# Introduction to Nanofood

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## 1 Introduction to Nanotechnology

Richard Feynman, a renowned physicist has first discussed the concept of nanotechnology and the scope for manipulating atoms for synthesis purpose by saying the fact that "There's Plenty of Room at the Bottom", (Feynman 1959).

The term "Nano" is derived from a Greek word that means "dwarf" or "small" thus nanotechnology takes into consideration all the science, engineering and technology operated at the nanoscale (Zhou 2013).

National Nanotechnology Initiative (NNI) is known to be world largest funding source for nanotechnology research and according to them, nanotechnology can be defined as "the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications not feasible when working with bulk materials or even with single atoms or molecules. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling and manipulating matter at this length scale" (Zhou 2013).

The field of nanotechnology is developing rapidly as it attracts the attention of everyone by offering novel application and benefits at the nanoscale. Nanoparticles show the different property at a different size, in other words, that nano and macroparticles of the same powder will have different properties (Chaudhry et al. 2008a). Several industries are being affected by this innovative and enabling technology. Starting from cleaning agents to edible items, personal care, sports, medicine, and materials science, there is no field left unchanged by the usefulness of nanotechnology to make things better and susceptible for humans. The food industry is one such area among generals where nanotechnology has already started to

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inspire and change not only the traditional way of industries existence but also the way research and innovation are being carried out in general. Nanotechnology conceptually has already started to provide the basic framework for the development required to understand the roots of food components into micro and nanoscale, which has led to influence the food structure and it's rheological and functional properties (Sanguansri and Augustin 2006). In a simple way, nanotechnology has the potential to transform, every aspect associated with the food industry. Food packaging, food storage, processing and pesticides sense are some of the aspects of food industry where notable research is in progress using and the unique physicochemical properties of nanomaterials (Chaudhry et al. 2008a).

## 2 Nanotechnology in Food Industry – Overview

The food and beverage industry are globally a multi-trillion-dollar industry and looking into the ways to improve in every aspect as possible, starting from production efficiency to food safety. Nanotechnology has emerged as a boon to this industry, as this innovative technology has provided one-stop solution to multiple problems. Food safety, waste reduction and authenticity of the product are the part of food industry dependent on several different industries such as electronics, data storage and advancement of integrated devices. Nanotechnology has tremendously affected this industry and is thus affecting food industries in indirect ways. For e.g. the development of nanosensors has affected both electronics and food industry (Cushen et al. 2012).

Food safety, molecular synthesis of new food products, food packaging, composition, storage etc. are some vital areas concerning food industries which have already being impacted by the incorporation of nanotechnology in food industries which has now let to the emergence of food nanotechnology as an independent field of its own (Chen et al. 2006). Since the physiochemical and biological properties of nanostructures and nanomaterials are different from their bulk product, there is a rise of a new approach to looking into food systems especially the biological and physical occurrence of food. Several studies show a significant improvement in food safety, packaging, processing, and nutrition available in food due to the usage of nanotechnology in the food industry (Chaudhry et al. 2008a; Dasgupta et al. 2015; He and Hwang 2016; Pathakoti et al. 2017; Pradhan et al. 2015; Sekhon 2010; Sekhon 2014).

Food preservation, colouring, flavouring, nutritional additives, usage of antimicrobial agents for food packaging are some of the most noteworthy application of nanotechnology in the food industry. However, food packaging is the area in which nanotechnology is in maximum demands as this has already challenged the conventional methods of packaging by adding an enhanced barrier, and mechanical and heat-resistant properties as merits to its list (Honarvar et al. 2016; Patel et al. 2018; Pathakoti et al. 2017).

Although nanotechnology has shown great potential in the formulation of innovative products and processes in the food sector, there are many challenges left to overcome in food science and technology. One such is the production of edible delivery systems of nutraceuticals using economic approaches that are effective for human consumption and meet the safety norms (Dupas and Lahmani 2007; Patel et al. 2018).

To meet the challenges of the food sector, a great knowledge of food materials and processes at the nanoscale is required, which will be helpful in the innovation of new and improved products. Although the number of nanofood currently available in market is limited, nanotechnology has already thrilled the manufacturers, as its potential seems unlimited. Available technology has so far promised the introduction of new food products in the market while bringing innovation like better food texture, improved taste, higher process ability, and increased shelf life (Gilligan 2008; Rao 2009). Nanotechnology thus has the potential to change the entire food Industry from its roots.

## 3 Nanofood

Usage of nanotechnology in food Industry has brought back the usage of term nanofood. The term "Nanofood" is now used to describe food that has been cultivated, produced, processed or packaged using nanotechnology techniques or tools, or to which manufactured nanomaterials have been added (Gilligan 2008; Joseph and Morrison 2006). However, nanofood was considered as a part of food industries since centuries as food structure naturally exists at the nanoscale. The idea of nanofood is to have food products in the market with improved safety, enhance nutrition's, flavour and cost-effective. Nanofood though is still a relatively new aspect, one of the earlier applications of nanotechnology is as a carrier to deliver antimicrobial peptides required to stop the antimicrobial decay of food quality in the food industry. The following was achieved by coating starch colloids filled with an antimicrobial agent so that when microorganism grow on the packaged food they will break the coating of starch leading to release of antimicrobial agents (Boumans 2003; Gilligan 2008). The recent application of nanotechnology focuses on detection of food pathogen using nanosensors, which have the merit of being quicker, more sensitive and less labor-intensive procedures than the existing one. On one side where the benefits of nanofood are increasing exponentially like health-promoting additives, longer shelf life, new flavour and smart food packaging the questions are being raised on its safety of the nanomaterials and being used as they may interact with the living system and thereby can cause toxicity (Das et al. 2009).

