Chapter 3
Nanotechnology in the Food Industry

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Abstract Nanotechnology delivers emerging applications in functional food by engineering biological and synthetic molecules toward functions that are exceptionally changed from those they have originally. Nanotechnology has enhanced the superiority of foods by making them flavoured, nutritive and more healthier. Nanotechnology generates also novel food products, better packaging, coating and shelf storage techniques. Applications in food also improve shelf life, food quality, safety and fortification. Biosensors in food packaging are designed to detect contaminated or spoiled food. Nanotechnology improve food processes that use enzymes to confer nutrition and health benefits. This report reviews applications of nanotechnology in agriculture, and food science and technology. Furthermore, risk assessment, safety concerns and social implications are discussed.

Keywords Food nanotechnology • Agriculture nanotechnology • Food processing • Food packaging • Nanotechnology in food supplements

Contents

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3.1 Introduction

Nanotechnologists are being hopeful that nanotechnology will able to transform the entire scenario of food industry by bringing significant changes in the various processes in the food industry: production, processing, packaging, transportation and consumption of food and food products. Increase and exploitation of nanotechnology in these processes ensures the safety of food and food products and creates a healthy food culture which dominantly enhancing the nutritional quality of foods which is the need of an hour (deAzeredo 2009; Ravichandran 2010; Dasgupta et al. 2017; Shukla et al. 2017; Jain et al. 2016). Moreover smart food packaging systems can be developed using nanotechnology that in turn boosts the shelf-life of food products by developing active antifungal and antimicrobic surfaces, improving properties like heat-resistance and mechanical, modifying the permeation behaviour of foils simultaneously detecting and signalling biochemical and microbiological changes (Neethirajan and Jayas 2011). Implication of nanotechnology in current food processing is creating an incredible impact on the advanced development of interactive and functional foods which deliver nutrients and respond to the body's requirements in an efficient manner (Dunn 2004). Nanocapsules which are added into food products with the aim to deliver nutrients and nanoparticles when added to food and food products increase the absorption of nutrients. Organic and polymeric nanoparticles are being used to deliver vitamins or other nutrients in food and beverages without affecting the taste and appearance of the product. The nutrients are encapsulated by the nanoparticles and carried all the way through the stomach and reaches into the bloodstream. This method applied for delivery of many vitamins in higher percentage of availability of the nutrients to be used by the body because, when nutrients are not encapsulated by the nanoparticles, few of the nutrients would be lost in stomach (Ezhilarasi et al. 2013). Researchers are also engaged in development of nanocapsules containing nutrients that would be released when nanosensors detect a deficiency in of particular nutrient in body. Fundamentally the phenomenon behind this is to construct a super vitamin storage system in body that gives only what body need and when body need. Dominantly nanomaterials are being developed to improve the overall quality viz. taste, color, and texture of foods. Taken an example "interactive" foods are continuously being developed that would allow consumer to choose which flavor and color a piece of food has (Dunn 2004). Nanosensors are enormously developed and improved that can prior detect bacteria and other contaminants on the surfaces of food at a packaging plants. Resultantly this will allow for frequent testings at a much lower cost than usually is acquire by sending samples to a lab for analysis and wait till the results will arrive. This particular packaging testing point is conducted more properly and carefully, has great potential to considerably reduce the chance of contaminated food reaching grocery store shelves.

In August 2006, the US Food and Drug Administration (FDA) formed a Nanotechnology Task Force with goals that include; (i) evaluate the effectiveness of the agency's regulatory approaches and authorities to meet any unique challenge that may be presented by the use of nanotechnology materials in FDA-regulated products. (ii) Explore opportunities to foster innovation using nanotechnology materials to develop safe and effective drugs, biologics, and devices, and to develop safe foods, feeds, and cosmetics. (The US Department of Agriculture 2015) Focusing this goals nanotechnology is having a significant impact on numerous facet of the food industry, from how food is grown to how it is travelled, processed and packaged. Industries are developing nanomaterials that will make a difference not only in the taste of food, but also in food safety, and the health benefits food going to delivers when consumed. Increasing developments in micro- and nanotechnologies are growing at a rapid rate and strongly offers the functional potential to not only improve the products in terms of textural and sensory qualities, stability and health benefits, but also develop new products or manufacturing processes for the food industry. Today food industry is the one of the largest manufacturing sector in the world, with counting an annual turnover approximating US $4 trillion. Worldwide, a large amount of foods are consumed after only minimum processing e.g., fresh fruits, vegetables, nuts, some cereals and with additionally high post-harvest losses considerably with fruits and vegetables (Fig. 3.1) (U.S. FDA 2014).

Nanotechnology offering wide ranges of opportunities for the development and improvement of innovative products and applications in food manufacturing system. Recently developed functional foods, neutraceuticals, bioactive compounds, enriched farmafoods, etc. are highlighted examples of it.

Majorly of the sector where nanotechnologies are settling to make a difference is in meat food processing in near future like, intelligent packaging of meat and meat products, meat derived bioactive peptides, pro- and pre-biotics inclusion in processed meat products, fat based nanoemulsions, nanosensors and nanotracers for meat biosecurity tracing and nanostructured meat food products with distinct functions (Table 3.1). Complex set of engineering techniques and occurrence of scientific challenges in the food and bioprocessing industries for manufacturing high quality and safe food through efficient and sustainable means can proven to be solved through nanotechnology. Identification of contaminating bacteria and monitoring of food quality using highly precised biosensors; intelligent, active, and smart food packaging systems; and nano-encapsulation of bioactive food compounds are strong establishing applications of nanotechnology for the next generation food industry. Nanotechnologies are not new and researchers have been making various polymers based on nanoscale subunits for many years. The result of new, previously unknown, properties attributed to engineered nanoparticles (NP) many inventive consumer products containing these Nanoparticles have been launched to the market recently. Application of nanotechnologies in

Fig. 3.1 Aims of next generation food industry of the future

electronics, medicine, textiles, defence, food, agriculture, cosmetics, and other areas are already a reality and fruits of it applications are beginning to impact the next generation of food production and processing industries (Chen et al. 2006). Within food and agricultural sector nanotechnologies covering many aspects, such as food security, packaging materials, disease treatment, delivery systems, bioavailability, new tools for molecular and cellular biology and new materials for pathogen detection (Maynard et al. 2006; Jasińska et al. 2010). The latent profit for consumers and producers of these innovative products are widely emphasized.

3.2 Role of Nanotechnology in Agriculture

There is huge potential in nanoscience and technology in the stipulation of state-of-the-art key for various challenges faced by and opportunities missed by agriculture development society today and in the future. Concerning to climate change, increase in urbanization, elevated use of natural resources and environmental issues like runoff and continuous accumulation of pesticides and fertilizers are the burning

Table 3.1 Applications of various nanoparticles in active functions

Type of nanoparticles	Deliverable application	Active functions
Metal nanoparticles (Silver, ZnO)	Food additive/supplement	Enhanced gastrointestinal uptake of metal
	Packaging materials/storage, Food preparation devices	Increase barrier properties Clean surface
	Refrigerators, storage containers	Anti-bacterial coating
	Water purification/soil cleaning	Removal/catalysation/oxidation of contaminants
Sprays	Refrigerators, storage containers	Anti-bacterial coating
Complex nanostructures	Nanosensors in packaging	Detection of food deterioration
Hand-held devices	Storage conditions evaluation	Monitoring of contaminants
Incorporated active nanoparticles	Migration out of packaging materials	Oxygen scavenging, prevention of growth of pathogens
Filters with nano-pores contaminants	Water purification	Removal pathogens
Nano-sized nutrients/ foods	Food additives/supplements	Claimed enhanced uptake
Delivery systems (nano-encapsulates)	Food additives/supplements	Protecting and (targeted) delivery of content

issues for today's agriculture sector and the researcher community, who are waiting for the recommendations of many nanotechnological strategies for the advancement of scientific and technological knowledge currently being examined. The future, demand for food will increase tremendously while natural resources such as land, water and soil fertility are actually limited. Utilization of nanotechnology in materials science and biomass conversion technologies applied in agriculture are the starting point of providing food, feed, fiber, fire and fuels in the agriculture sector. With reference to the cost of production inputs like chemical fertilizers and pesticides is increasing at an alarming rate due to the limited reserves of fuel such as natural gas and petroleum. To overcome these constraints, precision farming is proving a better option to reduce the initial production costs and to maximize agricultural product output. Possible through implicational advancement in nanotechnology, a number of techniques exist for the improvement of precision farming practices which will allow precise control at nanometer scale (Ingale and Chaudhari 2013).

Nanoencapsulation researchers are working on applications of pesticides encapsulated in nanoparticles; these only release active pesticide in a target insect's stomach, which minimizes the possibility of contamination of plants themselves. A further development being looked at is a network of nanosensors, nanotracers and dispensers throughout a food crop. The sensors and tracers have ability to recognize when a particular plant needs nutrients or water, before crop grower could see any sign that the plant is deficient of the nutrients and water. Dispensers release fertilizer, nutrients, or water as needed demand, optimizing the growth of each plant in the field one by one.

