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Potential Application of Nanotechnology in Food Processing and Packaging: A Review

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A B S T R A C T

The application of nano materials in agricultural industry has the potential to ensure food and nutritional security for the developing world, as they can potentially develop favourable interactions with various biomolecules. Nanotechnology consist of creating and manipulating organic and inorganic substance at the nanoscale. The manipulation of food polymers to provide improved food quality and safety. New ideas based on nanotechnology are being explored to develop product functionality and delivery efficiency. It promises to provide the means for designing nanomaterials which is made physical, chemical and biological properties. Application of nanobiotechnology exist in all of the traditional areas of biotechnology such as in the field of food and agriculture for example the design of biosensors for detecting pathogens, spores, meat tenderness, food spoilage and food adulteration and provide contamination free food and to ensure the consumer acceptability of the food with enhanced functional properties. This new field of technology will also arise a number of ethical and social issues as the new pathological agents or new ways of delivering them can be developed and can be used for many purposes. This review talks not only the current and future use of nanotechnology in the biological sciences, but also the significant ethical ramifications of such applications.

Introduction

Nanoscience is the study of structure and material of substances at atomic, molecular, and macromolecular scales, here properties differ significantly from those at a larger scale. Nanotechnology consist of the classification, fabrication and or manipulation of structures, devices or materials that have at least one dimension is approximately 1-100nm in length (Dancan, 2011). Materials at a nanoscale have markedly different properties to those at the macroscale. This means nanomaterials offer exciting new benefits to many applications, including food. While nanotechnology is used across a variety of different industries, from electronics to building and pharmaceuticals, there are only a small number of applications in the food sector. Where it is used in food, the application of nanotech is mainly concerned with supplements and packaging.

Applications of nanotechnology have emerged with shelf-life extension of food products and need of nanoparticle uses in various fields such as Food processing, food packaging, Food microbiology, functional food development, food safety, and detection of foodborne pathogens. The potential aspects of nanotechnology to increasing organoleptic properties and nutritional value of foods (Trepti Singh *et al.,* 2017).

Nanostructures present in foods are already common stabilizers, the stabilization of emulsions using an emulsifier at the interface of the oil and water in spreads or dressings like egg in mayonnaise. This is an emulsifier with protein and thin interface is present at the nano scale (less than 100nm) around the oil droplets and separate the water and oil and avoid pooling in the bottle or container. It also keeps the oil droplets at the right size to give a creamy texture and preventing microbial growth.

Nanotechnology in Food Processing

Nanotechnology is applied in the development of encapsulation, biopolymer matrices, emulsions, simple solutions, and association colloids offers effective delivery systems. Nanosensors can be used to prove the presence of mycotoxins, contaminants, and microorganisms in food (Bratovčić, 2015). Nano polymers are used to replace conventional materials in food packaging. With the help of nanotechnology the shelf-life of different kinds of food materials is increased and also brought down the extent of wastage of food due to microbial infestation (Pradhan *et al.,* 2015). Nanocarriers are utilized as delivery systems to carry food additives in food products without upsetting their basic morphology. Particle size may directly affect the delivery of any bioactive compound to various sites within the body (Ezhilarasi *et al.,* 2013). Nanoparticles hold better properties for encapsulation and release efficiency than traditional encapsulation systems. Nano encapsulations covers tastes or odors, control the release of the active agents, control interactions of active ingredients with the food matrix, protect them from moisture, heat and ensure availability at a specific rate and target time (Ubbink and Kruger, 2006). Chemical and biological degradation during processing, storage, and utilization, and also exhibit compatibility with other compounds in the system (Weiss *et al.,* 2006).The nanostructured food ingredients are developed and offer improved taste, texture, and consistency (Cientifica Report, 2006).

Nanotechnology has effective applications in all aspects of food processing, food packaging and food monitoring. Manufacturing of functional foods like chocolate, chips, ice cream and soft drinks are marketed as healthy foods by reducing carbohydrate, fat, or by increasing protein, fibre or vitamin contents and calorie content. Development of foods capable of modifying their colour, flavour or nutritional properties according to a person's dietary needs (Alfadul, 2010).