Sooner or later, the warnings about nanofoods product are going to reach a tipping point in terms of public attentions since nanofood is grabbing media attention worldwide. Questions are going to be raised about the materials and particles used in the products which are already available in the market, which may or may not have FDA approval (Gilligan 2008; Yiannaka 2012). A list of food products currently containing nanoproducts include: Canola Active Oil (Shemen, Haifa, Israel), Nanotea (Shenzhen Become Industry Trading Co. Guangdong, China), Fortified Fruit Juice (High Vive. com, USA), Nanoceuticals Slim Shake (assorted flavors, RBC Lifesciences, Irving, USA), NanoSlim beverage(NanoSlim), Oat Nutritional Drink (assorted flavors, Toddler Health, Los Angeles, USA), and ‘Daily Vitamin Boost’ fortified fruit juice (Jamba Juice Hawaii, USA) and nanocapsules containing tuna fish oil (a source of omega 3 fatty acids) in “Tip-Top” Up bread (Enfield, Australia) (Gilligan 2008; Kirdar 2015; Sekhon 2010). Thus, along with food industries, a deeper knowledge of nanotechnology is important for innovation.

## 4 Nanomaterials and Nanostructures

Nanomaterials can either be naturally occurring or be externally added. Most widely used nanostructures in the food industry are engineered nanomaterials, nanoemulsion, nanoliposomes, and nanofibers.

### *4.1 Engineered Nanomaterials*

Nanoemulsion of inorganic and organic substances both are used to form engineered nanomaterials (ENMs), which are used in food industry for multiple purposes. The ENMs are differentiated into three basic categories, inorganic, surface functionalized materials, and organic engineered nanomaterials (Chaudhry et al. 2008a).

Inorganic nanomaterials and surface functionalized nanomaterials are generally used as food additives or in food packaging and storage. While as organic nanomaterials are used to in products to enhance their uptake or absorption or as a carrier for certain nutraceuticals. Usage of inorganic nanomaterials has increased significantly in food packaging and on another hand; surface functionalized nanomaterials are used to enhance properties such as antimicrobial or gas-barrier properties etc. One of the examples of inorganic nanomaterials is nanoselenium which is soon going to be used as an additive to green tea product, in order to enhance its antioxidant effect (Sekhon 2010; Vance et al. 2015) (Table 1).

### *4.2 Nanoemulsion*

The fundamental components of food, the food ingredients are rarely used in their purest form and thus there is a constant need for a better and stable delivery system to deliver nutraceuticals such as vitamins, antioxidants, flavouring etc. The delivery system needs to not only deliver the functional food but also not react with the bio

**Table 1** The table lists examples of different type of nanomaterial used in Food Industry. Adapted from FSAI 2008 (Ireland 2008)

| Category | Nanomaterials | Application | Reference |
|---|---|---|---|
| Inorganic nanoparticle | Silver | consumer products such as health food and water, food contact surfaces and packaging materials | Sekhon (2010); Vance et al. (2015) |
| | Iron | as a health supplement, in the treatment of contaminated water | Sekhon (2010) |
| | Calcium and magnesium | health supplements and use as chewing gum | Gallus et al. (2003); Sekhon (2010) |
| | Silica | food contact surfaces, food packing | Joseph and Morrison (2006); Sekhon (2010) |
| Surface functionalized nanomaterial | Nanoclays (Montmorillonite) | improved properties in packaging (barrier, thermal, durability) | Avella et al. (2005) |
| Organic nanoparticles | Liposomes | bioactive agent nanoencapsulation, improved solubility and bioavailability, cell-specific targeting | Kumari et al. (2014) |
| | Protein | nanoencapsulation of hydrophobic nutraceuticals. improved functionalities (gelation, heat stability) | Semo et al. (2007) |
| | Polymeric | nanoencapsulation & improved functionalities (delivery, antimicrobial) | Chen and Subirade (2005) |

molecules being delivered, also need to protect the ingredient from various environmental factors and its own degradation (Ravichandran 2010). For this purpose, nanoemulsion and nanoliposomes are already being exploited in the food industry.

Nanoemulsion have been recently exploited in the food industry due to their greater stability, higher optical clarity, increased bioavailability and their efficiency to delivery nutraceuticals (Meghani et al. 2018). Due to above mentioned properties, nanoemulsion are considered as the best emulsion-based delivery systems as they make encapsulation, protection and delivery of hydrophobic nutraceuticals and drugs, very conveniently for both functional food and pharmaceutical application (Kumar et al. 2016; Mirhosseini 2016). However, nanoemulsion so far have been synthesized to decontaminate food packaging equipment, remove pesticide residues from fruits and vegetables, to reduce surface contamination of chicken skin etc (Drusch 2007; Gharsallaoui et al. 2007). Nanoemulsion have also shown great promise to be used in beverage industries (Shukla 2012). Nanoemulsion have been used as an antimicrobial agent against a broad range of food pathogens including some gram-negative bacteria e.g. *Salmonella typhimurium* (Mirhosseini 2016). These are currently being used to deliver nutraceuticals. For e.g. Cinnamon oil nanoemulsion synthesized using ultrasonic emulsification was used to deliver vitamin D (Meghani et al. 2018), while as a corn oil and orange oil were used to deliver polymethoxyflavones (PMFs) extracted from citrus peel (Li et al. 2012), both of the nutraceuticals are hydrophobic compounds (Chakraborty et al. 2009). One of the most successful used of nanoemulsion was to deliver megestrolacetate oral suspension (MAOS) which are used as appetite stimulant in patients with AIDS (Deschamps et al. 2009).

