraordinary properties at the nanoscale (such as super paramagnetic, high specific surface area, biocompatible etc.), because at this size scale, the quantum effects affect matter behaviour and optical, electrical and magnetic properties(Ajinkya *et al*., 2020).

NPs have started being considered as nano antibiotics because of their antimicrobial activities. Nanoparticleshave been integrated into various industrial, health, food, feed, space, chemical, and cosmetics industry of consumerswhich calls for a green and environment-friendly approach to their synthesis.

Nanoparticle synthesis methods

To fully harness the potential of zinc and iron oxide nanoparticles from natural resources, it is important to understand their synthesis and characterization methods. NPs with appropriate surface chemistry are prepared by the following threemethods

- *Physical methods:* These are elaborate procedures which suffer from the inability to controlthe size of particles in the nanometrerange.Hydrothermal synthesis is another method used for the synthesis of zinc and iron oxide nanoparticles. In this method, a precursor solution is heated under high pressure in an autoclave, resulting in the formation of nanoparticles. These are elaborate procedures which suffer from the inability to control the size of particles in the nanometre range (Kielbik*et al*., 2019).
- *Chemical methods:*Chemical precipitation is a commonly used method for the synthesis of zinc and iron oxide nanoparticles. In this method, a precursor solution containing zinc or iron salts is mixed with a precipitating agent under controlled conditions to induce the formation of nanoparticles. These methods are simple, tractable, and efficient, in which the size, composition, and even the shape of the NPs can be managed (Bekele *et al*., 2021).These methods are simple, tractable, and efficient, in whichthe size, composition, and even the shape of the NPs can be managed. Iron oxides can be synthesized through the coprecipitation of Fe^{2+} and Fe^{3+} by the addition of a base. The size, shape, and compositionof iron NPs synthesized through chemical methods depend on the typeofsaltused,Fe^{2+}andFe^{3+}ratio, pH, and ionicstrength.Chemical-based synthesis methods are mostly adopted due to low production cost and high yield. In general, magnetites are synthesized by adding a base to an aqueous mixture of Fe^{2+} and Fe^{3+} chloride at 1:2 molar ratio, resulting in black colour.
- *Biological methods:*Green synthesis is an emerging method for the synthesis of zinc and iron oxide nanoparticles from natural resources. In this method, biological resources such as plants, fungi, and bacteria are used as reducing agents to convert metal ions into nanoparticles (Arslanturk*et al*., 2019). Sindhura*et al*. (2013) synthesized biogenic zinc nanoparticles using the leaves of Parthenium hysterophorous by green synthesis method. The optical absorption peaks recorded at 327.50 and 330 nm confirms the formation of zinc nanoparticles.
- *Polyol's method:*Polyol's method is a significant technique for the preparation of well-defined NPs with controlled shape and size. After controlling the kinetics of the precipitation, non-agglomerated metal particles with well-defined shape and size can be obtained. The average size of the metal particles is controlled by reactive medium, heterogeneous nucleation. The synthesis steps are independent of resulting uniform particle size. Iron NPs of 100 nm can be obtained by ferrous hydroxide in organic media. The solvents used, such as polyols and polyethylene glycol, offer interesting properties due to their high dielectric constants. Polyols function as both reducing and stabilizing agents to control particle growth. These also prevent the aggregation of NPs. Type of polyols, salt ratio, concentration, and other physiological conditions affect growth, shape, size, and yield of the particles. The yield and size of

iron particles are found to be dependent upon the reduction potential of the polyols.

Green approach

Biosynthesis of nanoparticles is an approach of synthesizing nanoparticles using microorganisms and plants having biomedical applications. This approach is an environment-friendly, cost effective, biocompatible and safe. Green synthesis includes synthesis through plants, bacteria, fungi, algae etc. These natural strains and plant extract secrete some phytochemicals that act as both reducing agent and capping or stabilization agent.

Green synthesis of nanoparticlesmakes use of environmentally friendly,non-toxic and safe reagents. The "green" route for nanoparticles synthesis has become interesting as a result of eco friendliness, economic prospects, practicable and wide selection of applications in nanomedicine, chemical change drugs, nanophotoelectronics,etc.

Green synthesis of metallic nanoparticles has been adopted to accommodate various biological materials (e.g., bacteria, fungi, algae, and plant extracts) (ValanArasu, 2022). Among the available green methods of synthesis for metal/metal oxide nanoparticles, utilization of plant extracts is a rather simple and easy process to produce nanoparticles at a large scale relative to bacteria and/or fungi-mediated synthesis. These products are known collectively as biogenic nanoparticles (Annu*et al*., 2018).