Nanotechnology for controlled release

Nanotechnology alter and manipulate food products and more efficient, effective deliver nutrients, protein, antioxidants to target nutritional and health benefits to a specific site in the human body. Nanotechnology to encapsulate certain nutrients, flavour, colour and release then upon need. System consist of Nanospheres composed of a blend of food approved hydropholic materials encapsulated in moisture sensitive or pH-sensitive. Nanospher are made of starch derivatives, natural polymer, natural genes.

Nanotechnology systems used in baked goods and meat.

Nutritional value

A majority of bioactive compounds such as lipids, proteins, carbohydrates, and vitamins are sensitive to high acidic environment and enzyme activity of the stomach and duodenum. The nanostructuration, nano-emulsification and nanocomposite are the different type of techniques. Bioactive compound's (e.g., Flavonoids, Protein, Vitamins and Antioxidants) encapsulation not only assists them to resist such adverse conditions but also allows them to assimilate readily in food products.

A bioactive compounds consists of many proteins, lipids carbohydrates, and vitamins are sensitive to high acidic environment and enzyme activity of the stomach and duodenum. The aim of Nanoparticles-based edible capsules is to improve delivery of medicines, vitamins or fragile micronutrients in the daily foods are being created with to provide significant health benefits (Yan and Gilbert, 2004; Koo *et al.*, 2005).

Nanotechnology also deal with means of modifying food products to more efficiently deliver nutrients like protein and antioxidants for precisely targeted nutritional and health benefits. Shefer developed the encapsulated system, which resulted in nanospheres or microspheres (Shefer and Shefer, 2003a).

The major potential product applications for the nano-sphere system are baked and frozen foods, confectionery, chewing gums, processed meat products, seasonal specialty products, dessert mixes flat breads, and nutritious foods also (Shefer and Shefer, 2003a, Shefer and Shefer, 2003b, Shefer and Shefer).

Nanotechnology in Food packaging

Food packaging can increase shelf life of food products by providing suitable environment like separating moisture, light and oxygen (Wesley *et al.*, 2014; Pal 2017). The packaging materials not only contribute to the physical protection but also protect from physicochemical changes.

The novel nanopackaging enhances the shelf-life of food such as active, intelligent and bioactive packaging material and providing better packaging material with improved mechanical strength, barrier properties, and antimicrobial films to nanosensing for pathogen detection and alerting consumers to the safety status of food (Mihindukulasuriya and Lim, 2014).Many researchers were interested in studying the antimicrobial properties of organic compounds like essential oils, bacteriocins and organic acids (Gálvez *et al.*, 2007; Schirmer *et al.*, 2009) and their use in polymeric matrices as antimicrobial packaging.

Polymer nanocomposites are mixtures of polymers with organic and inorganic fillers with particular geometries (flakes, fibers, particulates, and spheres) have been introduced as novel packaging materials (Prateek *et al.*, 2016). Different type of nanomaterials like chitosan (Chang *et al.*, 2010), cellulose-based (Sandquist, 2013), silica (Bracho *et al.*, 2012),polysaccharide nanocrystals (Lin *et al.*, 2012) and other metal nanoparticles, such as, ZnO_2 (Esthappan *et al.*, 2013), Ti (Li *et al.*, 2011) are being extensively explored as fillers. The improvement of packaging through nanocomposites like Chitosan nanocomposites is a heteropolysaccharide is known for its biodegradability, biocompatibility along with metal complexation. The nature of chitosan is mainly acts as a antimicrobial activity in packaging (Arora *et al.*, 2016).

