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Nanotechnology in food preservation

Priyanka Singh

Nanotechnology deals with the atoms, molecules, or the macromolecules with the size of approximately 1–100 nm to create and use materials that have novel properties. The created nanomaterials possess one or more external dimensions, or an internal structure, on the scale from 1 to 100 nm that allowed the observation and manipulation of matter at the nanoscale. In functional foods where bioactive component often gets degraded and eventually led to inactivation due to the hostile environment, nanoencapsulation of these bioactive components extends the shelf-life of food products by slowing down the degradation processes or prevents degradation until the product is delivered at the target site. Microbial contamination has been leading to pathogenic infections and poor nutrition associated with foods. Novel nanoantimicrobials have shown promising effects on safeguarding food deterioration.Nano-based “smart” and “active” food packagings confer several advantages over conventional packaging methods from providing better packaging material with improved mechanical strength, barrier properties, antimicrobial films to nanosensing for pathogen detection and alerting consumers to the safety status of food.In this review, we mainly focus on the technology of nanoencapsulation in food preservation, and also discussed some negative facts associated with this technology.

Key Words : Nanotechnology, Nanoantimicrobials, Nanosensing, Nanoencapsulation

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INTRODUCTION

Nanotechnology deals with the atoms, molecules, or the macromolecules with the size of approximately 1–100 nm to create and use materials that have novel properties. The created nanomaterials possess one or more external dimensions, or an internal structure, on the scale from 1 to 100 nm that allowed the observation and manipulation of matter at the nanoscale. It is observed that these materials have unique properties unlike their macroscale counterparts due to the high surface to volume ratio and other novel physio-chemical properties like colour, solubility, strength, diffusivity, toxicity, magnetic, optical, thermodynamic, etc. (Rai *et al*., 2009 and Gupta *et al*., 2016).

AUTHOR FOR CORRESPONDENCE

Priyanka Singh, Babasaheb Bhimrao Ambedkar University, **Lucknow (U.P.) India**
(Email : priyankasinghbbau@gmail.com)

The major factors affecting food deterioration include the following: Growth and activities of micro-organisms, principally bacteria, yeasts and moulds, activities of food enzymes and other chemical reactions within food itself, infestation by insects, parasites and rodents, inappropriate temperature for the given food, either the gain or loss of moisture, reaction with oxygen, light, physical stress or abuse and time.The most important means of controlling bacteria, yeasts and moulds are heat, cold, drying, acid, sugar, salt, smoke, air, chemicals and radiation. As for preservation against such factors as moisture, dryness, air and light, protective packaging is the major means employed to retard losses.

In functional foods where bioactive component often gets degraded and eventually led to inactivation due to the hostile environment, nano encapsulation of these bioactive components extends the shelf-life of food products by slowing down the degradation processes or prevents degradation until the product is delivered at the target site. Microbial contamination has been leading to pathogenic infections and poor nutrition associated with foods. Novel nanoantimicrobials have shown promising effects on safeguarding food deterioration. Nano-based “smart” and “active” food packagings confer several advantages over conventional packaging methods from providing better packaging material with improved mechanical strength, barrier properties, antimicrobial films to nanosensing for pathogen detection and alerting consumers to the safety status of food (Mihindukulasuriya and Lim, 2014).

In this review, we have mainly focused on the nano-technology in food preservation and also discussed some negative facts associated with this technology.

Role of nanotechnology in food preservation through encapsulation technique:

The edible nano-coatings on various food materials could provide a barrier to moisture and gas exchange and deliver colours, flavours, antioxidants, enzymes and anti-browning agents and could also increase the shelf-life of manufactured foods, even after the packaging is opened (Weiss *et al*., 2006). Encapsulating functional components within the droplets often enables a slowdown of chemical degradation processes by engineering the properties of the interfacial layer surrounding them. The term nanoencapsulation describes the application of encapsulation on the nanometer scale with films, layers, coverings, or simply microdispersion. The encapsulation layer is clearly of nanometer scale forming a protective layer on the food or flavour molecules/ingredients. Often the active ingredient is in the molecule or nano state. The major benefit is that the homogeneity imparts, leading to better encapsulation efficiency, as well as physical and chemical properties. The protection of bioactive compounds, such as vitamins, antioxidants, proteins and as well as carbohydrates, may be achieved using this technique for the production of functional foods with enhanced functionality and stability (Sekhon, 2010). Nanotechnology derived food packaging materials are the largest category of current nanotechnology applications for the food sector (Duncan, 2011). These applications include incorporating nanomaterials to improve packaging properties (flexibility, gas barrier properties,temperature/moisture stability); incorporating nanoparticles with antimicrobial or oxygen scavenging properties; ‘Intelligent’ food packaging with nanosensors can monitor and report the condition of the food; biodegradable polymer nanomaterial composites.