## *4.3 Nanoliposomes*

Like nanoemulsion, nanoliposomesare nanometric version of liposomes, colloidal structures formed by input of energy to phospholipids in an aqueous solution. Nanoemulsion and nanoliposomes both are under extensive research by all different sectors including food industries for their use a colloidal delivery system to deliver hydrophobic bioactive and functional agents. Nanoliposomes technology offers all the merits to industries similar as nanoemulsion such as enhanced stability and the protection of encapsulated material from all the environmental factors, chemical and enzymatic changes, stability from range of pH and ionic strength and most importantly masking unwanted odour or taste (Reza Mozafari et al. 2008). However nanoliposomes offers food industry an extra benefit, a possibility of controlled release of food material, a approach still not feasible with nanoemulsions (Astete et al. 2009). Traditionally food industry has been using liposomes and nanoliposomes to deliver flavours and nutrient, however recently they are being use to deliver antimicrobials to provide protection against microbial contamination (Tumbarski et al. 2018). Since nanoliposomes can be synthesized from natural occurring ingredients such as soy, egg or milk, they have a edge over other in obtaining regulatory approval to be used in food industry (Reza Mozafari et al. 2008). The very first use of liposome was in synthesis of cheese (Law and King 1985). Recently nanoliposomes are used in delivery of concentrated enzyme during food processing and delivering antimicrobials to avoid microbial contamination (Fathi et al. 2012). Coenzyme q10 nanoliposomes are an example of stable nanoliposome used to delivery enzyme in with a desired concentration of the enzyme (Xia et al. 2006) (Fig. 1).

## *4.4 Nanotubes*

Carbon nanotubes (CNT) have been used in numerous application in different industries and thus the idea of using nanotubes emerged in the food industry (Weiss et al. 2006). Nanotubes are beneficial in food industry due to their large surface area which is exploited to immobilize antibodies, detect food pathogens and increase the sensitivity of immunosensors (Yang et al. 2008). Nanotubes having allyl isothiocyanate on their surface area are been used to have an antimicrobial effect and

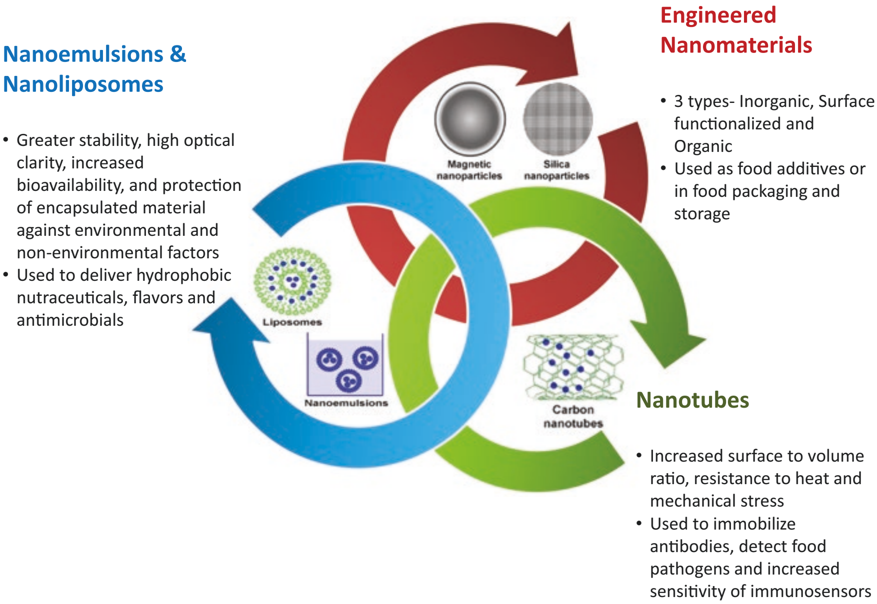


**Fig. 1** Schematic for the types of nanomaterials used in food industry

prohibited the growth of *Salmonella* in cellulose-based food packaging (Dias et al. 2013). Nanotubes are more beneficial compared to other particles because of their ability to resist heat and mechanical stress, improved gelation and viscosity and their increased surface to volume ratio which in turn increases the encapsulation or absorption efficiency of the functional food on their surface (Neo et al. 2013; Okutan et al. 2014). The example of nanotubes used in the food industry is the use of CNT assembled with milk protein α-lactalbumin (Graveland-Bikker and De Kruif 2006).

