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Opinion

Green synthesis of iron oxide nanoparticles (IONPs) and their nanotechnological applications

Abstract

Nanotechnology is the most upcoming field of science and technology in the recent years. Scientists are constantly in search of discovering new and innovative techniques in order to develop cost effective methods to deal with environmental as well as human health related problems. From the conventional chemical and physical methods of synthesis of nanoparticles (NPs), the focus is now shifted to more sound and safer biological route of NPs production. Microorganism based methods have been advantageous to some extent, however the scaling up of NPs for commercialization has become an exhaustive challenge. Recently, a number of reports have been published on plant mediated NPs synthesis. These studies are still at the research level but they have revealed the huge potential of these green metallic NPs for diverse applications ranging from biomedicine to environmental remediation. This article summarizes the work published on green iron oxide nanoparticles (IONPs) synthesis and their nano technological applications that could be explored in future for improving human health and combating environmental pollution.

Keywords: green synthesis, iron oxide nanoparticles, nanotechnological , biomedical, environmental remediation

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Abbreviations: NPs, nanoparticles; IONPs, iron oxide nanoparticles; MRI, magnetic resonance imaging

Introduction

Metallic nanoparticles are currently a hotspot of interdisciplinary research due to their inherent potential for diverse nanotechnological applications. Therefore, scientists are constantly trying to devise rapid and cost effective methods for the synthesis of these nanoparticles (NPs). Chemical and physical methods were mostly being used in the past. These methods have their own drawbacks owing to which the biological route is now being investigated for eco friendly and safe metallic NPs production. Microorganisms especially magnetotactic bacteria produce intracellular iron NPs in membrane bound organelles called 'magnetosomes'. These magnetosomes help the bacteria in responding to an external magnetic field.[1] Research on the magnetosome biosynthesis have paved a crucial way for the development of many biomedical and other potential applications.[2,3] However, the only limitation to the large scale synthesis has been the relatively small magnetosome yield which is not sufficient for commercialization.[4,5] Another challenge has been the isolation and cultivation of these bacteria as they are fastidious in their growth behaviour and difficult to grow under artificial laboratory conditions.[6] Overall, microorganism based methods are time consuming and not cost effective.[7–9] Hence, the alternate green route synthesis of metallic NPs from plant source has gained significant attention of late. NPs are synthesized either using the bottom-up approach or the top-down approach. In the bottom-up approach, the NPs synthesized from the reaction precursors, are assembled to obtain the final product either chemically or biologically.[8] Incase of the top-down approach, the physical or chemical procedure is used to breakdown the starting material to get nano-sized particles. Overall, the bottom up approach is found to be advantageous as NPs of uniform size, shape and homogeneous chemical composition can be achieved.[10,11]

Plant mediated synthesis of metallic NPs

Plant mediated NPs synthesis is currently the most efficient method to produce large scale NPs in a short time. The bioactive components contained in the plant extract act as reducing and capping agents in the synthesis process and reduce the metal ions to NPs[12,13] Therefore, no additional surfactants or capping agents are required for the synthesis.[14] The metal ions in the aqueous metal salt solution are reduced to form small nucleation centres. These nucleation centres grow in size by sequestering more metal ions and surrounding nucleation sites to form the NPs. These NPs are closely associated with the organic moieties present in the plant extract which aids in the capping of the NPs.[15–17] Synthesized NPs for example, iron oxide nanoparticles (IONPs), have high surface energies since they have large surface area to volume ratio. They are highly reactive and unstable. Capping of the NPs prevents agglomeration and stabilizes the NPs.[7,18] The entire process occurs rapidly and easily conducted at room temperature and pressure in a single step reaction. The synthesis eliminates the need to utilize hazardous chemicals and toxic solvents. Further, the waste products can be easily disposed off in the environment as they are mostly composed of the plant biomaterial. The overall synthesis procedure is simple, cost effective, reproducible and sustainable.[16,19–21] In addition, stable NPs of desired size and morphology can be achieved using this method.[11] Hence, biologically formed NPs have superior properties as compared to the chemically synthesized NPs.