Production technique of nanocapsule:

In general, the production of nanoparticles can be performed by both the “top- down” and”bottom-up” techniques and nanocapsules are not an exception. For the former approach, the nanonization is achieved by the application of energy, while for the latter; the aggregation of molecules, monomers, ions, or even atoms is controlled physico-chemically to form the nanocapsule.

The top down technique includes emulsification, solvent extraction, high pressure and homogenization. The bottom up technique includes coacervation, nanoprecipitation, inclusion complexation and supercritical fluid. The top up and bottom up techniques of nanotechnology has been described as below.

Emulsification:

The emulsification process allows mixing two liquids which are normally immiscible using aninterface agent (surfactant). This process permits the incorporation of a lipid into an aqueous media or *vice versa* by forming droplets (dispersed phase) which remain dispersed into a continuous phase (Solans *et al*., 2005).

Solvent extraction:

Most of the nanocapsule production techniques are performed in a solvent media. It is well known that the presence of solvents entails a number of disadvantages, such as risk of microbial contamination, increased costs and physico-chemical instability. In this context, it might be necessary to eliminate the solvent to make way to a redispersible powdered form. To this purpose, most popular techniques are spray drying and lyophilization.

High pressure homogenization:

As an advanced nanonization strategy, HPH offers an excellent choice for producing high-quality drug nanoparticles on an industrial scale. Two homogenization principles are applied; Piston gap fluidization and microfluidization.

Coacervation:

The coacervation technique involves the phase separation of a single or a mixture of polyelectrolyte from a solution and the subsequent deposition of the newly formed coacervate phase around the active ingredient. Further, a hydrocolloid shell can be cross-linked using anappropriate chemical or enzymatic cross-linker such as glutaraldehyde or transglutaminase, mainly to increase the robustness of the coacervate (Zuidam and Shimoni, 2010).

Nanoprecipitation:

The nanoprecipitation method is also called solvent displacement. It is based on the spontaneous emulsification of the organic internal phase containing the dissolved polymer, drug and organic solvent into the aqueous external phase.The nanoprecipitation technique involves the precipitation of a polymer from an organic solution and the diffusion of the organic solvent inthe aqueous medium. The solvent displacement forms both nanocapsules and nanospheres. Biodegradable polymers are commonly used, especially polycaprolactone (PCL), poly (lactide) (PLA) and poly (lactide-co-glicolide) (PLGA), Eudragit, poly (alkylcyanoacrylate) (PACA) (Reis *et al*., 2006 and Ezhilarasi *et al*., 2013).

Inclusion complexation:

Inclusion complexation generally refers to the encapsulation of a supramolecular association of a ligand (encapsulated ingredient) into a cavity bearing substrate (shell material) through hydrogen bonding, van der Waals force or an entropy-driven hydrophobic effect.

Supercritical antisolvent precipitation:

In this technique, the bioactive compound and the polymer were solubilized in a supercritical fluid and the solution was expanded through a nozzle. Then the supercritical fluid was evaporated in the spraying process and solute particles eventually precipitate (Reis *et al*., 2006). This technique has been widely used because of its low critical temperature and minimum use of organic solvent. Lutein and phytosterol nanoparticles were obtained by supercritical fluid with particle sizes of 219 and 500 nm, respectively (Jin *et al*., 2009; Türk and Lietzow, 2004).

Carrier material generalities:

Different types of materials can be used as building blocks to create nanostructures as nanoliposomes, nanoemulsions, nanoparticles and nanofibers. Nanomaterials used in food applications include both inorganic and organic substances (Sekhon, 2010). Typically, nanocarrier systems can be carbohydrate, protein or lipid based .Carbohydrate and protein based nanocapsules, do not have potential of fully scale up, due to the requirement of complicated chemical or heat treatments. On the other hand, lipid based nanocarriers have the possibility of industrial production and bear advantage of more encapsulation efficiency and low toxicity (Fathi *et al*., 2012).