3.2.1 Precision Farming

The precision farming is process that maximizes the crop yield and minimizing the excessive usage of pesticides, fertilizers and herbicides through efficient monitoring. Precision farming applies advanced remote sensing devices, computers and global satellite positioning systems to precisely analyze various environmental conditions in order to determine the growth behavior of plants under the conditions and identify problems related to crops and their growing environments. Mainly this helps in determine timely development of plant, soil conditions, usage and take up of water and chemicals, fertilizers and seeding and consequently controls environmental pollution to a minimum extent by helping in reducing agricultural waste. The implementation of nanotechnology in the form of sensors and monitoring devices will anticipate creating a positive impact on the future use of precision farming methodologies. Nanosensors enabling systems help in growing the use of autonomous sensors that are linked to GPS systems to provide proficient monitoring services which focusing on crop growth and soil conditions. The use of smart sensors in precision farming will results in incredibly increased agricultural crop productivity by providing accurate information that will enable the farmers to make accurate decisions related to plant growth and soil suitability. Applying precision farming tools like, centralized data storage and collection system to determine soil conditions and plant development, seeding, fertilizer, chemical and water use can be accurately fine-tuned to lowers the production costs and certainly increase production which all the way benefiting the hard worker farmer (Rickman et al. 1999).

Precision farming is also helping to reduce the massive generation of agricultural waste and thus keeping environmental pollution to a minimum extent. But still not fully put into practice yet, small sensors and monitoring systems enabled by nanotechnology certainly will have a huge impact on future precision farming methodologies. One of the major functionality of nanotechnology-enabled devices will be the increased use of autonomous sensors linked into a GPS system for real-time monitoring of the implemented field and its environmental conditions. These nanosensors are distributed throughout the field where they can monitor soil conditions and crop growth.

The use of nanotechnology in development of precision sensors will create equipment of increased sensitivity, allowing an earlier response to environmental changes. For example: Nanosensors which are utilizing carbon nanotubes (Fujii et al. 2005) or nano-cantilevers (Vashist 2007) are fairly small enough to trap and measure individual proteins or even small molecules of farmer interest. Nanoparticles or nanosurfaces can be specifically engineered to trigger a specific electrical or chemical signal in the existence of a active contaminant such as bacteria. While other nanosensors work by triggering a running enzymatic reaction or by using nanoengineered branching molecules called dendrimers as detecting probes to bind to target chemicals and proteins (Ruiz-Altisenta et al. 2010). Sooner or later, future precision farming, with the help of advanced smart sensors, will allow enhanced productivity in agriculture by providing accurate information, thus helping farmers to make better decisions and improving the profit folds.

Particular Nanobiosensors are successfully used for sensing of a wide variety of chemical fertilizers, herbicide, pesticide, insecticide, pathogens, moisture, soil pH, and their controlled use can support sustainable development of agriculture for enhancing crop quality and productivity (Rai et al. 2012). This technology provides farmers a better fertilization management, reduction of inputs, and better management of time and the environment. This system could help in the efficient use of available agricultural natural resources like water, nutrients, and chemicals through precision farming. Operational nanosensors which are dispersed in the field can also successfully detect the presence of plant viruses and other crop pathogens, and the level of soil nutrients in the defined area (Jones 2006; Brock et al. 2011). Levels of existing environmental pollution can be evaluated quickly by nano-smart dust (the use of tiny wireless sensors and transponders) and gas sensors (Mousavi and Rezaei 2011). Application of nanobarcodes and nanoprocessing could also be used to monitor the quality of agricultural produce (Li et al. 2005). By keeping an eye on nanotechnology-based plant regulation of hormones such as auxin helps scientists to understand how the plant roots adapt to their environment variations, especially to marginal soils where the variations are too flexible (McLamore et al. 2010). The biosensors based on specific interactions creats atomic force spectroscopy more effective in detecting enzyme-inhibiting herbicides. A nanobiosensor based on an atomic force microscopy tip functionalized with the acetolactate synthase enzyme was successfully detected for the herbicide metsulfuron-methyl, an acetolactate synthase inhibitor, through the acquisition of force curves (daSilva et al. 2013). Bionanosensors also allow the more quantification and rapid detection of bacteria and viruses, thereby increasing the safety of the food for the customer (Otles and Yalcin 2010).

It is difficult to predict the long-term and broad applications of nanotechnology in agriculture and agricultural process and product development. Within agriculture, precision farming is settling a promising objective. Applications like smart sensors for early warning of changing climatic and crop conditions, and the use of nanocapsules with pesticides that are able to respond to the raised different conditions (Fig. 3.2).

3.2.2 Agrochemicals

Extensive amount of work is also being carried out in the development of various nanosized agrochemicals, such as fertilizers, pesticides and veterinary medicines. The aim to use of nanosized active ingredients has been suggested to offer

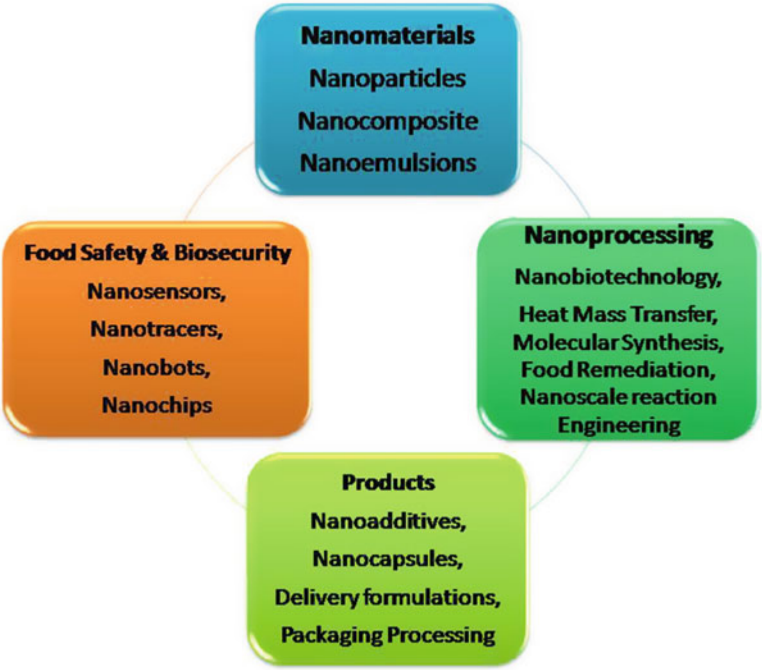

Fig. 3.2 Possible application areas of nanotechnology in food science and technology

improved and targeted delivery of agrochemicals in the only required area of field, better efficacy of pesticides in terms of minimal use and better control over necessary dosing of veterinary products. Nano-encapsulated and solid lipid nanoparticles have been widely discovered for the delivery of agrochemicals (Frederiksen et al. 2003); applicably it includes slow- or controlled-release of fertilizers and pesticides within the stipulated time and required area. Combination of fertilizer with pesticide formulation encapsulated in nanoclay for the slow release of growth stimulants and biocontrol agents, has been tested (Chung et al. 2010).

The progress of nano-emulsions (water/polyoxyethylene) non-ionic surfactant (methyl decanoate) containing the pesticide beta-cypermethrin has been characteristically described by Wang et al. (2007a, b) and similarly, the manufacturing of organic–inorganic nanohybrid material for controlled release of the herbicide 2,4-dichlorophenoxyacetate has been described by Bin Hussein et al. (2005). Porous hollow silica nanoparticles, developed for the controlled delivery of the water-soluble pesticide validamycin with a high loading capacity (36 wt%), have been shown to have a multistaged release pattern (Liu et al. 2006).

Use of zinc–aluminium layered double hydroxide to host the herbicide active ingredient by self-assembly. A few fertilizers claimed to contain nanosized micronutrients which are mainly oxides and carbonates of zinc, calcium, magnesium, molybdenum, etc. are available till date. For remineralisation of soil a micronized (volcanic) rock dust is available from a variety of sources. Product, which comprises sulphates of iron, cobalt, aluminium, magnesium, manganese, nickel and silver, is available for treatment of seed and bulbs prior to planting. Research and development into slow- or controlled-release fertilizers is continuously being carried out in China and India in large extent. The use of nanoforms of agrochemicals offers a number of potential benefits in terms to significantly reduced use of toxic chemicals, but may also raise numerous concerns over exposure of agricultural workers, and elevated contamination of agri-food products. Apart from the intended use and application of nanotechnologies in agriculture and food sectors, there may be seen instances where engineered nanomaterials can get into food and drinks through environmental contamination. Researchers identified possible route of exposure through environmental contamination from the manufacture, use and disposal of consumer products containing advanced engineered nanomaterials. In the product list the major share is contributed by cosmetics and personal care products (TiO_2, ZnO, fullerene (C60), Fe_2O_3, Ag, Cu, Au), catalysts, lubricants and fuel additives (CeO_2, Pt, MoS3), paints and coatings (TiO_2, SiO_2, Ag, quantum dots), water treatment and environmental remediation (Fe, Fe–Pd, polyurethane), agrochemicals (porous SiO_2 carriers and other nanosized agrochemicals), food packaging (Ag, nanoclay, TiO_2, ZnO, TiN), nanomedicine and carriers (silver, Fe, magnetic nanoparticles) (Dasgupta et al. 2016; Boxall et al. 2007).