Active Nano packaging

Active packaging can be defined as the packaging, which protect inert barrier between food product and external environment. The nano-based active packaging involves the incorporation of nanomaterials in the packaging system and it can also enhance the quality of food (Restuccia *et al.,* 2010; Echegoyen 2015; Momin; Pal 2017 and Joshi 2015).Active substances used in the ideal packaging improve and manipulation of packaging environment. The internal environment of food by absorbing O_2, CO_2, ethylene, flavor, moisture and other gaseous compounds which promote food preservation (Brody 2001; Wesley *et al.,* 2014; Momin and Joshi 2015). The components of active packaging divided into three parts (1) nanocomposites (metal nanoparticles like Ag, Cu, TiO_2 and MgO_2 magnesium oxide) (2) antimicrobial film (3) gas scavengers (Lee *et al.,* 2015).

Oxygen scavengers-incorporated active packaging materials can be used to prevent oxidation reaction and increase shelf life of food (Echegoyen 2015).

Oxygen absorber such as ferro compound, Ascorbic acid, gluco-oxidase and metal salts.

Carbon dioxide scavenges such as Ca (OH)2, NaOH and KOH.

Ethylene Scavengers such as KMnO4, Activated carbon and zeolite.

Smart or Intelligent nanopackaging

Intelligent packaging is a type of labeling. It is give information about the physical, chemical properties of food. Its internal packaging environment of package like temperature, pH, and chemical contaminants. Oxygen scavengers are also used in the intelligent packaging as it prevents the microbial growth, removes off flavours and off odours, prevents colour change, etc. Nanomaterials can be used for this aim leading to the maintenance of food quality (Echegoyen 2015; Ramachandraiah *et al.,* 2015).

The most promising use of smart packaging is the detection of moisture content in food. Nanoparticles is used to measure the changes in pH of food packaging material (Martins *et al.,* 2012) and incorporated with iron oxide nanoparticles also then acts as humidity sensor and measure humidity (Taccola *et al.,* 2013).

Incorporating nanosensors to monitor and report on the condition of the food. Nanosensors communicate the degradation of product or microbial contamination. (Bouwmeester *et al.,* 2009) and also give the history of storage and period of storage. Zinc Oxide and titanium dioxide nanoparticles are used to detect organic volatile compounds like (Ethanol and gaseous amine) with the help of nanofibers of perylene- based flurophores.

Benefits of Nanotechnology in Packaging

Many types of nanosensors used in the food packaging industries such as nanoparticles based sensors, electronic noses, array biosensors, nanoparticle in solution, Nano cantilevers, and nano-test strips. Pellets and containers throughout the food supply chain and Packaging with nano-sensors is useful to trace the external or internal conditions of food products. Nanosensors in plastic packaging to detect spoilage of foods and inside of packaging itself changes the color to alert the consumer.

Table.1 Food application of Nano-materials

Type of nano-materials	Proposed effect	Potential applications in Foods	References
Inorganic Nano-materials:			
Titanium dioxide nanoparticles	Photocatalysis mediated activation of Titanium Oxide induces the formation of free redicals which eliminates S.aureus, E. coli, E. faecalis, P. aeruginosa Light driven Oxygen scavenging packaging system. Titanium Oxide produces scattering of visible light thereby induces whitening effect in chewing sweets, candies, gums etc.	Active packaging- Antimicrobial Titanium Oxide-Ethylene vinyl hydroxide nancomposite films Food additive- Colour additive Active packaging- Oxigen scavenging Titanium Oxide coated glass and acetate films	Maneerat and Hayata,2006
Silver nanoparticles	Antibacterial activity agaist E.coli and S. aureus	Active packaging: PVA-cellulose- Silver nanoparticles composite film	Sadeghnejad *et al.*, 2014
Zinc Oxide	Hydrogen peroxide generation from ZnO surface exhibited antibacterial property against S. aureus and E. coli thereby increasing the shelf life of apples	Active Packaging- PVC Nano ZnO coated antimicrobial film	Li *et al.*, 2011
Organic Nano-materials			
Carbon tubes	Encapsulation of allylisothiocyanate into carbon nanotubes and its effective release into packaged chicken meat reduced microbial contamination and controlled oxidation on storage	Encapsulation of allylisothiocyanate into cellulose- allylisothiocyanate carbon nanotubes composite film.	Dias *et al.*, 2013
Cellulose nanofibers	Improves the tensile strength moisture barrier properties and thermal characteristics of the film.	Food packaging- All-cellulose nanocomposite film	Ghaderi *et al.*, 2014
Chitosan nanoparticles	Increase shelf-life of tomato by curing antibacterial activity against S. aureus and E. coli and B. subtilis.	Active Packaging- PVC Nano chitosan antimicrobial film	Tripathi *et al.*, 2009
Starch nanocrystals	Starch nanocrystals improve tensile strength and modulus of pullulan film.	Food packaging- pullulan films	Arora and Padua, 2010