## *4.5 Others*

An association colloid is also a nanosystem used in food industry, is basically a stable dispersion system made up of small particles used to deliver polar, nonpolar and amphiphilic functional ingredients (Flanagan and Singh 2006; Garti et al. 2004; Garti et al. 2005; Golding and Sein 2004). Association colloids have size generally in the range of 5–100 nm but have the disadvantage of compromising flavours and are known to dissociate spontaneously when diluted (McClements et al. 2005). Apart from this, another used nanoscale technique is nanolaminates, which are extremely thin food grade film comprising two or more layers of materials in their nanometer dimensions. Nanolaminates have a layer of 1–100 nm each and are known to have physical or chemical bonded dimensions are used in the preparation of edible films (Cagri et al. 2004; Cha and Chinnan 2004; Morillon et al. 2002; Rhim 2004).

## 5 Functionality and Applications of Nanoconstructs in the Food Industry

### *5.1 Functions*

Nanotechnology has a potential to play a significant role in the development of food packagings, such as intelligent packaging, active packagings like controlled atmosphere packaging, modified atmosphere packaging, and antimicrobial packaging. Antimicrobial packaging is an area of emerging interest and is evolving with the application of nanotechnology due to its critical role in improving microbial safety and extending the shelf life of the food products (Duncan 2011). It releases the antimicrobials and preservative into the food to elevate the quality of microbes and the safety of food, which is done by incorporating or coating the packaging materials with antimicrobial agents for slow release. This is more efficient as the direct addition of microbes may react with other food components and results in loss of its activity (Mauriello et al. 2005).

There are various nanomaterials used in food industry, which can be classified as organic and inorganic. Inorganic nanoparticles like zinc oxide, silver, copper and titanium oxide are used for improving the physical performance, durability, barrier properties and biodegradation. Nanoparticles are coated on food packaging film or materials which are utilized for preservation and safety, these nanoparticles have the antimicrobial activity against the food spoilage microorganisms and foodborne pathogens (Bradley et al. 2011). Plastics beer bottles are embedded with nanoclays, which increases strength, makes them more shatterproof, increases the shelf life by acting as a barrier to keep oxygen outside the bottle and carbon dioxide inside. ZnO nanoparticles are already integrated into food packaging, ZnO coated food packaging films are developed as ZnO nanoparticles show stability under intensive processing conditions and antibacterial properties (Patel et al. 2014; Taylor et al. 2005). Similarly, silver nanoparticles show antibacterial properties, biosynthesized silver nanoparticles are incorporated into sodium alginate films as it shows antibacterial effect (Mohammed Fayaz et al. 2009). Films are prepared using silver nanoparticles; they are deposited on multi-layered linear low-density polyethylene (LLDPE) by laminating, casting and spraying (Sánchez-Valdes et al. 2008). Nanoparticles of titanium oxide are used widely due to its photocatalytic activity, non-toxicity, and antibacterial activity against a wide spectrum of microorganisms and utilized as self-disinfecting of surfaces (Fujishima et al. 2000). Titanium oxide nanopowder coated on oriented-polypropylene (OPP) film showed a reduction in bacterial cells (Chawengkijwanich and Hayata 2008).

## 5.2 *Applications*

### 5.2.1 Nanosensors

Combination of advanced nanoelectronics and suitable functional nanomaterials with smart biological components allows the development of highly specific and selective sensing devices for the detection of viruses, pathogenic microorganisms, detrimental chemicals and physical contaminants in food (Archana H 2012). With the help of nano fluidic technology, miniature sensing devices are developed for field application (Fig. 2).

Nano-biosensors are used to detect gases, pathogens, or toxins in packaged foods. They are also used in food processing plants, alerting consumers, procedures, and distributors on the safety status of food (Baeumner 2004). An electrochemical glucose nano biosensor fabricated by layer by layer self-assembly of polyelectrolyte for detection and quantification of glucose (Rivas et al. 2007). Sensors prepared by liposome nanovesicles are used for detecting peanut allergenic proteins in chocolate and pathogens (Edwards and Baeumner 2006; Wen et al. 2005). An electronic nose is a device, which has a combination of chemical sensors, linked with data processing system; which mimics like the nose, helps to identify different types of odor. These electronic noses are used to detect the fruit odors (J. S Detection of fruit odors using an electronic nose (n.d)).

The electronic nose can be used to measure chemical and physical properties of pears (Zhang et al. 2008), helpful in monitoring strawberry aroma changes during osmotic dehydration (Buratti et al. 2006). The nanosensor can also be used to check the milk quality during the industrial processing. Ultimately, the nanotechnology-based electronic nose can be useful for monitoring and control; more accurate volatiles measurement than measuring temperature and the time is taken, quality assurance and more (J. S Detection of fruit odors using an electronic nose (n.d)). Nanosensors are integrated into food packaging and confirm if the food product is fit enough for the human consumption.

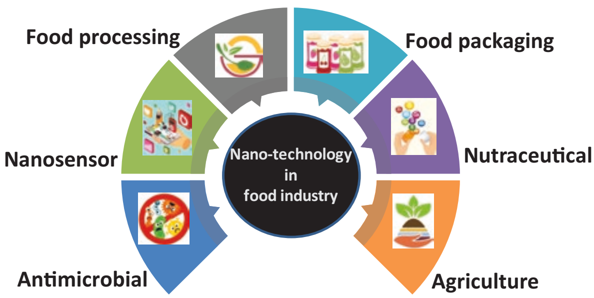


**Fig. 2** Applications of nanotechnology in food industry

### 5.2.2 Food Processing

Food products consist of nanoscaled biomolecules such as proteins, carbohydrates. These nanomaterials are either naturally present in foods or formed during the transformation of preliminary products. In food processing, nanoparticles can be used for improving the nutritional quality of food, flow properties, flavour, colour, and stability or to increase shelf life, to protect functional ingredients such as antimicrobials or vitamins, for instance, chitosan nanoparticles are used as antimicrobial compounds to enhance food safety (MF Hochella 2008).