3.3 Role of Nanotechnology in Food Processing

Consumers increasing demand of fresh, authentic, textured, convenient and flavourful food products in competitive market is keeping nanotechnology to leadership in the food and food processing industry. The next generation food industry belongs to innovative products manufactured by novel processes, with the ambition to enhancing the performance of the product, prolonging the shelf life, keeping the freshness, improving the safety and quality of food product. The advance processing of food products has been asserting to give new tastes; improved textures, consistency and stability of used emulsions, compared with conventionally produced and processed food products (Nandita et al. 2016; Walia et al. 2017). An increasing demand of the heath conscious society, benefit of this technology results in form of a low-fat containing food product that is as creamy as the full-fat alternative, and hence offers a healthy option to the consumer. The food product which is oil in water emulsion that contains nanodroplets of water inside the oil droplets is in the pipeline. This offers different taste and texture attributes similar to the full-fat equivalent, but with a substantial reduction in fat intake by the consumer (Kaiser 2004) (Table 3.2).

Another area of application of nanotechnology in food processing involves the development of nanostructures also termed nanotextures in foodstuffs. Mostly

Table 3.2 Application of nanotechnology for the food and bioprocessing industries

Technology	Description	Benefits
Nanostructures of food ingredients	Nanosized ingredients, additives	Improved texture, flavor, taste; Reduction in the amount of salt and sugar; enhanced bioavailability
Nanoparticle-based intelligent inks; reactive nanolayers	Nanolithography depositions	Traceability, authentication, prevention of adulteration
Nanoencapsulaton of supplements based on micelles and liposomes	Delivery systems for supplements	Taste masking; protection from degradation during processing
Membrane	Filtration effective separation of target material from food	Higher quality food products and fluids
Nanoparticle form of additives and supplements	Nano-engineered particulate additives	Antimicrobial; health benefits; enhanced bioavailability of nutrients
Nutrient delivery	Enzymatic structure, modification, emulsion and foams	Targeted delivery of nutrients, increased bioavailability of nutrients
Improved and active nanocomposites, intelligent and smart packaging	Food packaging	Improve flexibility, durability, temperature/moisture stability, barrier properties
Surface disinfectant	Engineering nanoparticles	Non-contaminated foods, protection from pathogens

mechanisms commonly used for preparing nanostructured food products include nano-emulsions, surfactant micelles, emulsion bilayers, double or multiple emulsions and reverse micelles (Weiss et al. 2006). Examples of nanotextured foodstuffs include spreads, mayonnaise, cream, yoghurts, ice creams, etc. a further area of application involves the use of nanosized or nano-encapsulated food additives. The broaden application is expected to exploit a much huge segment of the health food sector, and include colours, preservatives, flavourings and supplements. Efforts are taking to make better dispersion of water-insoluble additives in food products without the use of excessive fat or surfactants, and enhanced tastes and flavours due to the enlarged surface area of nanosized additives, compared with conventional additives forms. Quantities of consumer products containing nanosized additives are already available in some food markets, including foods, health foods, supplements and nutraceuticals. This includes minerals, antimicrobials, vitamins, antioxidants, etc. nearly all of these products are claiming to have improved absorption and bioavailability in the body compared with their conventional equivalents.

3.3.1 Monitoring Food Quality

Researchers are importantly keeping eye on quality assurance in food production and processing industry because consumers demands of more safe and wholesome food products in addition to the governments imposing to strictly follow stringent regulations to ensure food products safety and feed hygiene. For this sensor or advanced detection systems for rapid detection of spoilage of product and its components, for quality control, and for ignorance in detection at source and during production chain is possible through nanotechnology. In monitoring of food quality the analytical methods for contamination detection must have the flexibility to detect different analytes as well as the specificity to distinguish between different bacteria, and the sensitivity to detect bacteria directly and on-line in real samples without pre treatment to meet consumer expectations. Biosensor technology is holding a promise with manufacturing of inexpensive and simple devices to satisfy these requirements (Palchetti and Mascini 2008; Ozimek et al. 2010). Mainly biosensors can be an inherent alternative to the traditional methods for the detection of toxins and pathogens in food and food product (Bogue 2005, 2008; Connolly 2008).

3.3.1.1 Nanosensors for Bacteria Identification

Most commonly found food born *Campylobacter jejuni* are bacteria on infection which cause savoir abdominal cramps and diarrhea in humans (Ingale and Goto 2013). The campylobacter infections can possibly be traced from poultry meat products which have been contaminated with intestinal contents of the livestock during processing. Stutzenberger et al. (2007) group worked to tackle this food safety problem, they have developed a novel strategy that utilizes bioactive nanoparticles in the chicken feed which is specifically designed to bind to the biomolecular structures on the surfaces of campylobacters. This antibiotic enriched feed with functioning nanocarbohydrate particles successively binds with the bacterium's surface to remove it through the animals excretes.

Another biosensor developed by Fu et al. (2008) utilized fluorescent dye particles which attaches to anti-salmonella antibodies on a silicon or gold nanorod array. On testing the nanosized dye particles on the sensor become visible when the salmonella bacteria present in the food. In contrast to the time-consuming conventional laboratory testings that are based on bacterial cultures maintenance and labour consuming process, this biosensor can detect the salmonella in food instantly.

An analytical technology called reflective interferometry have been developed by Horner et al. (2006), which provides specific, rapid, and label-free optical detection of biomolecules in complex mixtures. This new technology has provided food quality assurance by detecting *Escherichia coli* (*E. coli*) bacteria in a food sample by measuring and detecting light scattering by cell mitochondria. This sensor works on the principle of this sensor is that a protein of a known and characterized bacterium is set on a silicon chip and can bind with any other *E. coli* bacteria present in the food sample. A nanosized light scattering is emitted by this binding and detected by analysis of digital images.

Industry named Agromicron Ltd, located in Hong Kong has developed a low cost Nano Bioluminescent Spray (Plexus Institute 2006), which can react with the pathogen strain on food and produce a visual glow for easy detection. The spray contains nanoparticles and would work based on its adherence reaction with the bacteria. The higher the number of adherence between bacteria and molecules, the more intense the glow produced by the particles. A broad range of food related pathogens are identified by this spray, such as *Salmonella and E. coli*. Cheng et al. (2009) demonstrated detection of *E. coli* in food using biofunctional magnetic nanoparticles (about 20 nm in diameter) in combination with adenosine triphosphate bioluminescence. Zhao et al. (2004) successfully developed an ultrasensitive immunoassay for in situ pathogen quantification in spiked ground beef samples using antibody-conjugated silica fluorescent nanoparticles (about 60 nm in diameter).

3.3.2 Nanoencapsulation

Recently role of food materials has progressed from being only a source of energy and nutrients to actively contributing to the health conscious consumers. The nutrients such as enzymes can be sensitive to proteases and other denaturing compounds to protect this nutrients there is need to immobilise it on different tailored carriers this may also improved nutrients stability to pH and temperature changes. Hence the protection as well as controlled release of bioactive compounds at the right time and the right place can be implemented by encapsulation. Nanoencapsulation remains to be the one of the most promising technologies having the feasibility to entrap bioactive compounds offers targeted site-specific delivery and efficient absorption through cells. Encapsulation is mostly carried out by physical and chemical techniques such as emulsification, coacervation, inclusion, complexation nanoprecipitation, emulsification–solvent evaporation, and supercritical fluid for food ingredients, drying techniques such as spray drying and freeze drying for stabilization of nanoparticles describes in Table 3.3.

Microencapsulation of foods components or products is well established technique, microencapsulated fish oil has been added to bread for a health benefit which masks the unpleasant taste of fish oil (Chaudhry et al. 2008a, b) and this bread is marketed successfully. The nanoencapsulation of food components and additives is a coherent advancement of the encapsulation technology to provide protective barriers, flavour and taste masking, increased bioavailability, increased potency, controlled release and better dispersion in aqueous systems for water-insoluble food ingredients and additives (Chaudhry et al. 2008a, b; Mozafari et al. 2006).