Literature study

Sanaz*et al.,* synthesized Zinc Oxide nanoparticles from S.*ebulus* leaf extracts which indicates the formation of nanocrystalline phase. The biosynthesized ZnO-NPs shows higher antibacterial activity for Gram-negativebacteria.

Hedayatnasab*et al*. (2017) discussed the potential of iron oxide nanoparticles in cancer hyperthermia therapy where the nanoparticles are used to elevate the temperature of tumour cells, causing their destruction.

Sharma *et al*. (2015) demonstrated the use of Aloe vera extract as a reducing agent in the synthesis of zinc oxide nanoparticles. The study found that the Aloe vera extract effectively reduced zinc ions, leading to the formation of uniformly distributed nanoparticles with a narrow size range. Furthermore, the nanoparticles synthesized using plant extracts exhibited excellent stability and varied in shape and size, which is an advantage over nanoparticles synthesized through chemical methods that are typically more uniform in shape and size.

Mohan *et al.,*(2016) conducteda study on the preparation of zinc oxide nanoparticles using conventional process. ZnO-NPs were successfully prepared with and withoutsurfactants.

Hosseinkazemi*et al*. (2022)showed that iron oxide nanoparticles could be used in drug delivery system. 4634

Horvath *et al*. (2019) conducted a study that highlighted the potential of iron oxide nanoparticles in removing arsenic from water, indicating their potential in wastewater treatment.s, specifically in the targeted delivery of anticancer drugs.

Agarwal*et al.,*(2017) study reveals that various inorganic metal oxides can be manufactured such as TiO_2, CuO, ZnO. Among these, manufacturing of ZnO is economic.Utilizing plant extracts, microbes, and other natural resources for nanoparticle synthesis is more sustainable and often requires less energy compared to chemical synthesis.

Kumar *et al*. (2014) investigated the antibacterial efficacy of zinc oxide nanoparticles synthesized using plant extracts. The study found that the nanoparticles showed significant antibacterial efficacy against various bacterial strains, indicating their potential application in the field of medicine and healthcare.

Rochman*et al.,*(2017) explained the synthesis of ZnO nanoparticles made by Sol-Gel method. The process parameters used are variations in pH from 7 to 12, to produce compound oxides. Research reveals that greater the pH of the Sol-Gel will increase the agglomeration of particles and viceversa.

Sindhura*et al.,* (2013) synthesized biogenic zinc nanoparticles using the leaves of Parthenium hysterophorous by green synthesis method. The optical absorption peaks recorded at 327.50 and 330 nm confirms the formation of zinc nanoparticles.

Espitia*et al.,*(2012) Zinc oxide shows photocatalytic properties andexhibit greater stability,better crystallinity and smallerdefects.

Mazumder*et al*., (2020) study reveals that many modern studies are focusing on the benefits of ZnO-NPs as plant growth and development fertilizers and nano pesticides.

Bettini *et al*., (2015) introduced a simplified precipitation approach in ZnO-NpsusingZnSO_4andNaOHsolutionwitha molar ratio of 1:2 by vigorous stirring for 12h at room temperature. The prepared ZnO-Nps shows a flake-like structure of size 100nm.

Sarwar *et al*., (2016) reveals that Zinc oxide nanoparticles was observed to be more effective in hindering the growth of EI TOR (N16961) biotype of V.*Cholera*. These results would damage bacterial membrane, increase permeabilization and substantially modify their morphology.

Justin *et al*., (2012), studies on antibacterial activity of ZnO-Nps revealed 500µg ml- 1dose with a diameter of 20 nm, reduced S.*aureus* populations by four orders of magnitude after 8 to 24 hours.

Muthuraman*et al*., (2015) studies show that, ZnO nanoparticles induces cytotoxicity and mitochondrial dysfunction in RKO colon carcinoma cells.

Siddiqi *et al*., (2018) have reported that the antimicrobial activity against both gram-negative (E-coli &P.*aeruginosa*) and gram-positive (*Bacillus Subtilis*) bacteria increased with increasing surface to volume ratio due to decrease in particle size of Zinc oxide nanoparticles.

Parthasarathy *et al*., (2017) Zinc oxide nanoparticles synthesis using Aloe- Vera gel extract shows better antimicrobial activity against S.*aureus* and S.*typho* than other organisms.

Hasnidawani H.N *et al*., (2015) The zinc oxide nanostructure was successfully synthesized by using sol-gel method. The results showed that the ZnO rod like structure was successfully synthesized by sol gel method innanosized range about 84.98nm. The synthesized ZnO nano-powder obtained exhibit goodcrystallinity.

