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Review Article

Nanotechnological Applications of Green Iron Oxide Nanoparticles (IONPs): A Review

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Abstract

In the past twenty years, scientists worldwide have been taking extreme interest in synthesizing green metallic nanoparticles (NPs). Various plant based synthesis protocols have been devised and different dimensions of NPs applications have been explored. A lot of research has already been published on the synthesis of metallic NPs. Currently, scaling up process for the commercialization of these NPs is at the prime focus. The rapid and cost-effective synthesis of metallic NPs especially, iron oxide nanoparticles (IONPs) have opened up new avenues. This review article mainly emphasizes on the role of IONPs synthesized using different plant extracts for diverse nanotechnological applications.

Keywords: *Synthesis; Iron Oxide Nanoparticles; Applications; Bioremediation; Biomedical*

Abbreviations

NPs: Nanoparticles; IONPs: Iron Oxide Nanoparticles; Cr(VI): Hexavalent Chromium; As: Arsenic; MRI: Magnetic Resonance Imaging; DNA: Deoxyribonucleic Acid

Introduction

Synthesis of plant mediated metallic nanoparticles especially, iron oxide nanoparticles (IONPs) is currently the most interesting subject of research. The main advantage of using these IONPs is that they are non toxic, biodegradable and biocompatible [1-5]. Microbe based IONPs also have the potential to be used for different applications, however the drawbacks are many. Some of the bacterial strains are very difficult to isolate and cultivate under the artificial laboratory conditions for example, magnetotactic bacteria. Overall, the synthesis of these NPs from bacteria is time consuming, costly and exhaustive. With plant based NPs synthesis method, bulk production of NPs can be obtained instantly [6-10]. The biomolecules in the plant extract play a superior role as reducing, capping and stabilizing agents in the reduction of metal ions to NPs [11-13]. This makes the entire process eco-friendly in contrast to the chemical synthesis procedure which may employ toxic and hazardous chemicals as reducing agents [14,15]. Further, addition of chemical stabilizers can be completely avoided in green synthesis since the metal ions are in close association with the organic groups which themselves act as stabilizing agents [16,17]. The binding of plant biomolecules to NPs prevents aggregation and individual NPs with relatively small and uniform sizes can be easily obtained. A study on IONPs synthesized with and without *Juglans regia* green husk extract has highlighted the significance of the extract compounds in size controlling [18]. The resulting small size, large surface area to volume ratio and high surface energy imparts excellent physicochemical properties to the IONPs [19]. The NPs surface ultimately becomes vulnerable for functionalization, adsorption and other nanotechnological applications [20].

Green iron oxide nanoparticles for environmental applications

There are a lot of studies published on the diverse applications of IONPs for environmental bioremediation. One of the major sources of environmental pollution is the industrial waste effluents [21]. Usage of heavy metals like hexavalent Chromium [Cr(VI)] has great impact on human health due to its toxicity and carcinogenicity. It persists in the environment and being soluble in soil and water can enter the food chain causing harmful health effects [22-24]. Several remediation methods are currently being undertaken to convert Cr(VI) to less harmful Cr(III) form [24]. In one of the methods, IONPs were synthesized using coprecipitation without the incorporation of any plant extract. D-sorbitol was added to prevent aggregation of NPs formed. These NPs were found to be good adsorbent materials exhibiting high chemical specificity. The study revealed that electrostatic attraction between IONPs and Cr(VI) ions ultimately lead to the removal of latter from the wastewaters [25]. More recently, research on iron NPs produced from aqueous extract of *Citrus maxima* peels (a waste product), revealed that these cost effective NPs were efficient in removal of Cr(VI) ions from the solution. Further, there was no requirement for addition of any chemical stabilizers or reducing agents during NPs synthesis [26]. Therefore, it can be inferred that plant based NPs have paved an eco-friendly way towards the removal of Cr(VI) ions. The extremely small sized IONPs have been found to remove heavy metals and organic substances very effectively from the contaminated environment [25]. Similarly, other metals such as arsenic (As) were also found to be easily removed from As-contaminated sources. Magnetite NPs prepared using aqueous extract of *Azadirachta indica* exhibited high affinity for As(V) ions suggesting these NPs to be an excellent adsorbent material for its removal [27]. The strong affinity of magnetite NPs towards As ions could be attributed to the high stability of arsenic-iron bond [28]. Other applications include use of IONPs in textile industries that release large amount of dyeing effluents in the environment [21]. Plant based iron NPs have promising physicochemical properties hence they are ideal catalysts in dye degradation reactions. In one of the research works, it has been demonstrated that the polyphenols contained in Tie Guanyin tea extract act as reducing and capping agents in iron NPs synthesis. The nanocatalyst so formed was found to possess excellent bromothymol blue degradation potential [29]. Synthesized IONPs from *Carica papaya* leaf extract have been reported to carry out photocatalytic degradation of remazol yellow RR dye [30]. The intermediate compounds chlorobenzenes, used in the synthesis of dyes and pesticides have also been found as contaminants in surface and ground waters. Fenton-like degradation of one such compound namely, monochlorobenzene (MCB) has been demonstrated in one of the studies. Results indicated that the IONPs prepared using green tea extract containing mainly polyphenols and caffeine efficiently removed this recalcitrant compound from the wastewaters [31]. IONPs synthesized from *Ocimum tenuiflorum* leaf extract were also reported to possess excellent capacity to degrade two commonly used dyes namely, malachite green and bromothymol blue [32].