Synthesis and applications of IONPs using different plant parts

IONPs synthesis is in focus due to their characteristic features such as superparamagnetism, non-toxic nature, being biocompatible as well as biodegradable and the production of these NPs is cost effective.[22–26] Research on the synthesis of IONPs using different plant parts have been reviewed in detail by many authors.[27,28] IONPs have been synthesized using green tea (*Camellia sinensis*) extract.[29]

The polyphenols contained in plant extracts act as a rich source of antioxidants which catalyses the synthesis process.[30] Green tea synthesized NPs have been used as a Fenton like catalyst in the degradation of cationic (Methylene blue) and anionic (Methylene Orange) dyes.[19] Degradation of malachite green dye[31] and other compounds like monochlorobenzene[32] using IONPs produced from tea extract have also been reported. In other studies, *Eucalyptus globules* leaf extract synthesized IONPs were used for the removal of hexavalent chromium from soil[33] and treatment of eutrophic wastewater.[34] Plant extract derived from agrowaste (Sorghum sp.) such as Sorghum bran extract was employed for IONPs production and the degradation of the dye bromothymol blue was monitored using these NPs.[16] Synthesis of magnetite nanoparticles using Plantain peel extract has also been carried out. The authors have suggested the potential of these NPs for bioremediation of toxic metals and dyes.[35] Pomegranate leaf extract was used to synthesize IONPs by Rao et al.,[36] and these NPs were coated on two strains of heat-killed yeast cells, *Yarrowia lipolytica*. It was found that this bionano composite was three times more efficient in the removal of hexavalent chromium than the uncoated yeast cells. Reports on the green route synthesized IONPs have demonstrated the non-toxicity of these NPs when compared with that of NPs produced using the routine sodium borohydride reduction method of chemical synthesis.[37] In another study, Omani Mango tree leaves were employed in the production of IONPs and these NPs were used in the treatment of heavy oil viscosity of the crude oil.[38] The use of synthesized IONPs for diverse applications such as bioremediation of toxic metals[33], in wastewater treatment [34], degradation of organic dyes[16,19,31,32] and pollutants[39] have been investigated. In addition, IONPs produced using leaf extract of a shrub (*Dodonaea viscosa*) have been studied for their antimicrobial activity against different human pathogenic strains.[40] Antibacterial activity of green IONPs towards pathogenic bacteria has also been evaluated in other studies.[41–43] Besides being used for environmental remediation,[44] IONPs have also been used as biosensors,[45] catalysts,[46] ferrofluids[47] and in Magnetic storage media.[48] Further, IONPs have a range of promising biomedical applications. These NPs possess magnetic properties hence they are potential candidates for targeted drug delivery, magnetic hyperthermia, magnetic resonance imaging (MRI) etc.[49–52] Govindan et al. have used IONPs as a drug nanocarrier in anti-cancer drug delivery for the treatment of human epidermoid carcinoma.

Conclusion and future scope of work

Research on metallic NPs, especially IONPs is gaining tremendous attention in the recent years. These NPs have potential biomedical uses besides other environmental applications. However, the large scale production of these NPs is still limited. There is a crucial need to explore the different plant biomaterials for NPs synthesis and optimization of the reaction parameters to achieve bulk quantities of desired NPs for commercial applications. So far there are a large number of reports published on the green route production of silver and gold NPs; however IONPs have been synthesized and evaluated for various applications only at a research level. It is required that these NPs be used on a commercial scale at an urgent basis especially for biomedical uses such as cancer treatment since the routine chemotherapeutic methods have a lot of side effects on the patients. Using magnetic field, the injected NPs coated drug could be targeted to the tumour site without damaging the normal healthy cells thus leading to a specific approach of site directed killing of cancerous cells.

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Conflict of interest

Authors declare that there is no conflict of interest.

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