Magnetic Nanoparticles in Food Industry: Paving the way for enhanced Food Safety and Quality

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Introduction

The novel class of materials combining the magnetic properties with excellent material properties of nanomaterials have resulted in the emergence of magnetic nanoparticles. They are characterised by its unique size, shape, morphology, surface chemistry and magnetic moments that has increased in application portfolio to the fields of medicine, food safety, bio processing, electronics, data storage, energy, catalysis reactions and environmental remediation. The extremely lower size with corresponding higher surface to volume ratio and interesting surface chemistry confers unique material properties both physically and chemically. Magnetic responsive elements such as iron, cobalt, nickel and their alloys are known to exhibit super magnetism at its reduced size (1-100 nm) exhibiting single domain and are found to be highly susceptible to external magnetic field. To say in brief, these magnetic nanoparticles are in extremely sensitive state of receptance to any external magnetic field. Due to its saturation magnetisation, good biocompatibility, versatility, non-toxicity, lower cost of production and its ability to manufacture at larger scale, magnetic nanoparticles have gained the attention in food quality assessments. The conventionally used material of interest is limited to magnetite (Fe_2O_3) and its oxidised form - maghemite (γ-Fe_2O_3) due to its abundance in availability, and versatility. The other commonly used source for MNP are metals (cobalt, nickel), oxides and alloys of metals. The limitations of corrosion and agglomeration are reduced by the use of coatings and modification treatments that will enable to perform in wide range of materials.

Synthesis of Magnetic Nanoparticles

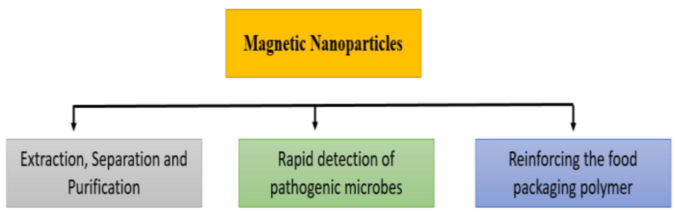
Synthesis of magnetic nanoparticles collaborates the field of material science, fluidics, physics and chemistry in its organisation and arrangement. The synthesis occurs in different shapes and formats such as cubes, rods, disks, tubes, plates, hexagons, octahedrons, truncated octahedrons, tetrahedrons, octopods, tetrapod rings, flowers, and concave shaped each suiting to different applications. Nanomaterials in general gets synthesised from top-down approach and bottom-up approach. The top-down approach follows the breakage of bulky matrix to materials of nanoscale thus eventually consuming more of energy and expense in the process. Ball milling, ultrafine grinding, electron beam lithography, attrition is some of the methods followed in top-down approach. The bottom-up approach tends to synthesise nanomaterials by precise combination or reaction mechanism leading to complexation and synthesis. It follows the combination mechanism of individual atoms and molecules to form nanomaterials. Methods such as co-precipitation, sol-gel method, microemulsion, chemical reduction etc, which are being limited by its higher cost for energy, eventually releasing toxic residues in the system. Owing to the sustainable concept of green synthesis approach, plants and microbe mediated magnetic nanoparticles are gaining rapid momentum. Due to the ability of plants and microbes to host several type of reducing and stabilising agents this method has attracted increased response and various sources have been explored to increase the scope and synthesis of magnetic nanoparticles.