Green IONPs as antibacterial and antimicrobial agent

With the overuse of different antibiotics for past several years many of the pathogenic bacterial strains have become antibiotic resistant. Therefore, scientists are examining different plant extracts as they are rich in bioactive chemical components that can act as efficient antibacterial agents. Several reports have been published revealing the antibacterial potential of IONPs prepared using different plant extracts. According to one study, the synthesized IONPs using *Carica papaya* leaf extract were found to exhibit moderate antibacterial activity against *Klebsiella spp, E. coli, S. aureus* and *Pseudomonas spp* [30]. *Musa ornata* (banana) flower sheath extract was also used for iron NPs synthesis. Antibacterial activity was exhibited by these NPs against the most common food borne pathogens and multi drug resistant bacteria such as *S. agalactiae, S. aureus, E. coli* and *S. enterica* [33]. Potent antibacterial activity against Gram positive and moderate activity against Gram negative bacteria has been reported using green synthesized IONPs from *Wrightia tinctoria* leaf extract [34].

IONPs in biomedical applications

IONPs for use in biomedical applications have created a new ray of hope as far as healthcare is concerned. Magnetic induction hyperthermia and cancer treatment, magnetic resonance imaging (MRI) contrast agents, drug delivery, tissue repair and cell separation are some of the important applications where IONPs are in demand. One of the crucial properties of NPs is that they get heated up when placed in an alternating magnetic field. This makes them suitable for magnetic induction hyperthermia application. Heat has been used in the treatment of tumours for a long time. Using IONPs especially for cancer treatment is advantageous as the heated magnetic particles surrounding the tumour site causes destruction of cancer cells under the influence of applied magnetic field [35,36]. Recent reports on use of IONPs in drug delivery have made it possible to coat NPs surfaces with specific drugs. The coated NPs can be channelled to the target site with the help of an external magnetic field. Finally, the drug is released upon removal of the applied field. The use of IONPs as a drug nanocarrier for treatment of human epidermoid carcinoma has been demonstrated. Targeted drug delivery is an important aspect mainly because it avoids the immense side effects of chemotherapeutic drugs on normal human cells rather than cancerous cells [37-39]. IONPs can also be used as MRI contrast agents to identify healthy and pathological tissues. These NPs help to detect apoptosis, wherein self destruction of cells within the body takes place leading to several disorders. Detection of this condition at the primary stage could be very useful in treating the neurodegenerative diseases [40,41]. Magnetic NPs can be employed for repairing tissue damage using stem cells. The NPs coupled to the stem cells can be transported to the target area within the body along with the necessary growth factors and other important proteins (bound to these NPs) required for specific tissue development [42]. IONPs have also been used in magnetically enhanced nucleic acid delivery of viral or non-viral vectors. In this case, the target cells are transfected with magnetic NPs bound to the vector DNA under the influence of an external magnetic field. This technique called magnetofection is based on the charge of the NPs and can be used for enhancing specific gene transfer [43,44]. Cellular labelling is an in vivo method for cell separation which can be detected using MRI. One way of cell labelling is by tagging or attaching a ligand to the NPs surface such that the ligand conjugated NPs can be readily taken up by the cell via receptor mediated endocytosis [45-47].

Conclusion

Green IONPs are potential candidates for diverse applications in the field of science and nanotechnology. Research on IONPs in the last two decades has been extremely important in standardizing methods for their synthesis using various plant extracts and characterization. The main advantage in use of these NPs is due to their intrinsic ability to get attracted to a magnet which makes the overall recovery process simple and cost effective. The NPs can be moved to the desired location by applying an external magnetic field. The next step would be to elucidate different ways in order to scale-up the production of these NPs. It is time to bring this research to use and explore the diverse possibilities of IONPs for multiple applications, especially in the biomedical field. There is an instant need to improve and engineer IONPs for developing patient-friendly diagnostic procedures. This work was therefore focussed on highlighting the different nanotechnological applications of IONPs that can be immediately considered for large-scale production.