Table.2 Nano- structured systems for delivery of nutrients

Delivery systems	Potential applications	Descriptions	References
Nano- emulsions	Delivery and stabilization of lipophilic compounds	Stable dispersion, droplet size on order of 100 nm, uses different lipids and emulsifiers	McClements *et al*.,2009 Wang, *et al*.,2014 Singh, *et al*.,2012 Harjinder Singh, 2016 Tadros, *et al*., 2003 Flanagan, *et al*., 2006 Van der Linden, *et al*., 2007
Solid lipid nanoparticles	Delivery and stabilization of hydrophobic materials	Emulsified systems made with crystalline or semi-crystalline	
Liposomes	Delivery of both hydrophobic and hydrophilic compounds	Vesicles formed with phospholipid bi-layer with aqueous interior.	
Casein micelles	Delivery of minerals, proteins and vitamins	Self-assembled nanostructures in milk size range 20-300nm	
Microemulsions	Solibilisation and delivery of hydrophobic and hydrophilic compounds	Stable mixtures of water, Oil and surfactants. Size range 5-100nm	
Protein nanoparticles	Delivery of various hydrophilic compounds, provide nanoscale structure tofood to affect texture and mouthfeel	Hydrogels and nanoparticles formed by controlled aggregation of proteins	
Protein fibrils	Delivery of various hydrophilic compounds, affect texture of foods	Some proteins can form fibrils and nanotubes under certain processing conditions.	
Protein-polysaccharide nanoconjugates	Delivery of both hydrophobic and hydrophilic compounds	Covalent conjugation or electrostatic complexation between proteins and polysaccharides	

Table.3 Nano-composite biodegradable plastics development and their Purposes in Food Technology

Nano- materials	Purposes	Institute or company
Nanocomposite biopolymer filler unspecified	combustible compostable ,renewable and CO_2 neutral	Australia's Commonwealth Scientific and Industrial Research Organization
Nano composite biopolymers ,filler unspecified	Supplied to 80% of Australian chocolate tray market , including Cadbury Australia	Plantic Technologies, Australia
Nanocomposite biopolymers using Paraloid BPM-500	To strengthen PLA, a biodegradable plastic resin made from corn ,while maintaining the plastic's transparency	Rohm and Haas, USA
Nanocomposite biopolymers using nano clay and other minerals	Nanoclay and other minerals to strengthen bioplastics	Technical University of Denmark and others
Nanocomposite biopolymers using nano clay	To strengthen fiber based, biodegradable packaging , and to make the packaging water repellent	"Sustainpack": 35 research Institutes, Universities and corporate partners from European

Source: (Sulaiman Mohammed Alfadul, 2010)