The chief protein found in corn, zein, has received attention in food nanotechnologies because it has the potential to form a mesh like tubular network resistant to

Table 3.3 Encapsulation techniques used for various bioactive compounds utilized in food and bioprocessing industries

Techniques used for encapsulation	Purposes for encapsulations	Functional compounds used	Active emulsifiers and wall materials used	References
Emulsification	Enhancement of anti-inflammation Activity	Curcumin (L)	Tween-20	Wang et al. (2008a, b)
	Protection of the droplets from recoalescence	D-Limonene (L)	Maltodextrin; emulsifiers: modified starch (Hi-Cap 100)	Jafari et al. (2007b)
	Increase the oxidative stability	Salmon oil (L)	Other materials: marine lecithin, α-tocopherol, quercetin, chloroform, methanol, diethylic ether, hexane	Belhaj et al. (2010)
	Improvement in physical stability and commercial application	β-Carotene (L)	Tween-20, Tween-40, Tween-60, and Tween-80	Yuan et al. (2008b)
	Optimization of the conditions to produce nanoemulsion	Sunflower oil (L)	Tween-80, Span-80, and sodium dodecyl sulfate	Leong et al. (2009)
	Improving the physical stability	β-Carotene (L)	Tween-20	Yuan et al. (2008a)
	Improving the stability for use in food or pharmaceutical industry	MCT (L)	OSA starch, chitosan, and lambda-carrageenan	Preetz et al. (2008)
	Optimizing operating conditions to prevent the droplet from coalescence and cavitational bubble cloud formation	Flax seed oil (L)	Emulsifiers: Tween-40	Kentish et al. (2008)
Coacervation	Masking its pungent odor and improving the stability	Capsaicin (L)	Gelatin, acacia, and tannins; emulsifiers: Tween-60; other material: glutaraldehyde	Jincheng et al. (2010)
	Improving the efficiency and delaying the release property	Capsaicin (L)	Gelatin, acacia, and hydrolysable tannins; emulsifiers: hydroxylethyl, cellulose; other material: glutaraldehyde	Xing et al. (2004)
	Masking the pungent odor, giving biocompatibility and biodegradation	Capsaicin (L)	Gelatin, maltodextrin and tannins; emulsifiers: Tween-60; other material: glutaraldehyde	Wang et al. (2008a, b)

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Table 3.3 (continued)

Techniques used for encapsulation	Purposes for encapsulations	Functional compounds used	Active emulsifiers and wall materials used	References
Nanoprecipitation	Improving the bioavailability, bioactivity, encapsulation efficiency and enhancing the cellular uptake	Curcumin (L)	Poly (lactide-co-glycolide); emulsifiers: polyethylene glycol-5000	Anand et al. (2010)
	Improving physical, chemical stability and bioavailability	β-carotene (L)	Poly(D,L-lactic acid) and poly(D,L-lactic-coglycolic acid); emulsifiers: gelatin or Tween-20	Ribeiro et al. (2008)
	Improving the solubility	Curcumin (L)	Monomethoxy poly (ethylene glycol)-poly (3-caprolactone) micelles	Gou et al. (2011)
	Improving the solubility and bioavailability	Astaxanthin (L)	Poly (ethylene oxide)-4-methoxycinnamoylphthaloylchitosan,poly (vinylalcohol-co-vinyl-4-methoxycinnamate), poly(vinylalcohol), and ethyl cellulose	Tachaprutinun et al. (2009)
Emulsification–solvent evaporation	For controlled release	Curcumin (L)	Chitosan cross-linked with tripolyphosphate; emulsifiers: Span-80 and Tween-80; other materials: acetic acid and ethanol	Sowasod et al. (2008)
	Enhance absorption and prolong the rapid clearance of curcumin	Curcumin (L)	Hydroxyl propyl methyl cellulose and polyvinyl pyrrolidone; emulsifiers: D-α-Tocopheryl polyethylene glycol 1000 succinate, Tween-80, Tween-20, cremophor-RH 40, pluronic-F68, pluronic-F127	Dandekar et al. (2010)
	Improving the controlled release and encapsulation efficiency	Quercetin	Poly-D,L-lactide and polyvinyl alcohol	Kumari et al. (2010)
	Improving the reproducibility, stability and target drug loading yield	Coenzyme Q10 (L)	Poly (-methyl methacrylate) and polyvinyl alcohol	Kwon et al. (2002)
	Optimize the operating conditions and reduce phytosterol loss	Phytosterol (L)	Tween-20; other materials: hexane, isopropyl alcohol, ethanol, and acetone	Leong et al. (2011)
	Minimizing the recoalescence improve the physical stability and solubility	α-Tocopherol (L)	Tween-20,	Cheong et al. (2008)

	Optimizing the processing condition and improving bioavailability	Astaxanthin	Sodium caseinate	Anarjan et al. (2011)
	Improving the physical stability	β-carotene (L)	Tween-20	Silva et al. (2011)
	It gives smooth, spherical PLGA nanospheres formation, high yield, drug entrapment efficiency with a narrow size range and sustained delivery	Curcumin (L)	Poly(D,L-lactide-co-glycolide) and polyvinyl alcohol; other materials: chloroform and ethanol	Mukerjee and Vishwanatha (2009)
Spray drying	Increasing the stability, protecting from oxidation and incorporation into beverages	Catechin (H)	Carbohydrate matrix and maltodextrin; other materials: acetone	Ferreira et al. (2007)
	Improving dispersibility, coloring strength and bioavailability	β-carotene (L)	Modified n-octenyl succinatestarch; other materials: ethyl acetate (droplet size); 12 um (particle size)	De Paz et al. (2012)
	Increasing the retention, stability during process	D-Limonene (L)	Maltodextrin; emulsifiers: Hi-Cap, whey protein concentrate, and Tween-20 (emulsion droplet size); 21–53 μm (dried particle size)	Jafari et al. (2007a)
	Minimizing the un-encapsulated oil at the surface and maximizing encapsulation efficiency	Fish oil (L)	Maltodextrin; emulsifiers: modified starch (Hi-Cap)/whey protein concentrate (droplet size); 25–41 μm (particle size)	Jafari et al. (2008)
Freeze drying	Preventing oxidation and masking the odor	Fish oil (L)	β- cyclodextrin, polycaprolactone; emulsifiers: pluronic F68; other materials: ethyl acetate	Choi et al. (2010)
	Increasing the oxidative stability and encapsulation efficiency	Fish oil (L)	Poly-ε-caprolactone	Bejrapha et al. (2010)
	Improving the stability and Rehydrating to study the dispersion characteristics and gel network formation prevents the denaturation	Capsicum oleoresin (L)	Poly-ε-caprolactone and gelatin; emulsifiers: pluronic F68	Nakagawa et al. (2011)
	Effect of excipients on the stability and particle size of nanocapsules	Capsicum oleoresin (L)	Poly-ε-caprolactone; emulsifiers: pluronic F68; other materials: trehalose, D-sucrose, D-mannitol, dextrose, D-sorbitol gelatin and κ-carrageenan	Bejrapha et al. (2011)

(continued)

Table 3.3 (continued)

Techniques used for encapsulation	Purposes for encapsulations	Functional compounds used	Active emulsifiers and wall materials used	References
	Extending the shelf-life, minimizing environmental stress and can apply to the food products	Capsicum oleoresin (L)	Poly-ε-caprolactone; emulsifiers: pluronic F68	Surassamo et al. (2010)
	Improving stability and protecting from environmental factor	Tocopherol (L)	Chitosan, zein; emulsifiers: Tween-20 α-	Luo et al. (2011)
	Increasing the stability, retention percentage and extending the shelf-life	Vitamin E (L)	Polyethylene glycol; emulsifier: Tween-80	Zhao et al. (2011)
	Improving the stability	Curcuminoids (L)	Dioctyl sodium sulfosuccinate, poloxamer 188, glyceryl monostearate	Tiyaboonchai et al. (2007)
	Protecting catechin from degradation	Catechin (H)	Chitosan and sodium tripolyphosphate	Dube et al. (2010)
Inclusion complexation	Formation of transparent solution, improve the colloidal stability, protection against degradation and useful for enrichment of acid drinks	DHA (L)	Beta-lactoglobulin and low methoxyl pectin	Zimet and Livney (2009)
	Improving the thermal stability	Linoleic acid (L)	α- and β-cyclodextrin	Hadaruga et al. (2006)
Supercritical antisolvent precipitation	Bioactivity, promote to food industry and to avoid thermal/light degradation	Lutein (L)	Hydroxylpropyl methyl cellulose phthalate	Heyang et al. (2009)

microorganisms. The zein nanomaterial is widely as a vehicle for flavouring ingredients of the food product and the nanoencapsulation of dietary supplements has been explored (Sozer and Kokini 2009). Just like carbon nanotubes, the nanotubes of a-lactalbumin have a cavity diameter ranging of 8–10 nm which may enable the binding of food components such as vitamins and enzymes (Srinivas et al. 2010), cavities could also be used to encapsulate neutraceuticals or to cover undesirable flavour or aroma compounds (Graveland-Bikker and de Kruif 2006). Nanotubes can be obtained from milk protein by appropriately conditioning the partial hydrolysis of milk with a specific protease, a-lactalbumin will self assemble into nanotubes (Graveland-Bikker and de Kruif 2006). As the origin of these nanomaterials used for encapsulation is milk protein or in the case of zein, corn protein, they are considered to be food grade material and so their introduction to the market should be relatively easy for a nano ingredient. The food grade association of these proteins may facilitate widespread applications in nanoencapsulating nutrients, supplements and pharmaceuticals.