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Conflict of Interest

The author declares that there is no conflict of interest.

Bibliography

1. Latha N and Gowri M. "Biosynthesis and characterisation of Fe3O4 nanoparticles using Caricaya papaya leaves extract". *International Journal of Science and Research* 3.11 (2012): 1551-1556.

2. Ahmad N., *et al.* "Biosynthesis of silver nanoparticles from Desmodium triflorum: a novel approach towards weed utilization". *Biotechnology Research International* 2011 (2010): 454090.

3. Niraimathee VA., *et al.* "Green synthesis of iron oxide nanoparticles from Mimosa pudica root extract". *International Journal of Environment and Sustainable Development* 15.3 (2016): 227-240.

4. Mahdavian AR and Mirrahimi MA. "Efficient separation of heavy metal cations by anchoring polyacrylic acid on superparamagnetic magnetite nanoparticles through surface modification". *Chemical Engineering Journal* 159.1- 3 (2010): 264-271.

5. Hu FQ., *et al.* "Preparation of biocompatible magnetite nanocrystals for in vivo magnetic resonance detection of cancer". *Advanced Materials* 18.19 (2006): 2553-2556.

6. Blakemore R. "Magnetotactic bacteria". *Science* 190.4212 (1975): 377-379.

7. Prabhu NN and Kowshik M. "Magnetosomes: the bionanomagnets and its potential use in biomedical applications". *Journal of Nanomedicine Research* 3.3 (2016): 00057.

8. Balamurugan M., *et al.* "Synthesis of iron oxide nanoparticles by using Eucalyptus globulus plant extract". *e-Journal of Surface Science and Nanotechnology* 12 (2014): 363-367.

9. Sathishkumar M., *et al.* "Immobilization of silver nanoparticles synthesized using Curcuma longa tuber powder and extract on cotton cloth for bactericidal activity". *Bioresource Technology* 101.20 (2010): 7958-7965.

10. Rai M., *et al.* "CRC 675-Current trends in phytosynthesis of metal nanoparticles". *Critical Reviews in Biotechnology* 28.4 (2008): 277-284.

11. Venkateswarlu S., *et al.* "Bio-inspired green synthesis of Fe3O4 spherical magnetic nanoparticles using Syzygium cumini seed extract". *Physica B* 449 (2014): 67-71.

12. Mittal AK., *et al.* "Synthesis of metallic nanoparticles using plant extracts". *Biotechnology Advances* 31.2 (2013): 346-356.

13. Kumar V and Yadav SK. "Plant-mediated synthesis of silver and gold nanoparticles and their applications". *Journal of Chemical Technology and Biotechnology* 84 (2009): 151-157.

14. Shahwan T., *et al.* "Green synthesis of iron nanoparticles and their application as Fenton-like catalyst for the degradation of aqueous cationic and anionic dyes". *Chemical Engineering Journal* 172.1 (2011): 258-266.

15. Ge L., *et al.* "Nanosilver particles in medical applications: synthesis, performance and toxicity". *International Journal of Nanomedicine* 9 (2014): 2399-2407.

16. Zayed MF., *et al.* "Malva parviflora extract assisted green synthesis of silver nanoparticles". *Spectrochimica Acta Part A; Molecular and Biomolecular Spectroscopy* 98 (2012): 423-428.

17. Njagi EC., *et al.* "Biosynthesis of iron and silver nanoparticles at room temperature using aqueous Sorghum Bran extracts". *Langmuir* 27.1 (2011): 264-271.

18. Izadiyan Z., *et al.* "Cytotoxic assay of plant-mediated synthesized iron oxide nanoparticles using Juglans regia green husk extract". *Arabian Journal of Chemistry* 13.1 (2020): 2011-2023.

19. Shameli K., *et al.* "Green synthesis of silver/montmorillonite/chitosan bionanocomposites using the UV irradiation method and evaluation of antibacterial activity". *International Journal of Nanomedicine* 5 (2010): 875-887.

20. Gupta AK and Gupta M. "Synthesis and surface engineering of iron oxide nanoparticles for biomedical applications". *Biomaterials* 26.18 (2005): 3995-4021.

21. Lachheb H., *et al.* "Photocatalytic degradation of various types of dyes (Alizarin S, Crocein Orange G, Methyl red, Congo red, Methylene blue) in water by UV-irradiated titania". *Applied Catalysis B: Environmental* 39.1 (2002): 75-90.

22. Ali H., *et al.* "Environmental chemistry and ecotoxicology of hazardous heavy metals: environmental persistence, toxicity, and bioaccumulation". *Journal of Chemistry* (2019): 6730305.

23. Mohan D and Pittman CU. "Activated Carbons and Low Cost Adsorbents for Remediation of Tri- and Hexavalent Chromium from Water". *Journal of Hazardous Materials* 137.2 (2006): 762-811.