Fig.1 Role of Nanotechnology in various Aspects

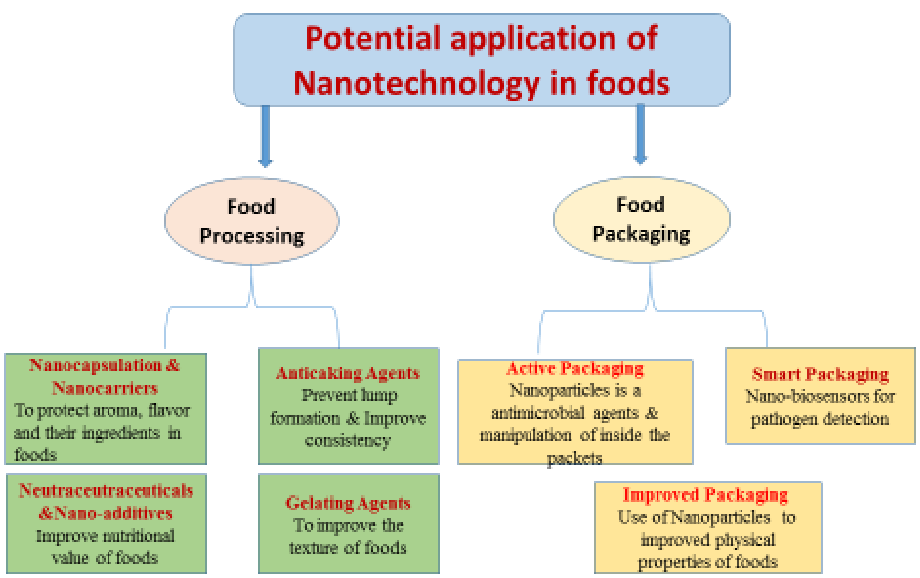
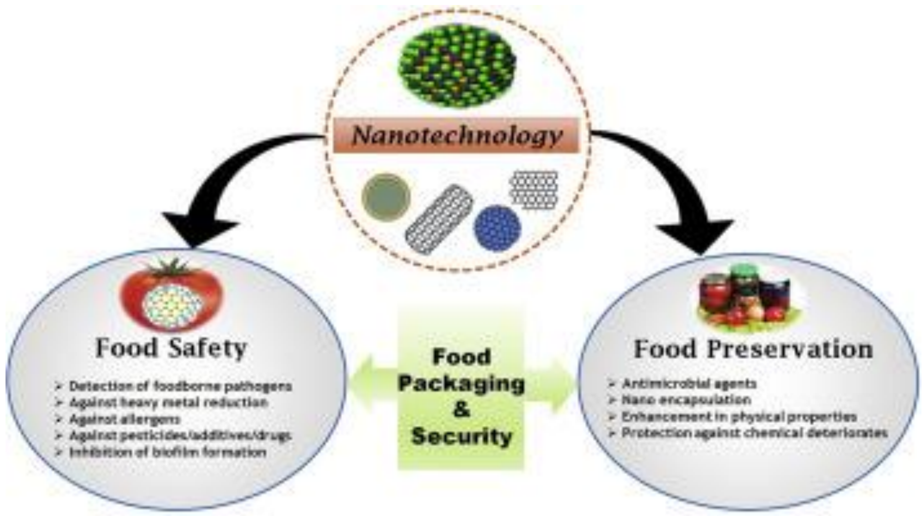


Fig.2 Food Preservation and Safety measures on nanotechnology



The flow of oxygen into the package and leaking of moisture can be reduced with the help of Nanoparticles, which can keep the food fresh. It can prevent the growth of mould inside the refrigerator. Sensors are developed to detect *Escherichia coli* contamination in packaged foods. With the use of nanotechnology, packaging waste associated with processed foods can be reduced.

The preservation of fresh foods and thereby extending their self-life. The recent technology can detect the microbial Pathogens in food products in 2 to 7 days. It is used for detection of toxin, pesticide, and spoilage (Wesley *et al.,* 2014).

Nano Coating

Waxy coating is used for few foods like apples and cheeses. Development of new technology of nanoscale edible coatings. Its thickness is 5nm wide, which are invisible to the human eye. These edible nano-coatings could be used on cheese, confectionery, fruits and vegetables, bakery products and fast foods. They could provide a barrier to gas exchange and moisture, it is act as a vehicle to deliver antioxidants and anti-browning agents, colours, flavours and enzymes. The edible nanocoating is also increase the shelf life of foods (Renton, 2006 and Weiss *et al.,* 2006). The U.S. Company Sono-Tec Corporation announced in early 2007 that it's developed an edible antibacterial nano-coating, which can be applied bakery goods.(El Amin, 2007b).