Thus the size and the structure of food is influenced the functionality of foods by providing the taste, texture, and stability properties that desired by the consumer. Here nanotechnology can prove to play a vital role in controlling the size and structure of food to a greater extent to make the desirable texture of food. It serves healthier foods (lower fat, lower salt) with desirable sensory properties; ingredients with improved neutraceutic properties; and the potential for removal of certain additives without loss of spreadability and stability (Garti and Benichou 2004).

3.3.3 Ultrafiltration in Food Processing

Filtration process has been widely applied in numerous foods processing industries for the last two decades due to its operational advantages over conventional ingredient separation processes such as gentle product treatment, high selectivity, and lower energy consumption (Mohammad et al. 2012). Ultrafiltration becomes an essential part in food technology as a tool for separation and increase the concentration. Same time membranefouling compromises the benefits of ultrafiltration as fouling significantly reduces the performance and hence increases the cost of ultrafiltration resulted in overall increase in product cost. Recently various advanced intensive studies carried out to improve ultrafiltration, focusing on membrane fouling control and cleaning of fouled membranes.

Membrane filters are extensively used in dairy processing industries. The dairy industry has been one of the pioneers in the development of equipment and techniques of ultrafiltration based on the practice gained from its application in the dairy processing field (Daufin et al. 2001; Fox et al. 2004; Moresi and Lo Presti 2003; Pouliot 2008; Rosenberg 1995; Saxena et al. 2009). Ultrafiltration has found a major appliance in the making of cheese, during cheese production, whey was discharged to the sewer due to its high salt and lactose content, causing the direct use as a food supplement difficult, but now whey can be processed to obtain additional food values through a newer process using ultrafiltration membrane by increasing the fraction of milk proteins used as cheese or some other useful products and reduce the waste disposal problem represented by whey (Saxena et al. 2009). Membrane filtration technology is documented as a standard tool in the food processing and beverage industry (Cheryan 1998). It is being in use for processing a variety of fruit and vegetable juices (lemon, orange, grapefruit, tangerine, tomato, pomegranate, sweetlemon, cucumber, carrot, and mushroom) (Echavarria et al. 2011). For clarification of juices, ultrafiltration can be used to separate juices into fibrous concentrated pulp and a clarified fraction free of spoilage microorganisms. The clarified fraction can then undergo non-thermal membrane concentration and eventually whole juice reconstitution by combination with pasteurized pulp, in order to obtain a product with improved organoleptic qualities (Cassano et al. 2008). In addition, a better quality clarified fruit juice could able to stand in new market areas, such as clear juice blends, liqueur and related food juice products such as carbonated soft drinks (de Barros et al. 2003). Ultrafiltration is also applied in the concentration process in fruit juice production and processing industry. To recover bioactive components in fruit juice ultrafiltration were employed; bioactive compounds of the depectinized kiwifruit juice were recovered in the clarified fraction of the ultrafiltration process (Galaverna et al. 2008). Ultrafiltration used for fractionation and recovery of waste in fish processing industry. To improve the bioactivity of a saithe protein hydrolysates the ultrafiltration process were employed, by fractionating or concentrating some specific molecular weight peptide classes it increases the concentration of the protein in the filtrate (Chabeaud et al. 2009). Using cross-flow membrane ultrafiltration and nanofiltration the protein recovery from fish meal effluents were made technically and economical feasible (Afonso et al. 2004).

3.4 Role of Nanotechnology in Food Packaging

Increasing the shelf life of food by avoiding spoilage, bacteria, or the loss of food nutrient can be achieved by smart packaging. Nanotechnology offering advanced hopes in food packaging by promising its longer shelf life, safer packaging, better traceability of food products, and does providing healthier food. Intelligent, smart, and active packaging systems produced by nanotechnology would be able to repair the tears and leakages, and respond to environmental conditions. In addition polymer nanocomposite technology also holds the key to future advances in flexible, intelligent, and active packaging (Cushena et al. 2012).

Smart food packaging can detect when its contents are spoiling, and alert the consumer prior to start or in the early stages of the spoiling, as active packaging will release a preservative such as antimicrobials, flavors, colors, or nutritional supplements into the food when it begins to spoil (Ranjan et al. 2014). Nanotechnology provide solutions for food packaging by modifying the permeation behavior of foils, increasing barrier properties (mechanical, chemical, and microbial), providing antimicrobial properties, and by improving heat-resistance properties (Brody et al. 2008; Chaudhry et al. 2008a, b).

3.4.1 Nanoparticles for Food Packaging

The application of bionanocomposites for food packaging protects the food and increases its shelf life, and also be considered a more eco friendly solution because it reduces the requirement to use plastics as toxic, nondegradable packaging materials. Conventional packaging materials are made from nondegradable materials, which increase environmental pollution in addition it consuming restricted fossil fuels for their production. This current alternative of biodegradable films exhibit poor barrier and mechanical properties and these properties need to be improved considerably before they could replace traditional plastics (Suyatma et al. 2004; Tharanathan 2003) and thus help to manage the global waste problem (Sorrentino et al. 2007. The use of inorganic particles, such as clay, into the biopolymeric matrix enhances the biodegradability of a packaging material and can also be controlled with surfactants that are used for the modification of layered silicate. The inorganic particles use also makes it possible to introduce multiple functionalities, which might help to improve the delivery of fragile micronutrients within edible capsules (Bharadwaj et al. 2002; Alexandre and Dubois 2000).

3.4.2 Improved Food Storage

Storage of food is the major concern in the food industry as there are numerous reasons which affect the food storage. The main cause for food deterioration inside food packaging is oxygen; as a result of it oxidation of fats and oils and growth of microorganisms develops in the package. It also accelerates the processes inside food packaging leading to discoloration, changes in texture, rancidity and off-odor, and flavor trouble. Nanotechnologies effectively produce oxygen scavengers for sliced and processed meat, beer, beverages, cooked pastas, and ready-to-eat snacks; moisture absorber sheets for fresh meat, poultry, and fish; and ethylene-scavenging bags for packaging of fruit and vegetables. A functional packaging film for selective control of oxygen transmission through the package and aroma affecting enzymes has been developed by using the nanotechnology approach (Rivett and Speer 2009). The modification of the surface of nanosized materials by dispersing agents can act as substrates for the oxidoreductase enzymes based on reactions catalyzed by food grade enzymes oxygen absorbing s packaging system are also commercially available in the market. Packaging film supplemented with silicate nanoparticles produced, reduces the entrance of oxygen and other gasses, and the exit of moisture and can prevent the food from spoilage. The clay nanoparticles embedded in the plastic bottles strengthen the packaging, reducing gas permeability, and minimizes the loss of carbon dioxide from the beer and the ingress of oxygen to the bottle, keeping the beverage fresher and increases the shelf life (Avella et al. 2005).

3.4.3 Antimicrobial Packaging

Antimicrobial packaging systems holds the impression of being significant for the food industry and the consumers sight because these systems can help extend the product shelf life and maintain food safety by reducing or merely inhibiting the growth rate of microorganisms. Antimicrobial nanoparticle covering in the matrix of the packaging material can reduce the growth of bacteria on or near the food product, inhibiting the microbial growth on nonsterilized foods and maintain the sterility and quality of pasteurized foods by preventing the post manufacture contamination (Table 3.4). Sophisticated techniques of antimicrobial packaging systems contain adding an antimicrobial nanoparticle sachet into the package, dispersing bioactive antimicrobial agents in the packaging; coating of bioactive agents on the surface of the packaging material or utilizing antimicrobial macromolecules with film forming properties or edible matrices (Coma 2008). Foods such as cheese, sliced meat, and bakery that are prone to spoiling on the surface can be protected by contact packaging imbued with antimicrobial nanoparticles, a typical antimicrobial coating nanopackaging film was developed (Buonocore et al. 2005). Paper having active antifungal properties developed for packaging by Rodriguez et al. (2008) which incorporating cinnamon oil with solid wax paraffin using nanotechnology as an active coating was shown to be used as an effective packaging material for numerous bakery products. Working with oregano oil and apple puree, Rojas-Grau et al. (2006) have created edible food films that are able to kill *E. coli* bacteria.

Nanoparticles posing antimicrobial property have been synthesized and tested for applications in antimicrobial packaging and food storage boxes which include silver oxide nanoparticles (Sondi and Salopek-Sondi 2004), zinc oxide, and magnesium oxide nanoparticles (Jones et al. 2008) and nisin particles produced from the fermenation of a bacteria (Gadang et al. 2008). Many antimicrobials are hypothetically proposed to be used in the formulation of edible films and coatings in order to inhibit the spoilage flora and to decrease the risk of pathogens. There is a trend to select the antimicrobials from natural sources and to use generally recognized as safe compounds so as to meet consumer demands for healthy foods, free of harmful chemical additives (Devlieghere et al. 2004).