Lipids based nanosystems:

The main lipid-based nanoencapsulation systems that can be used for the protection and delivery of foods and nutraceuticals are nanoliposomes, nanocochleates and archaeosomes (Sekhon, 2010).

Nanoliposomes:

Temperature-sensitive liposomes can be produced by the modification of the lipid bilayers with specific polymers.

Colloidosome:

Colloidosomes are capsules made of particles one tenth the size of a human cell and assemble themselves into a hollow shell. Molecules of any substance can be placed inside this shell (fat blockers, medicine and vitamins).

Nanocochleates:

Nanocochleates are nano coiled particles that wrap around micronutrients and have ability to stabilize and protect an extended range of micronutrients and the potential to increase the nutritional value of processed foods (Thangavel and Thiruvengadam, 2014).

Nanoemulsions:

The use of high homogenizers or microfluidizers often causes emulsions with droplet diameters of less than 100 to 500 nm, these emulations are often called "nanoemulsions". Functional food components can be incorporated within the droplets, the interfacial region, or the continuous phase.

Solid lipid nanoparticles:

Solid lipid nanoparticles (SLN) are formed particles consisting of a matrix made of solid lipid shell, formed by controlled crystallization of food nanoemulsions (Awad *et al*., 2008).

Polymeric type nanoparticles:

Research into the production and use of biodegradable polymers for their use in the manufacturing of dispersed systems began 70 years ago. Polymeric nanoparticles are generally developed to obtain controlled release and targeted delivery of functional compounds. They are made using polymers and surfactants. Biopolymer nanoparticles are highly bioactive solid particles with diameters of 100 nm or less.

Nanocomposites:

They are fine nanoparticulates (100 nm or less) incorporated into plastics in order to improve the properties over those of conventional counterparts. Polymer nanocomposites are thermoplastic polymers that have nano-scale inclusions (nanoclays, carbon nanoparticles, nanoscale metals and oxides and polymeric resins), 2 per cent - 8 per cent by weight.

Nanofibres:

An emerging technology is the production of nanofibre. These fibres have diameters of less than 100 nm, produced by the electrospinning process. Electrospinning is capable of producing thin, solid polymer strands from solution by applying a strong electric field to a spinneret with a small capillary orifice. Fibres used in food and agriculture are not typically composed of biopolymers; they are made primarily from synthetic polymers. As progress in the production from food biopolymers is made, the use of biopolymeric nanofibers in the food industry will increase.

Carbohydrate based nano systems:

Polysaccharides, due to their massive molecular structure and ability to entrap bioactives are suitable as building blocks of delivery systems.Thus, they are widely used as safe and inexpensive ingredients (Fathi *et al*., 2014).

Starch-starch:

Which is the most abundant storage polysaccharide in plants, is a biodegradable,biocompatible and digestible polymer, that has been used to encapsulate insulin, flax seed, unsaturated fatty acids and flavours (Li *et al*., 2010; Chung *et al*., 2008 and Fathi *et al*., 2014).

Cellulose:

Has been physically, chemically and biochemically modified to be used as an encapsulating agent (Ozeki *et al*., 2011; Jin *et al*., 2009 and Alonso *et al*., 2010). Cellulose esters are modified celluloses that are divided into two categories: non-enteric and enteric esters. Non-enteric cellulose esters are insoluble in water across a wide range of pH values. As a consequence they are not suitable for encapsulation. On the other hand, enteric cellulose and cellulose esters [acetate phthalate (CAP) orhydroxypropylmethyl cellulose phthalate (HPMCP)] are insoluble in acidic solutions, but soluble in mildly acidic to slightly alkaline solutions, so they are widely used as encapsulating agents (Alonso *et al*., 2010 and Ozeki *et al.,* 2011)

Pectin:

Pectin is a linear anionic polysaccharide. It is resistant to enzymatic digestion in the mouth and stomach, but is degradable by the microbiome in the colon, which makes it suitable for delivery of acid sensitive food bioactives. It is usually classified according to the degree of esterification: low methoxyl (LM) pectin and high methoxyl (HM) pectin. LM can form gels in the presence of divalent calcium ions, whereas HM can form gels.