Food processing includes removal of toxins, prevention from pathogens, preservation, enhancing the consistency of foods. Food processing is equally an important section along with formulation and preparation, as it has a significant impact on the physicochemical properties of food such as texture, flavour release profile, stability and others (A. Wallace and Sahu 2017).Properties of different food-based nanomaterials vary from material to material, like peptide and polysaccharide nanomaterial properties vary from the properties of metal and metal oxide nanoparticles and hence several nanostructured food ingredients are being developed which acts as anticaking agents and gelatin agents and claims to offer an enhanced taste, texture, and consistency (Cientifica Report Nanotechnologies in the Food Industry 2006). It also helps to increase the shelf life of different food materials and also reduces the extent of wastage of food due to microbial infestation (Pradhan et al. 2015). Nanocarriers have been introduced as delivery systems to carry food additives in food products without disturbing their elementary morphology. Nanocapsules as a delivery system play an important role in processing sector as the functional property are maintained by encapsulating simple solutions, colloids, emulsions, biopolymers and others into foods. Self-assembled nanostructured lipids serve as a liquid carrier of healthy components that are insoluble in water and fats called nanodrops, these nanodrops are useful to inhibit transportation of cholesterol from the digestive system into the bloodstream (Abbas et al. 2009; Dingman 2008).

Furthermore, the role of nanotechnology in food processing can be evaluated by considering its part by upgrading the food products in terms of texture, appearance, taste, nutritional value, and food shelf-life. Nanoencapsulation techniques have been implemented to improve the flavour release, retention and to deliver culinary balance (Nakagawa 2014). Multifunctional nanocarriers are fabricated for bioactive molecule protection and delivery, for instance, rutin is one of the basic dietary flavonoids with essential pharmacological activities but due to its poor solubility, it has limited application in the food industry. To eliminate this problem, ferritin nanocages are used which enhances the solubility along with better thermal and UV radiation stability of ferreting trapped rutin (Yang et al. 2015). The main advantage of using nanomaterials is that it can release encapsulated compounds much slower and over longer time periods, carriers of fragrances and flavours (Dekkers et al. 2011), and also provides a favourable improvement in the bioavailability of nutraceuticals due to its subcellular size (Singh et al. 2017).

Various nanomaterials used in food processing are nanocapsules in cooking oils to improve the bioavailability of neutraceuticals, nanotubes, and nanoparticles as gelation and viscosifying agents, nancapsule infusion of plant-based steroids to replace meat cholesterol, nanoemulsions and particles for better availability and dispersion of nutrients, nanoparticles to selectively bind and remove chemicals or pathogens from food.

### 5.2.3 Food Packaging

Food packaging techniques are designed to maintain the food flavour, quality, and protect from an infestation of microorganisms that leads to food spoilage. Utilization of nanomaterial helps to enhance the shelf life of food by avoiding the spoilage or loss of food nutrients. Nanomaterials as carriers, are used these days as delivery systems in food products which transport food additives without disturbing their basic morphology. An ideal delivery system consists of following properties: (i) targeted delivery of the active compound (ii) ensure availability at a target time and specific rate, and (iii) capability to conserve active compounds at suitable levels for long periods of time. Various nanomaterials in the form of emulsions, encapsulations, biopolymer matrices, colloids offer different and efficient delivery systems with all the above-mentioned properties (Bratovcic et al. 2015).

One of the main reasons behind the deterioration of food is due to oxygen, oxygen inside the food packaging causes oxidation of fats and oils and growth of microorganisms. It also responsible for discoloration, changes in texture, rancidity, and off-odor, and flavour problems. Nanotechnology plays a very significant role here, it has the potential to scavenge oxygen by using moisture absorber sheets and scavenging bags prepared using nanomaterials (Gaikwad et al. 2018). Nanocomposites are used for the controlled release of active substances from the food packaging materials, referred to as 'active' food packaging. Active packaging enhances the condition of the packed food, longer shelf life and improves sensory properties while maintaining the freshness and helping the migration of functional additives, such as minerals, probiotics, and vitamins, into food quality of food. Nanocomposites used in 'active' packaging consist of polymer composites with antimicrobial nanomaterials, like silver, zinc oxide, copper oxide, magnesium oxide (Chaudhry et al. 2008b). The most common material used in active food packaging is nanosilver in plastics which confers antimicrobial properties to improve food and beverage shelf life (de Azeredo 2013).