The most commonly used antimicrobials are organic acids, the polysaccharide chitosan, some polypeptides as nisin, the lactoperoxidase system, and some plant extracts and its essential oils among others. Organic acids such as lactic, acetic, malic, and citric acids, among others, are present in the ingredients of many foods and are broadly used for preservation. The efficacy of antimicrobial activity is

Table 3.4 Food borne pathogens causing illness, their major sources and time taken for action

Pathogen	Sources	Symptoms	Incubation and duration
Campylobacter jejuni	Raw milk, untreated water, raw and undercooked meat, poultry, or shellfish	Diarrhea (sometimes bloody), stomach cramps, fever, muscle pain, headache, and nausea.	Generally 2 to 5 days after eating contaminated food
Clostridium botulinum	Home-canned and prepared foods, vacuum-packed and tightly wrapped food, meat products, seafood, and herbal cooking oils	Dry mouth, double vision followed by nausea, vomiting, and diarrhea. Later, constipation, weakness, muscle paralysis, and breathing problems may develop. Botulism can be fatal.	12 to 72 h after eating contaminated food (in infants 3 to 30 days)
Clostridium perfringens	Meat and meat products	Abdominal pain, diarrhea, and sometimes nausea and vomiting.	8 to 16 h after eating contaminated food
Pathogenic *Escherichia coli (E. coli)*	Meat (undercooked or raw hamburger), uncooked produce, raw milk, unpasteurized juice, and contaminated water	Severe stomach cramps, bloody diarrhea, and nausea. It can also manifest as non-bloody diarrhea or be symptomless. Must-know: *E.coli*0157:H7 can cause permanent kidney damage which can lead to death in young children.	Usually 3 to 4 days after ingestion, but may occur from 1 to 10 days after eating contaminated food.
Listeria monocytogenes	Refrigerated, ready-to-eat foods (meat, poultry, seafood, and dairy – unpasteurized milk and milk products or foods made with unpasteurized milk)	Fever, headache, fatigue, muscle aches, nausea, vomiting, diarrhea, meningitis, and miscarriages.	9 to 48 h after ingestion, but may occur up to 6 weeks after eating contaminated food.
Salmonella Enteritidis	Raw and undercooked eggs, raw meat, poultry, seafood, raw milk, dairy products, and produce	Diarrhea, fever, vomiting, headache, nausea, and stomach cramps must-know: Symptoms can be more severe in people in at-risk groups, such as pregnant women.	12 to 72 h after eating contaminated food
Salmonella Typhimurium	Raw meat, poultry, seafood, raw milk, dairy products, and produce	Diarrhea, fever, vomiting, headache, nausea, and stomach cramps must-know: Symptoms can be more severe in people in the at-risk groups, such as pregnant women.	12 to 72 h after eating contaminated food

(continued)

Table 3.4 (continued)

Pathogen	Sources	Symptoms	Incubation and duration
Shigella	Salads, milk and dairy products, raw oysters, ground beef, poultry, and unclean water	Diarrhea, fever, stomach cramps, vomiting, and bloody stools	1 to 2 days after eating contaminated food
Staphylococcus aureus	Dairy products, salads, cream-filled pastries and other desserts, high-protein foods (cooked ham, raw meat and poultry), and humans (skin, infected cuts, pimples, noses, and throats)	Nausea, stomach cramps, vomiting, and diarrhea	Usually rapid – within 1 to 6 h after eating contaminated food
Vibrio cholerae	Raw and undercooked seafood or other contaminated food and water.	Often absent or mild. Some people develop severe diarrhea, vomiting, and leg cramps. Loss of body fluids can lead to dehydration and shock. Without treatment, death can occur within hours.	6 h to 5 days after eating contaminated food
Vibrio parahaemolyticus	Raw or undercooked fish and shellfish	Diarrhea, stomach cramps, nausea, vomiting, headache, fever, and chills	4 to 96 h after eating contaminated food
Vibrio vulnificus	Raw fish and shellfish, especially raw oysters	Diarrhea, stomach pain, nausea, vomiting, fever, and sudden chills. Some victims develop sores on their legs that resemble blisters.	1 to 7 days after eating contaminated food or exposure to organism
Yersinia enterocolitica	Raw meat and seafood, dairy products, produce, and untreated water	Fever, diarrhea, vomiting, and stomach pain Must-know: Symptoms may be severe for children.	1 to 2 days after eating contaminated food

Table 3.5 Antimicrobial compounds used in nanocomposites, films and coatings for food packaging showing antimicrobial activity

Antimicrobial compounds used in the nanocomposite	Active compounds	Microorganism target	Assay performed	Inhibitory observations	Reference
Acidulants					
Citric, lactic, malic, tartaric acids in combination with nisin	Soy protein	*L. monocytogenes, E. coli O157:H7, S. gaminara*	Film disk agar diffusion assay; total plate count of survivors	L. monocytogenes was inhibited by all acids Salmonella	Eswaranandam et al. (2004)
Sodium lactate	Sodium caseinate	*L. monocytogenes*	Plate count of mo population from inoculated agar systems in contact with antimicrobial films	A slight inhibition was observed by addition of 40% w/w	Kristo et al. (2008)
Malic, citric, lactic acids	Whey protein	*L. monocytogenes*	Film disk agar diffusion assay	Antimicrobial activity in increasing order: lactic < citric < malic	Pintado et al. (2009)
Lipophilic acids					
Sorbic acid or paraminobenzoic acid	Whey protein isolate	*L. monocytogenes, E. coli O157:H7, S. typhimurium*	Film disk agar diffusion assay	L. monocytogenes and E. coli were inhibited for all levels of both antimicrobials	Cagri et al. (2001)
Potassium sorbate	Xantham gum and tapioca starch	*Z. bailii*	Plate count of mo population from inoculated film disk in contact with agar plates	A microbiostactic effect was observed; xanthan gum exert a negative effect on inhibition	Flores et al. (2010)
	Alginate	*Total aerobic bacteria*	Plate count of microbial population in coated potato samples	A delay in microbial growth was observed	Mitrakas et al. (2008)
	Sweet potato starch	*E. coli, S. aureus*	Film disk agar diffusion assay	E. coli growth was inhibited by a 15% w/w KS	Shen et al. (2010)
	Tapioca starch	*Z. bailii, Lactobacillus spp.*	Plate count of microbial population from inoculated film disk in contact with agar plates	No inhibition of Lactobacillus spp. was observed Z. bailii population decreased 2 log cycles after 48 h	Vásconez et al. (2009)

(continued)

Table 3.5 (continued)

Antimicrobial compounds used in the nanocomposite	Active compounds	Microorganism target	Assay performed	Inhibitory observations	Reference
Chitosan					
Chitosan	Chitosan	*P. aeruginosa,* *S. aureus* *L. monocytogenes*	Plate count of mo population from film disk in contact with surface inoculated agar plates	S. aureus and L. monocytogenes surface growth was inhibited by chitosan film; P. aeruginosa was not inhibited	Coma et al. (2003)
	Chitosan with thyme, clove and cinnamon essential oils	*S. aureus,* *L. monocytogenes,* *P. aeruginosa,* *S. enteriditis*	Film disk agar diffusion assay	Chitosan alone did not inhibit the bacteria, thyme essential oil showed the highest antimicrobial efficacy	Hosseini et al. (2009)
	Sweet potato starch	*E. coli S. aureus*	Film disk agar diffusion assay	E. coli and S. aureus growth was inhibited by chitosan	Shen et al. (2010)
	Chitosan	*A. niger* *A. alternata* *R. oryzae*	Measurement of radial growth form film disk in contact with surface inoculated agar plate	Molds growth was decreased by films and coatings, effectiveness varied with the type of mold	Ziani et al. (2009)

based on pH reduction, disruption of substrate transport, and reduction of proton motive force. The most common acidulant agents are acetic, lactic, and malic acids. They are obtained by fermentation and are effective against the main pathogen bacteria encountered in foods (Samelis and Sofos 2003).