Mirzaei H *et al*., (2017) The ZnO-NPs has proven to be a strong medicinal drug agent within the formulation of microscale and nanoscale systems for therapeutic applications.

Alvarez-Berrios *et al*. (2016) demonstrated the use of iron oxide nanoparticles as contrast agents in MRI, improving the quality and accuracy of imaging.

Yuan Q *et al.,* (2010) used of ZnO quantum dots as a drug delivery system for targeting doxorubicin to HeLa cells.

Ambika S *et al*., (2015) NPssynthesizedfrom *Vitex negundo* leaf and flower showed the similarsizeof38.17nmconfirmedbyXRD analysiscalculatedthroughDebye-Scherrer equation. 4635

JianLing, L I *et al.*, (2010), prepared Fe_3O_4 nanoparticles using chemical coprecipitation and studied the factors affecting the magnetic characteristics of nano-Fe_3O_4 particles.The optimum reaction conditions for the preparation of nano-Fe_3O_4 magnetic particles are an Fe^{3+} to Fe^{2+}molar ratioof 1.75 using 0.02 mol $FeCl_3{\cdot}6H_2O$ dissolved in 200 mL deionized water to give a 0.1 mol/L solution and 0.5 mL surfactant with 30 mL ammonia.

Khan, S T *et al*., (2016) has reportedantimicrobialactivityofZnONPs againstanumberofpathogensincluding,C. *jejuni*, S. *typhimurium*, K. *pneumoniae* and N. *gonorrhoea*, and against foodborne pathogens like E. *coli*, *Listeria monocytogenes*, and V. *cholerae*.

He, F *et al.,* (2005) used water soluble starch for stabilisation ofbimetallic Fe/Pd nanoparticles. In another study, synthesis of magnetite (Fe_3O_4) nanoparticles was achieved by a biopolymer sodium alginate by redox-based hydrothermal method using $FeCl_3{\cdot}6H_2O$ and urea as the starting materials.

Sirelkhatim*et al.* (2015) have reviewed the potential use of zinc oxide nanoparticles for targeted and controlled drug delivery systems. Due to their biocompatibility and physicochemical properties, these nanoparticles can be functionalized with various drugs for cancer therapy. Furthermore, their small size allows for easy penetration into cells, making them an ideal candidate for intracellular drug delivery.

Blinova, I, *et al.*, (2015) evaluatedthetoxicityofnanosizedandbulk iron oxide nanoparticles on D. magna. Iron oxideNPsinducedverylowtoxicity(EC50< 100 ppm) to D. magna and duck weed Lemnaminor in the standard acute assays. It was observed that at acutely subtoxic magnetite concentrations (10 and 100 ppm), the number of neonates hatched from D. magna ephippia was decreased.

PrasadKS*et al.*, (2014)studied the removal of Arsenite(III) and Arsenate(V) from aqueous solution using green synthesised ironnanoparticles.

Wang, D, S *et al*., (2004) introduced the superparamagnetic c-Fe_2O_3 beads CdSe@ZnS quantum dots NPs prepared by thiol–metal bondsconjunction, and their average diameter of this luminescent / magnetic nanocomposite was 20 nm, and it exhibited high emission quantum yield and, was easily separated from solution by magnetic decantation using a permanentmagnet.

Roonasi, P, *et al.*, (2009)studied the mechanism of Fe_3O_4 formation using the Isotope Fractionation study.Inthis report, Fe (II) and Fe (III) alkali solutions were used. Synthesis of magnetite nanoparticles was performed by Co- Precipitation of Iron (II) and (III) and oxidation of Ferrous Hydroxide.

Conclusion

In conclusion, the synthesis of zinc and iron oxide nanoparticles from natural resources offers numerous advantages in terms of safety, scalability, cost-effectiveness, and sustainability. Green sources act as both stabilizing and reducing agent for the synthesis of shape and size-controlled nanoparticles. Zinc oxide nanoparticles hasadvantages because of its physical, chemicalproperties, it's usage and manufacturing method. To manufacture this ZnO leads to pollution and environment hazardous. This paper exhibits both natural and artificial synthesis of zinc oxide using different methods. Biosynthesis of nanoparticles using eco-friendly approach has been the area of focused research in the last decade. Futureprospectof plant-mediated nanoparticle synthesis includes an extension of laboratory-based work to industrial scale, elucidation of phytochemicals involved in the synthesis of nanoparticles using bioinformatics tools.

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