Other nanocomposites are used to enhance other physical properties to make the packaging more tensile, durable, or thermally stable, e.g. nanocomposites of titanium dioxide, iron oxides, silica, and alumina are UV absorbers and hence are used to prevent UV degradation of plastic polymers (Beltran et al. 2014). Similarly, nano-titanium nitride is used to advance strength of packaging materials, nano-calcium carbonate-polymer composites, nano-chitosan-polymer composites, biodegradable nanoclay, biodegradable cellulose nano-whiskers, and other gas-barrier coatings (e.g. nano-silica) (Reig et al. 2014). Nanocomposites of nanosilver and nanoclay or other nanomaterials are formulated to enhance the barrier and antimicrobial properties. Nano clay-nylon nanocomposites are used to maintain freshness and block out food odour. Nano-precipitated calcium carbonate is used to improve the mechanical properties, heat resistance and printing quality of polyethylene, nanofilms made up of zinc oxide calcium alginate are used as food preservative, the nanoscale hybrid structure of silica/polymer for better oxygen-diffusion barriers for plastics (Smolander and Chaudhry 2010). Biodegradable nanocomposites are used for packaging, as it has favourable potential towards the environment.

### 5.2.4 Delivery of Nutraceuticals

Nutraceuticals are a combination of nutrition and pharmaceuticals which have health benefits with their actual function of providing nutrition and hence used to prevent the occurrence of a disease or as its treatment. Principles of nanotechnology have been implemented by various researchers for the efficient delivery of nutraceuticals with the aim to enhance their biological activity. Several formulations have been utilized for the efficient delivery of this nutraceutical, like nanoemulsion, micelles, nanoparticles, nanocapsules, nanocochleats, nanocrystals, etc. (Gupta S 2010). These nanoformulations are benefitted in targeted delivery of encapsulated nutraceuticals with the controlled release and better bioavailability as well as provide protection for bioactive compounds such as vitamins, antioxidants, proteins, carbohydrates and lipids with enhanced functionality and stability (Quintanilla-Carvajal et al. 2010). When a multitude of bioactive and active ingredients are nano-encapsulated, they have an ability to break down and get absorbed by the common food after delivering their active ingredients (Ezhilarasi et al. 2012).

Lipid-based nanoencapsulation systems are used to elevate the performance of antioxidants by producing better solubility and bioavailability, stability, controlled release of food materials, protection of foods and nutraceuticals and prevention against unnecessary interactions with other food components. These lipid-based nanoencapsulation which delivers food and nutraceuticals are mainly nanoliposomes, nanocochleates, and archaeosomes. They act as carrier vehicles of nutrients, nutraceuticals, enzymes, food additives, and food antimicrobials (Mozafari et al. 2008). Preparation of Coenzyme Q nanoliposomes was done with the preferred encapsulation quality and stability (Mozafari et al. 2006). Tiny capsules made of particles one-tenth the size of a human cell known as Colloidsomes, assemble themselves into a hollow shell, where other molecules of any substance such as fat blockers, medicines, and vitamins can be placed inside this shell (Xia et al. 2006). Nanocochleates are nanocoiled particles that wrap around micronutrients and have the ability to stabilize and protect an extended range of micronutrients and can elevate the nutritional value of processed foods (Pathakoti et al. 2017).

Development of nanoencapsulation of probiotics, which blends of bacteria species incorporated in foods in the form of yogurts and yogurt-type fermented milk, cheese, puddings and fruit-based drinks. Encapsulation enables the longer shelf life of the product. These can be useful to deliver the probiotic bacterial formulations to certain parts of the gastrointestinal tract with specific receptors and may act as *de* *novo* vaccines with the capability of modulating immune responses (Vidhyalakshmi and Subhasree 2009).

### 5.2.5 Agriculture

Nanomaterials have a significant role in the agriculture sector as it has the potential to boost agricultural production by improving nutrient use efficiency with nanoformulation of fertilizers, boosting the ability of plants to absorb nutrients, agrochemicals for crop enhancement; introducing new tools for detection and treatment of disease, host-parasite interactions at the molecular level using nanosensors, contaminants removal from soil and water, postharvest management of vegetables and flowers, and reclamation of salt-affected soils, precision farming techniques and ultimately leading to highly qualitative and quantitative yield. (Avensblog 2016; Kumar et al. 2018; Mousavi and Rezaei 2011).

Nanomaterials enabled tiny sensors and monitoring systems will have an enormous impact on future of precision farming methodologies. As precision farming makes use of global satellite positioning systems, remote sensing devices through which it can measure highly confined environmental conditions which help determine whether crops are growing at supreme efficiency or precisely identifying the nature and location of problems. Nano-structured smart delivery systems could help in the efficient use of agricultural natural resources like water, nutrients, and chemicals through precision farming. When these nanosensors, are scattered on fields, they are expected to monitor and provide detailed data on crop growth and soil conditions, seeding, fertilizers, usage of chemicals and water. These nanosensors can be useful for diagnosis of the presence of the plant viruses or the level of soil nutrients. At the nanoscale, due to high surface to volume ratio and, ease of access to modify its surface makes it possible to bind selectively with particular biological proteins. Sensors prepared using nanomaterials such as carbon nanotubes or nanocantilevers can be used to trap and measure individual proteins or even molecules. Nanoparticles can be engineered to trigger an electrical or chemical signal, in presence of crop pathogens like bacteria and viruses (Morrison 2006). Nanostructured catalysts will help elevate the efficiency of pesticides and herbicides, with minimal usage, and also protect the environment indirectly through the use of alternative energy supplies and clean-up existing pollutants (Ditta 2012).