Magnetic Nanoparticles in Food Industry

Separation and Purification procedures

The complexity of extraction procedures with repeated centrifugation and filtration steps has attracted the magnetic nanoparticles to refine and redesign the conventional approach of food sampling and analysis. The use of MNP in sampling ultra trace quantity of targeted compound by behaving as a sorbent molecule delivers the higher recovery of analyte with reduced time constraint (Fig 1). This has promoted the yield of innovations in the field of extraction chemistry particularly in the solid phase micro extraction (SPME). In brief, the MNP embedded sorbent matrix is placed in a suspension or aliquot of interest that attracts the required analyte via dipole-dipole, dipole-induced dipole, ionic interaction, dispersive forces in case of non-polar analyte and Vander walls force or hydrophobic interaction with polar analyte. The adsorbed analyte gets further desorbed via solvent system assisted with external magnetic field. Hence this process dismisses the cumbersome procedure of separation and filtration. The choice of sorbent materials is not limited to the carbon derived materials (graphene, fullerene, nanotubes, nanofibers, nanohorns), polymers (alginate, chitosan, dextran, polystyrene, polydopamine), and metal organic frameworks. Often there is a requirement for modification to cater the extraction of various chemical species with differing functional groups or reduce the aggregative effects of MNP. Various coatings in the group of organic acids, inorganic acids, surfactants, and ionic liquids are used that can aid in enhanced dispersion, and protect from acidic groups.

Detection of microbes



Global food industry is faced with the challenge pressure to reduce the food borne disease outbreaks occurring due to contamination of the produced food. The process is highly complex requiring the necessity to reduce the microbial build up and culminate the source of infection in the supply chain. Conventional procedure to enumerate the microbial count is highly reliable but is faced with the issue of time constraint and its laborious nature of culturing and counting. The present world situation demands the technology that is highly sensitive with greater limit of detection (LOD). MNPs owing to its smaller size, larger surface volume and enormous magnetism tend to assist the microbial detection strategy. The property of supermagnetism is used to selectively remove or concentrate or extract the microbial species based on electrostatic interactions, covalent bonding etc. Immunomagnetic separation by surface modification of MNP with additives such as aptamers (nucleic acid), antibodies (IgG antibodies), antibiotics (vancomycin, gentamycin), biomolecules (carbohydrate, protein) acts as recognition moieties for the specific cell surface attachments which in turn assist in recognising microbial species (Fig 2). As the bacteria tends to possess net negative charge owing to teichoic acids and lipopolysaccharides, modifying the MNP with functionalised materials to induce positive charge assist in enhanced adhesion strategies thereby detecting the targeted microbial pathogens.

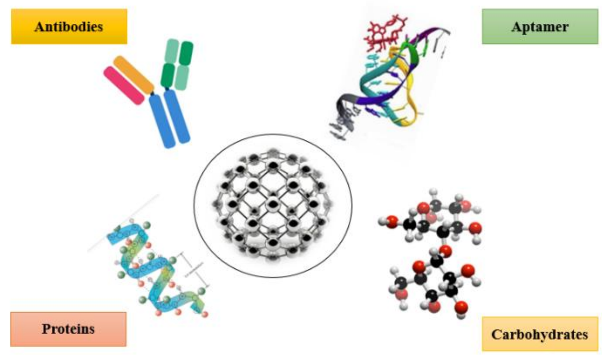


Fig 2: Surface modification for pathogenic bacteria detection

Food Packaging

The material property of MNP supports the packaging functionary of enhanced thermal, barrier and mechanical properties. They are particularly used in smart packaging systems where the primary intention is to deliver the functionality to the inert packaging matrix either by incorporating active materials (oxygen scavengers, ethylene scavengers) or by monitoring the status of food during the supply chain via sensors. Specifically, these MNP are known for antimicrobial activity owing to disrupt the DNA synthesis machinery and the associated enzyme activity. The MNP can be impregnated or embedded in food coatings, labels and film matrices that can function either by pH sensing, temperature monitoring and real time sensing of volatile and gas molecules.

Conclusion

Magnetic nanoparticles (MNP) hold significant potential in the food, pharma and biomedical avenues purely owing to its material characteristics. In special interest to food industry, MNP are the present-day requirement for enhancing food safety, quality and preservation. The smaller size with larger surface area coupled with enhanced biocompatibility, lower toxicity, ease of production and modification has broadened the scope and application perspective of MNP. Given the increasing benefits of MNP, no doubt these materials play a greater role in the green chemistry and extraction protocols thereby lowering the use of harmful solvents and lowering the burden of residual management. However, there is a scope for further refinement in terms of the miniaturisation of the matrix allowing the simultaneous detection or capture of several metabolites. Future works shall integrate the concept of automation and artificial intelligence (AI) to further strengthen the quality detection principles.

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