Guar gum:

Guar gum is a water soluble polysaccharide derived from the seeds of cyamopsis tetragonolobus. This biopolymer has been used as thickening, emulsification, and retrogradation retardant agent in food products. It is soluble in cold water and forms a gel-like structure in hot water. It has been depolymerized to obtain a low molar mass, water-soluble fibre by different methods of hydrolysis (Fathi *et al*., 2014).

Chitosan:

Chitosan, a natural linear, cationic, biocompatible, and biodegradable polymer, is obtained by alkaline deacetylation of chitin. It also has antimicrobial and antioxidant activity (Alonso *et al*., 2010). Chitosan exhibits pH-sensitivity as it dissolves easily at acidic pH values (pH< 6.5), but is insoluble at higher pH ranges.This polymer was also physical or chemical modified to extend or improve its functional properties (Fathi *et al*., 2014).

Alginate:

Alginate is a linear polysaccharide extracted from brown sea algae. It has been used for the encapsulation of lipid nanoparticles, lipase and different essential oils (Rojas-Graü *et al*., 2007; Belšèak-Cvitanovic *et al*., 2011 and Yeh *et al*., 2011). Due to its hydrophilic properties, this biopolymer has potential for entrapment of hydrophilic food bioactives.

Dextran:

Dextran is a bacterial polysaccharide of glucan, composed of chains of varying length of glucose. It is a linear polysaccharide containing hydroxyl groups, used for the covalent attachment of various organic functional groups, especially hydrophobic compounds.

Cyclodextrins:

Cyclodextrins (CDs) are well-known truncated cone shape oligosaccharides. They possess a lipophilic central cavity and a hydrophilic outside surface. They are able to form inclusion complexes with hydrophobic food bioactives entrapped in the inner cavity.

Proteins based nanosystems:

The benefits of protein nanoparticles include non-toxicity, stability for long duration, non-antigenicity and biodegradability (Hilty *et al*., 2009).

Application of nanotechnology in food:

Nanotechnology has been used for the production of food additives (benzoic acid, citric acid and ascorbic acid), dietary supplements and functional food ingredients (vitamins A and E, lipoic acid, soybean isoflavones, β-carotene, lutein, omega-3 fatty acids and coenzyme Q10) (Mohammadi *et al.*, 2015 and Ezhilarasi *et al.*, 2013). A number of nanomicelle based carriers for nutraceuticals and nutritional supplements have been developed: nanocochleates (50 nm in size), based on a phosphatidylserine carrier derived from soya bean, generally regarded as safe (GRAS).They are obtained by the addition of calcium ions to small phosphatidylserine vesicles. The nanocochleate system is claimed to protect micronutrients and antioxidants from degradation during manufacture and storage. Another application are self-assembled nanotubes, developed from hydrolysed milk protein lactalbumin, which can offer a new naturally derived carrier for nanoencapsulation of nutrients, supplements and pharmaceuticals (Graveland-Bikker and de Kruif, 2006).

Safety issues:

A wide range of nanotechnologies rely on nanoscale components that are confined in closed systems and therefore cannot come into direct contact with organisms, neither the human body nor bacteria in the environment. Thus exposure is close to zero, reducing their risk close to zero as well – apart from the fact that for some nanocomponents, it's even hard to imagine a direct hazard at all.

Nanostructures in the food sector may not create a direct effect on human health; however, their nanoscale property may cause some unavoidable side effects. Nanoscale edible coatings have emerged as an attractive alternative to preserve food quality, extend storage life, and prevent microbial spoilage , allowing direct exposure of humans to nanomaterials. Nanoparticles from engineered or other nanomaterials can enter the body by inhalation, ingestion or by dermal penetration. Toxicity of nanoparticles depends on their properties and rout of entrance in the body, concentration and duration of exposure to nanoparticles, but also on individual susceptibility and state of organism. Results when oral route of transmission was studied showed that signs of toxicity were noted only with relatively high doses of nano silver or nano -TiO_2 applied (Aschberger *et al*.,2011).

Conclusion:

Nanotechnology has a great scope in prolonging the shelf-life of food product. The use of an appropriate nanotechnique can help in the production of high quality and wholesome food product. However, the study on nanotechnology also need to focus on the potentially adverse effects of nanoparticales on the human body. There is urgent need for regulatory systems capable of managing any risk associated with food.

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