The concept of nano-fertilizers- nano-enabled bulk fertilizers can help enhance crop productivity and reduce nutrient losses. There will thorough and rapid absorption of nano fertilizers by plants. Nano-encapsulated fertilizers with slow release have become a trend to minimize the fertilizer consumption and environmental pollution. Nutrients are released at a slower rate throughout the crop growth and plants are able to take up most of the nutrients without waste, this is done using naturally occurring minerals at nanoscale having a honeycomb-like crystal structure known as zeolites, it has a network of interconnected tunnels and cages which are loaded with nitrogen and potassium, mixed with other gradually dissolving ingredients containing phosphorous, calcium and a complete suite of minor and trace nutrients.

The releases of nutrients from the fertilizer capsule are regulated using a coating and cementing of nano and sub nano-composites (Liu et al. 2006).

Smart seeds are seeds which are imbibed with nano-encapsulations with specific bacterial strain, it helps reduce seed rate, safeguard right field stand and improvement in crop performance. Seeds are coated with nanomembranes, can sense the availability of water and allows seeds to release when ready for germination, aerial broadcasting of seeds embedded with a magnetic particle, detecting the moisture content during storage to take appropriate measure to reduce the damage and use of bio analytical nanosensors to determine the aging of seeds (Manjunatha et al. 2016).

Nanomaterial has a significant role in agriculture machinery as well, like application in machines structure, agriculture tools to increase their resistance to wear and corrosion. Developing strong mechanical tools having nano coating and sensors to control weed growth, to reduce friction in bearings, and in the production of alternative fuels to reduce environmental pollution (DeRosa et al. 2010). Eventually, by implementing the use of smart sensors, productivity in agriculture will be enhanced by providing accurate information and hence help farmers to make better decisions.

Multidisciplinary approaches could potentially improve food production, incorporating new emerging technologies, and disciplines such as chemical biology integrated with nanotechnologies to tackle existing biological bottlenecks that currently limit further developments. The potential benefits of nanotechnology for agriculture, food, fisheries, and aquaculture need to be balanced against concerns for the soil, water, environment, and the occupational health of workers (Sekhon 2014).

## 6 Toxicity and Safety Aspects

Generally, food and beverage industry are conservative and cautious when the future of nanotechnology and food comes into the picture, despite the evident potential of nanotechnology in the application of food engineering and processing. Nanomaterials, due to their high surface area, might have toxic effects which are not apparent in the bulk materials (Dowling 2004; Kumar et al. 2018). Apart from that, there might be potential and unexpected risks for their use in food industry. It is extremely unlikely that the representatives, scientists from food and beverage corporations and others involved with food and nanotechnology to provide specific details about the level of funding and industry partners. The food industry may be skittish about owning up to R&D on “atomically modified” food products after witnessing widespread rejection of genetically modified foods (Ravichandran 2010) (Fig. 3).

With the application of nanotechnology in food industries, there will be a wide range of food products, like any other new technologies, but there are some serious queries regarding the safety which requires attention by the industry and the policy-makers. The generally recognized as safe (GRAS) list of additives universally accepted will have to be reassessed when used at the nanoscale. It was observed that

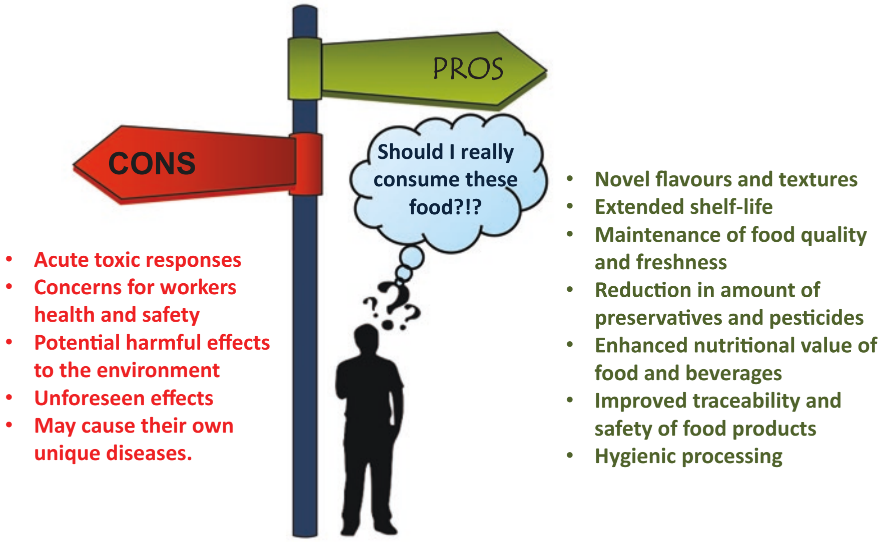


**Fig. 3** Nanofood- a dilemma of the decade. The image depicts the positive and negative side of nanotechnology being used in food industry

rats breathing nanoparticles revealed a tendency of collecting nanoparticles in their brain and lungs, leading to increasing in biomarkers for inflammation and stress response. The main concern of any consumer will be about the toxicity and as nanoparticles are more reactive, more mobile and likely to be more toxic which must be addressed. Nanoparticles, when in the body have strong potential to result in increased oxidative stress which can generate free radicals, leading to DNA mutation, cancer, and possible fatality. It is yet to be understood whether enhancing the bioavailability of certain nutrients or food additives might affect human health negatively (Savolainen et al. 2010).