In whey-protein-based packaging films containing of glycerol as plasticizer, the use of formic, acetic, and fumaric acids or citric acid produced films of extreme brittleness. In the case of use of acetic acid, whey proteins precipitated since pH was close to isoelectric pH of proteins; as a consequence, gels formed were thick and could not form films (Pintado et al. 2009). Different molecular weighted chitosan can be extracted from shell wastes with different degree of deacetylation, due to difference in molecular weight different functional properties and biological activities were exerted by these chitosan (No et al. 2007). The antimicrobial activity is related to its positively charged amino group which interacts with negatively charged microbial cell membrane promoting an increase in their permeability in the cell and causing disruptions that lead to cell death (Ziani et al. 2009). Chitosan inhibit the growth of many spoilage causing, yeast, molds and pathogenic bacteria (No et al. 2007; Roller 2003). The antimicrobial activity of chitosan is depends on the type of chitosan, degree of acetylation, its molecular weight, the target microorganism, pH of the medium, and presence of other additives or food components (Aider 2010). Researchers have reported that efficacy of chitosan activity depends on the application technique used; in a coating solution it is more available to act as a preservative than when the preservative is forming the film (Vásconez et al. 2009; Zivanovic et al. 2005). Addition of other antimicrobials to chitosan films and coatings generally enhances the antimicrobial activity and also modified physical and mechanical properties of films and coatings. Taking into consideration the mentioned trend, addition of another antimicrobial agent such as potassium sorbate, nisin, and essential oils, to enhance chitosan antimicrobial action explained in Table 3.5 (Hosseini et al. 2009; Pranoto et al. 2005; Vásconez et al. 2009). Combination of compounds from aromatic plant, clove, and cinnamon essential oils to chitosan films, in general, inhibited the growth of *L. monocytogenes, S. aureus, Salmonella enteriditis, and Pseudomonas aeruginosa* (Hosseini et al. 2009). Essential oil exhibited the greatest inhibitory action on contaminating bacteria and also modifies physical and mechanical properties of films and coatings. It has seen in essential-oil-free films, inhibition of bacterial growth was not observed, suggesting that chitosan is unable to diffuse through the agar layer and pointed out the necessary addition of other antimicrobial in the film to exert chitosan its influence (Pranoto et al. 2005). Zinc oxide nanoparticles have been incorporated in different materials including glass, low density polyethylene, polypropylene, polyurethane, paper and chitosan using different incorporation methods (Espitia et al. 2012). Antimicrobial activity if zinc oxide nanocomposites material has been tasted by agar diffusion test, direct contact with culture broth contained microorganisms followed by colony counting (Applerot et al. 2009; Jin et al. 2009; Vicentini et al. 2010). Antimicrobial activity of ZnO nanocomposites performed against Gram-negative bacteria such as *E. coli* as well as Gram-positive bacteria such as *B. subtilis, S. aureus* and *L. plantarum* (Applerot et al. 2009; Emamifar et al.

2010; Jin and Gurtler 2011). Paper coated with ZnO nanoparticles has shown antimicrobial activity against *E. coli* (Ghule et al. 2006).

3.4.4 Green Packaging

Use of natural biopolymer, bio-nanocomposites-based functional packaging materials have generated great potential for enhancing food quality, safety, and stability as smart packaging and processing technology. Researchers are taking efforts to manufacture biodegradable and fully compostable bioplastics packaging (CSIRO 2006), made from organic corn starch using aspects of nanotechnology. Use of bio degradable biopolymer in food packaging material also provide enhanced organoleptic characteristics such as appearance, odor, and flavor (Zhao et al. 2008). The exceptional advantages of the use of natural biopolymer packaging are that these can easily handle particulate foods, can act as carriers for functionally active components, and provide nutritional supplements (Rhim and Ng 2007). A natural polymer and a main component of lobster shells called chitin is used for the making of biodegradable green food packaging using electrospinning technique. The electrospinning technique involves dissolving chitin in a solvent and drawing it through a tiny hole with applied electricity to produce nanoslim fiber spins (Kriegel et al. 2009).

3.4.5 Edible Films and Coatings

Development of edible films and coatings has been possible due to the film forming capacity of natural biopolymers. Hydrocolloids have good ability to form a uniform and cohesive matrix with controlling mechanical properties (Bourtoom 2008, 2009). This ability of hydrocolloids is related to the chemical structure of these compounds, which allows the association through hydrogen bonding of their polymeric chains. The most common biopolymers used for edible antimicrobial film production are polysaccharides, proteins single or mixtures from different sources, and combination of carbohydrates and proteins. While lipids such as waxes and fatty acids are main constituent of edible films and coatings, they do not possess a stand-alone film making nature. For this reason, lipids are often supported on a polysaccharide matrix to provide a film with mechanical strength (Bourtoom 2009). Incorporation of lipids in hydrocolloid-based film formulations facilitates to improve their water barrier characteristics or change their visual appearance (Karbowiak et al. 2010; Maftoonazad et al. 2007) (Table 3.5).

Polysaccharides Polysaccharides make transparent and homogeneous edible films with moderate mechanical properties. The application of these films is limited by their water solubility and poor permeability. To solve this issue, the blending of this with different biopolymers (Xu et al. 2005), addition of hydrophobic materials like oils or waxes (Anker et al. 2001; Ayranci and Tunc 2003; García et al. 2000), or chemical modification of polymer structure have been proposed (Marques et al. 2006).

Cellulose and Derivatives Cellulose is the major structural material of plant cell walls and it is composed of linear chains of (1 → 4)-β-D-glucopyranosyl units. Chemical substitution of some hydroxyl groups along the chain gives origin to ionic (carboxymethylcellulose, CMC) and nonionic cellulose ethers (methylcellulose, MC; hydroxypropylcellulose, HPC; hydroxypropyl methylcellulose, HPMC). Cellulose derivatives films are tough, flexible, totally transparent, and highly sensible to water presence but resistant to fats and oils (Lin and Zhao 2007; Vargas et al. 2008). Crosslinking treatments can be used to decrease the water solubility of cellulose ethers (Coma et al. 2003).

Chitosan Chitosan is a natural carbohydrate polymer derived by deacetylation of chitin [poly-β-(1 → 4)-N-acetyl-D-glucosamine]. It is a high molecular weight cationic polysaccharide that exhibits antibacterial, antifungal activity and film-forming properties (Fernandez-Saiz et al. 2009; Ziani et al. 2009: Arvanitoyannis 2008; Sebti et al. 2005). Numerous information has been reported about chitosan potential to act as a food preservative, function that was evaluated either on the basis of in vitro trials or through direct application of chitosan on real complex matrix foods (Durango et al. 2006; Han et al. 2004; Park et al. 2004; Ribeiro et al. 2007; Vásconez et al. 2009). Because of the good film-forming capacity of chitosan, it is broadly used to protect, improve quality and extend the shelf life of fresh and processed foods. Only chitosan coating was successfully applied on silver carp (Fan et al. 2009) and ready-to-eat roast beef coating (Beverlya et al. 2008); chitosan coatings incorporated with cinnamon oil retained the good quality characteristics as well as extended the shelf life during the refrigerated storage of rainbow trout (Ojagh et al. 2010); modified atmosphere packaging in combination with chitosan edible coating maintained quality and enhanced phenolic content in carrot sticks (Simões et al. 2009) and coatings based on selectively high molecular weight chitosan alone (Han et al. 2005) or combined with oleic acid extended strawberry shelf life (Vargas et al. 2006).

3.4.6 Nanocomposites for Food Packaging

Efficient nanocomposite materials for food packaging are developed with nanotechnology can provide better solutions to food industry challenges concerning to product safety and performance as well as economic and environmental advantages (Silvestre et al. 2011; Ingale 2014). In preservation of food, implications of nanotechnology can extends and improve functional packaging, which like been inhibition and protection from contaminants, preservation, marketing and communication, leading to a active food packaging system. In synthesis of nanocomposite, the composites are made of a polymeric matrix act as continuous phase and a discontinuous phase known as filler, fibres, platelets and particles have been widely used as fillers, so as to improve the mechanical properties and heat resistance of polymers hence it also enhances the overall properties of nanocomposites. (Ajayan et al. 2003; Chaudhry et al. 2008a, b; Arora and Padua 2010). Zinc oxide (ZnO) is an inorganic compound enormously used in everyday applications and also facilitates in formation of nanocomposites since currently listed as a generally recognized as safe (GRAS) material by the Food and Drug Administration and hence is used as element of food additive. ZnO nanoparticles have shown antimicrobial properties and been incorporated in polymeric matrices in order to fabricate nanocomposite which provide antimicrobial activity to the packaging material and improve packaging properties (Espitia et al. 2012). Polyurethane films incorporated nanoparticles have shown antimicrobial activity against *E. coli* and *B. subtilis*, amongst *E. coli* being more sensitive to the developed nanocomposite material, eventually this may be the result of a strong affinity of the nanoparticles with *E. coli* cells and consider that the antibacterial activity of ZnO is due to the generation of H_2O_2 in nanoparticle surface (Li et al. 2009).

3.5 Role of Nanotechnology in Food Supplements

Food supplements are generally considered to include vitamins, minerals, fiber, fatty acids, or amino acids, among or within other food substances. Nutrients are essential to the sustainability of a body, the bioactive compounds are not essential since the body can functions without them but bioactive compounds can have an influence on health and can believe to act as alternative of direct drug use external to the body. Bioactive compounds are known to be considering are flavonoids, caffeine, carotenoids, carnitine, choline, coenzyme Q, creatine, dithiolthiones, phytosterols, phytoestrogenss, glucosinolates, polyphenols, anthocyanins (Golmohamadi et al. 2013).

3.5.1 Bioactive Compounds

Bioactive compounds defined as extra nutritional constituents that normally occur in small quantities in foods, include beta-carotene from carrots, lycopene from tomato, beta-glucan from oats, omega-3 acid from salmon oil, conjugated linoleic acid from cheese, *Lactobacillus* from yogurt, and isoflavones from soybeans, etc. There is evidence to recommend consuming food sources rich in bioactive compounds. From a practical perspective, this translates to recommending a diet rich in a variety of fruits, vegetables, whole grains, legumes, oils, and nuts (Kris-Etherton et al. 2002). Nanotechnology has made known better potential in improving the efficiency and delivery of nutraceuticals and bioactive compounds in functional foods ultimately to improve human health. Enhanced solubility; improve bioavailability and protection of the stability of micronutrients and bioactive compounds during processing, storage and distribution results by efforts of nanoencapsulation (Chen et al. 2006).