Packaging material can release nanoscale antioxidants, fragrances, antimicrobials or nutraceuticals, flavours into the beverages or foods to prolong the shelf life and to improve its taste or smell (Nachay, 2007).

Nanotechnology in Preservation

Bioactive component of functional foods often gets degraded and 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. The edible nanocoatings applied on different food material could provide a barrier to moisture and gas exchange and deliver colors, flavors, 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; Renton, 2006).

Encapsulating functional components within the droplets often enables a slowdown of chemical degradation processes by engineering the properties of the interfacial layer around them.

Nanoscience and nanotechnology are very effective in providing new solutions in the development of functional foods, in particular the inclusion of bioactive compounds without affecting the sensory perception of the consumer and improving the uptake of certain components.

Nano science is described as the study of phenomena and the manipulation of materials at the atomic, molecular, and macromolecular scales, where the properties differ from those at a larger scale. These terms are used and applied to structures less than 100 nm in size in one dimension.

Safety measures on nanotechnology

We could recommend that there is an urgent need for safety regulation of nanomaterials before their incorporation into packages, during processing. Nanomaterials must not cause any health risk for consumers or to the environment. Nano food additives and ingredients are regulated by FSANZ (Food Standards Australia and New Zealand), under the Food Standards Code(Bowman D and G Hodge,2006).Although a material is being considered as generally regarded as safe (GRAS) substance, additional studies must be acquired to examine the risk of its nano counterparts because the physiochemical properties in nanostates are completely differ from that are in macrostate. Besides this, the small size of these nanomaterials may increase the risk for bioaccumulation within body organs and tissues (Savolainen *et al.,* 2010). There are many factors which affect dissolution including surface morphology of the particles, surface energy, concentration, aggregation, and adsorption. In food processing technique that produce nanoparticles and nanoscale emulsions its need to the health implications under the attention of food law. Government also respond to nanotechnology's social, economic and ethical challenges. To ensure new technologies (U. R., 2004).

Application of nanometals as an antimicrobial agents

The nanotechnology applications in food sector can be summarized in two main groups that are food nanosensing and food nanostructured ingredients. Food nanostructured ingredients usea wide area from food processing to food packaging. In food processing, nanostructures can be used as anti-caking agents, antimicrobial agents, food additives, carriers for smart delivery of nutrients, durability of the packaging material, and fillers for improving mechanical strength etc. whereas food nanosensing can be enforced to achieve better food quality and safety evaluation (Ezhilarasi *et al.,* 2013).

Antimicrobial agent used in the food industry. It divide into two groups organic and inorganic composites. Organics are their robustness, stability and long shelf life (Sawai, 2003) and inorganic metal oxide. Nanometals such as Ag (Silver), Zn (Zinc), Cu (Copper), Mg (magnesium) and TiO_2 (Titanium oxide).

Nanometals with antimicrobial activity can be coated onto the surface in many application like water treatment, biomedical devices, food processing and packaging. Silver nanopackaging are used to their high antimicrobial capacity and, Copper-Zinc and Titanium (Cu, Zn) and Ti) nanopackaging in food safety. The bactericidal effects of several nanometals including, Ag, Zn, Cu, and Ti have been well documented (Llorens *et al.,* 2012). The nutraceutical and pharmaceutical industry have developed various Nano particulate delivery systems like associated colloids, nanoemulsion, nanofibers, liposomes, bipolymeric nanoparticles, and nanotubes based delivery systems for the functional foods, supplements or both. The impact of nanotechnology on such products like enhanced packaging, improved delivery system, enhanced uptake, kinetics and distribution inside the body. This is new technology to assure the safe foods and to improve the quality of products.

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