## 7 Regulations

It is essential for manufacturers to demonstrate that the food ingredients and food products are not injurious to health, according to the Food and Drug Administration (FDA) in the United States. However, this regulation does not explicitly cover nanoparticles, which could become harmful only in nanoscale applications. Therefore, no such distinct regulations exist for the use of nanotechnology in the food industry (Administration.). On the other hand, the European Union has suggested special regulations which are yet to be accepted and imposed. As FDA regulates on a product-by-product basis, it emphasizes that many products that are already under regulation contain particles in the nanoscale range. FDA expects that many products of nanotechnology will come under the jurisdiction of many of its centers; thus, the Office of Combination Products will likely absorb any relevant responsibilities (Chau et al. 2007).

The Institute of Food Science and Technology (IFST), a United Kingdom-based autonomous Professional form for food scientists and technologists has a different opinion of nanotechnology, it states that size matters and suggests that nanomaterials can be treated as potentially harmful until testing proves otherwise (TARVER). IFST recommended that the conventional E-numbering system for labeling should be used along with subscript "n" when nanoparticles are used as food additives (Maynard and Kuempel 2005). The UK government agrees with the Royal Society and the Royal Academy of Engineering that the presence of nanoparticles on ingredient labels is essential for consumers to make informed decisions. Therefore, an updated version of ingredient labeling will be a necessary requirement. Recently, The Swiss center for technology assessment analyzed the circumstances concerning nanotechnologies and food in Switzerland (Ireland 2009).

Certain rules and guiding principles for nanomaterials are established by the regulatory forms around the world that have ramifications for use in food. Due to lack of essential safety data, there is uncertainty over the regulation of nano-based products, which needs to inform regulatory bodies (Sandoval 2009). Efforts are made to facilitate international collaboration and information exchanges are underway to confirm approval and utilization of the advantages of nanotechnology (Magnuson 2009). Hence, organizations across the world are collecting information in an effort to decide how best to proceed (Kahan et al. 2009).

## 8 Future Aspects

In the past two decades, nanotechnology in the field of food sector has shown 40% increase in publications and 90% patent filings. More than 1000 companies now have an R&D focus on nanotechnology-based products (food?). In the previous few years, it was observed by the food industries that the nanotechnology has integrated into numerous food and food packaging products. Currently, there are around 300 and more nanofood products available in the market worldwide, which has motivated a huge rise of R&D investments in nanotechnology for food industries. Nanotechnology in food has a massive impact, ranging from basic food to food processing, from nutrition delivery to intelligent packaging (Pereira de Abreu et al. 2007) (Fig. 4).

Nanotechnology can benefit exclusively from processed foods in numerous ways. Programmable foods considered the ultimate dream of the consumer, will have designer food features built into it and a consumer can make a product of desired color, flavor, and nutrition using specially programmed microwave ovens. The trick is to formulate the food at the manufacturer's end with millions of nanoparticles of different colors, flavors, and nutrients and under the program in the oven set by the consumer based on his preferences, only selective particles are activated while others stay inert, giving the desired product profile (Kaynak and Tasan 2006).

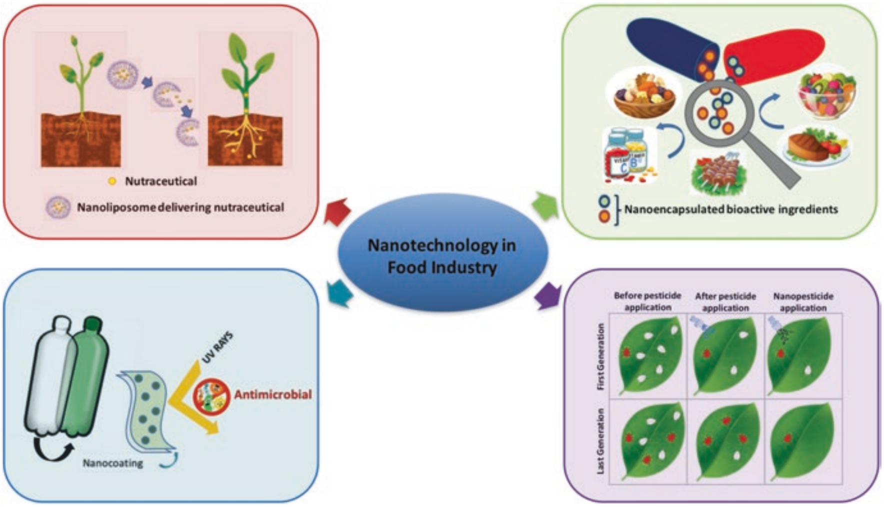


**Fig. 4** The image highlights the few areas where nanotechnology is being exploited and how

Nanoscaled resources in food packaging will help amplify nourishment life, upgrade food safety, prepared customers that food is sullied or destroyed, repair tears in packaging, and uniform release added substances to grow the life of the food in the package.

Nanotechnology and nano-bio-info are one of the promising fields to maintain the leadership in food and food-processing industry, in the future. The first step towards it will be improving the safety and quality of food. Nanotechnology permits the change in the existing food systems to ensure products safety, creating a healthy food culture, and enhancing the nutritional quality of food.

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