Bioactive compounds can be protected by nanoencapsulation from absorption and ensures controlled release of beneficial live probiotic species to promote healthy and targeted gut function. Thus the viability of probiotic organisms including *Lactobacillus acidophilus, Lactobacillus casei, Lactobacillus rhamnosus*, and *Bifidobacterium* spp. within freeze dried yogurt can be improved by encapsulation of this bioactive component with calcium alginate (Kailasapathy and Rybka 1997). The bioavailability of antioxidant component from mainly from tomato; lycopene can be increased by synthesizing nanoparticles of lycopene and incorporating in tomato juice, pasta sauce, and jam (Auweter et al. 1999). Casein a bulky found milk protein, was used to make nanosized micelles and has been employed as a vehicle for delivering sensitive health promoting ingredients like various vitamin (Semo et al. 2007). Biopolymer nanofibers prepared by electrospinning technique by zein for encapsulating beta-carotene show the potential of nanotechnology in food and nutraceutical formulation and catings, bioactive food packaging, and food processing industries (Fernandez et al. 2009). New naturally derived carrier nanotubes for nanoencapsulation of nutrients, supplements, and pharmaceuticals are assembled from hydrolysed milk protein α-lactalbumin (Graveland-Bikker and de Kruif 2006).

3.5.2 Interactive Foods

Nanotechnology is helping to develop interactive foods which can allow consumers to choose and modify the food depending on their own nutritional needs or choice of tastes and flavors. The nanocapsules containing flavor or color enhancers or added nutritional elements would remain in dormant phase in the food and will only be released when triggered by the consumer (Dunn 2004). Efforts are made to develop foods which are capable of changing their color, flavor, or nutritional properties according to a consumer nutritional needs, allergies, or taste preference. Nanotechnology can facilitate techniques to make foods such as soft drinks, ice cream, chocolate, or chips to be commercially marketed as 'health' foods by reducing fat, carbohydrate or calorie content or by increasing protein, fiber or vitamin content. In addition, nanotechnology can help in the production of stronger flavorings, colorings, and nutritional additives, and processing aids to increase the speed of manufacturing and lowers costs of ingredients and processing (Burdo 2005). Utilization of nanofilters and membranes successfully can screen out or pass through certain molecules based on the shape and or size to remove toxins or adjust flavors, Nestle and Unilever are reported to be developing a nanoemulsion based ice cream with a lower fat content that retains a fatty texture and flavor (Renton 2006).

3.5.3 Texture

Commonly Texture Described as What Things Are Made of and how they Feel on Contact. Textures can Be Illustrated as Rough, Smooth, Hard, Soft, Liquid, Solid, Lumpy, Gritty Etc. Consumer like or Dislike Food because of its Taste, but the Texture of the Food Also Plays a Part in whether Consumer like it or Not. Texturing Is Big Business and the Science of Food Structure Even Has its Own Logy that Is Food Rheology.

Reduction of the size of food molecules to nanosized crystals creates more particles for providing greater surface area. Smaller particles improve food's spreadability and stability, and can assist in developing healthier minimal fat food products. Multiple emulsions such as water-in-oil-in-water can distribute the lipids more evenly to reduce extra stabilizers and thickeners to achieve a desirable food texture (Garti and Benichou 2004). Food texturing researchers, prepared nanoscale assays can activate the taste receptors of human tongue and can reduce the bitterness naturally inherent in some foods. (Wenner 2008). In beverages industry, photocatalytic process developed using gold nanoparticles by Lin et al. (2008) for decreasing the aging period and enhancing the sensory quality of sorghum spirits. Contreras et al. (2009) showed that zinc nanoparticles can be used to optimize conditions for surface enhancement of infrared absorption of food components. This technique able to demonstrate that butter treated with zinc naoparticles exerts trans fat spectral information along with the degree and the unsaturation of the acyl groups. These results clearly indicate the potential of nanomaterials in real time imaging sector to reveal useful information concerning food allergens, bioactive compounds, and microbial pathogens.

3.6 Safety and Societal Implications

Recently, interest has extensively grown in safety issues regarding the use of nanoparticles, nanocomposites, nanoconjugates in food packaging. Awareness about food safety and quality as well as its potential impact on consumers are key issues related to food processing and packaging which are developed by nanotechnology (Jain et al. 2016). Researchers are particularly more concerned with the possible ways of nanoparticles migration from the process to packaging material into the packed food and whether this migration would have a negative impact on the safety of food and consumer or quality of the packaged product (Bradley et al. 2011). Nanoparticles have much larger surface area to volume ratios, thus they may exhibit substantially different physicochemical and biological properties compared to conventionally larger sized particles (Ingale and Chaudhari 2013). There are three key factors majorly concerned of nanoparticle toxicity test strategies includes, physicochemical characterization, in vitro assays and in vivo studies (Oberdörster et al. 2005).

The existing functional safety laws, safety testing protocols, and the workplace health procedures are apparently inadequate to measure the exposure and assess the risks posed by nanofoods, nanofood packaging material and nanobased chemicals. Still the industries following established guidelines in the safety assessments of nanomaterials used for manufacturing nanofoods and nanopackaging materials and are not assessed as new chemicals. Novel experimental protocols and research tests should be performed to generate hazard and exposure information leading to risk assessments and to reliably answer concerns about the possible toxicological effects of exposure to nanoparticles, nanocomposites in the food product. A study shows that toxicities of nanoparticles and large particles were similar when the dose was expressed in surface area (Monteiller et al. 2007).

Toxicological evaluation of nanomaterials in food applications has done by high content screening technique and utilizing Zebrafish model can provide valuable developmental toxicity information in terms of endpoint identification and mechanism elucidation (Donofrio 2006). Nevertheless, currently there is a huge demand for low cost in vitro assays without reducing the efficiency and reliability of the risk assessment, since in vivo experiments are expensive, slow and ethically questionable (Siripireddy et al. 2017; Maddinedi et al. 2015, 2017; Tammina et al. 2017; Sannapaneni et al. 2016; Ranjan et al. 2016).

3.7 Conclusion and Perspective

Numerous varied opportunities for nanotechnology exist to play an important role in techniques of agriculture, food processing and packaging. The uses and benefits of nanotechnology are countless, from productivity enhancement through nanotechnology driven advanced precision farming and maximization of output in terms of yield with profit and minimization of inputs of fertilizers through better monitoring and targeted action only where required is desirable. Precision farming enables plants to use water, pesticides, and fertilizers more efficiently and reduces its excessive use. Use of nanotechnology may bring great benefits to farmers through ease in food production and to the food industry through development of new products through food processing, preservation, and packaging.

Expected applications of agricultural food nanotechnology include nanosensors or nanobiosensors for detecting contaminants and for soil quality and for plant health monitoring, for steady release and efficient dosage of water and fertilizers for plants, nanocapsules for agrochemical delivery, creating biofuels, nanocomposites for bioplastic film coatings used in food packaging, antimicrobial nanocomposites used for applications in decontamination of food, nanobiosensors for identification of pathogen contamination, and improving plant breeding (Dasgupta et al. 2015a, b). Additionally existing efforts are extra oriented to effectively reduce the negative impact of developed agrochemical products in the environment and human health, rather than its direct applications to improve the properties for food production. Agro formulations with higher bioavailability and efficacy and better selectivity will be seen actively functioning the near future of agriculture.

The use of biopolymers in the food industry has solved feasibility problems related to their relatively high cost and overall performance when compared to those of synthetic polymers. Several nanocomposites can provide active and or smart properties to food packaging materials, such as antimicrobial properties, oxygen scavenging ability, enzyme immobilization, or indication of the degree of exposure to some degradation related factor. Nanocomposites can not only protect the food against environmental factors, but also incorporate properties to the packaging material so it may actually enhance quality of foods to be consumed. Nanotechnological developed Membrane filters and filtration processes are gaining more attention and focus in food industry due to its exponential advantages (environmental friendliness, cost saving, and product improvement) when compared with other traditional methods. Use of nanotechnology in food industry, has provided sensors and diagnostic devices with improved sensitivity and selectivity to monitor food processes and assure food quality measurements along the real time production lines. Moreover antimicrobial edible films and coatings are utilized for improving the shelf life of food products without impairing consumer acceptability.

In addition to antimicrobial properties of antimicrobial edible films and coatings, zinc nanocomposites has presented modifications in the structure and properties of packaging materials like mechanical and thermal resistance. The design of a food packaging is significant since each industrial trait influences the physical integrity of the developed packaging and, therefore, ensures the protection of the packaged food. Understanding gap in addressing and framing the authority regulations of nanotechnology usage for foods, food additives, and food packaging materials is in progress through various regional and international agencies. Majorly the potential benefits of nanotechnology in agriculture and next generation food industry need to be balanced concerning for the soil, water, environment, and the occupational health of workers.

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