24. Covaliu CI., *et al.* "Synthesis and characterization of a hydroxyapatite coated magnetite for potential cancer treatment". *Revista de Chimie* 60.12 (2009): 1254.

25. Matei E., *et al.* "Properties of magnetic iron oxides used as materials for wastewater treatment". *Journal of Physics: Conference Series* 304 (2011): 012022.

26. Wei Y., *et al.* "Green synthesis of Fe nanoparticles using Citrus maxima peels aqueous extracts". *Materials Letters* 185 (2016): 384-386.

27. Parajuli K., *et al.* "Green synthesis of magnetite nanoparticles using aqueous leaves extracts of Azadirachta indica and its application for the removal of As(V) from water". *Green and Sustainable Chemistry* 10 (2020): 117-132.

28. Chen W., *et al.* "Arsenic removal by iron-modified activated carbon". *Water Research* 41.9 (2007): 1851-1858.

29. Xin H., *et al.* "Biosynthesis of iron nanoparticles using Tie Guanyin tea extract for degradation of bromothymol blue". *Journal of Nanotechnology* (2016): 4059591.

30. Bhuiyan MSH., *et al.* "Green synthesis of iron oxide nanoparticles using Carica papaya leaf extract: application for photocatalytic degradation of remazol yellow RR dye and antibacterial activity". *Heliyon* 6 (2020): e04603.

31. Kuang Y., *et al.* "Heterogeneous Fenton-like oxidation of monochlorobenzene using green synthesis of iron nanoparticles". *Journal of Colloid and Interface Science* 410 (2013): 67-73.

32. Prabhu NN and Kowshik M. "Green route synthesis and preliminary characterization of iron oxide nanoparticles using leaf extract of Ocimum tenuiflorum". *Journal of Applied Material Science and Engieering Research* 3.1 (2019): 1-5.

33. Saranya S., *et al.* "Green synthesis of iron nanoparticles using aqueous extract of Musa ornata flower sheath against pathogenic bacteria". *Indian Journal of Pharmaceutical Sciences* 79.5 (2017): 688-694.

34. Sravanthi M., *et al.* "Green synthesis and characterization of iron oxide nanoparticles using Wrightia tinctoria leaf extract and their antibacterial studies". *International Journal of Current Research and Academic Review* 4.8 (2016): 30-44.

35. Nielsen OS., *et al.* "A future for hyperthermia in cancer treatment?". *European Journal of Cancer* 37.13 (2001): 1587-1589.

36. Gordon RT., *et al.* "Intracellular hyperthermia. A biophysical approach to cancer treatment via intracellular temperature and biophysical alterations". *Medical Hypotheses* 5 (1979): 83-102.

37. Chouly C., *et al.* "Development of superparamagnetic nanoparticles for MRI: effect of particles size, charge and surface nature on biodistribution". *Journal of Microencapsulation* 13 (1996): 245-255.

38. Govindan B., *et al.* "Designed synthesis of nanostructured magnetic hydroxyapatite based nanocarrier for anti-cancer drug delivery towards the treatment of human epidermoid carcinoma". *Nanomaterials* 7.6 (2017): 138.

39. Alexiou C., *et al.* "Targeting cancer cells: magnetic nanoparticles as drug carriers". *European Biophysics Journal* 35.5 (2006): 446-450.

40. Zhao M., *et al.* "Non-invasive detection of apoptosis using magnetic resonance imaging and a targeted contrast agent". *Nature Medicine* 7 (2001): 1241-1244.

41. Thompson CB. "Apoptosis in the pathogenesis and treatment of disease". *Science* 267 (1995): 1456-1462.

42. Bulte JW., *et al.* "Magnetodendrimers allow endosomal magnetic labelling and in vivo tracking of stem cells". *Nature Biotechnology* 19 (2001): 1141-1147.

43. Scherer F., *et al.* "Magnetofection enhancing and targeting gene delivery by magnetic force in vitro and in vivo". *Gene Therapy* 9 (2002): 102-109.

44. Krotz F., *et al.* "Magnetofection potentiates gene delivery to cultured endothelial cells". *Journal of Vascular Research* 40.5 (2003): 425-434.

45. Olsvik O., *et al.* "Magnetic separation techniques in diagnostic microbiology". *Clinical Microbiology Reviews* 7.1 (1994): 43-54.

46. Yeh TC., *et al.* "Intracellular labelling of T-cells with superparamagnetic contrast agents". *Magnetic Resonance in Medicine* 30.5 (1993): 617-625.

47. Weissleder R., *et al.* "Magnetically labelled cells can be detected by MR imaging". *Journal of Magnetic Resonance Imaging* 7.1 (1997): 258-263.

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