Chapter 9

Nanotechnology: A Boon for Food Safety and Food Defense

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9.1 Introduction

Richard Feynman, a famous physicist, first proposed the concept of nanotechnology in 1959. Subsequently, the term "nanotechnology" was coined by Norio Taniguchi in 1974. In 1980, nanotechnology usage became multidisciplinary, and by 2014 the

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global market value of nanotechnology was calculated around US$1 trillion per annum (Handford et al. 2014). The efficacy of nanotechnology is calculated with processing device, application of structure, system, design and by changing the size and shape of nanomaterial (10^{-9} m) of materials (Ravichandran 2009, 2010). Nanotechnology involves a wide range of technological activities for characterization, regulation, and fabrication of a huge range of materials, encompassing chemical applications and processes, electronic sciences, and physical and biological engineering (Handford et al. 2014; Bata-Vidács et al. 2013). It has proved to be a boon for food processing and production of different foodstuffs with an enhanced shelf life. Nanoparticles and nanomaterials are used in various forms such as nanocoatings, nanorods, nanosheets, nanofilms, nanolayers, nanofibers, and nanotubes, with a size between 1 and 100 nm. These nanoparticles are capable of displaying unique chemical, physical, and biological properties that are absent in the bulk forms of the same materials (Cushen et al. 2012). Nanoscale devices are generally made to copy nanodevices that already exists in nature, involving DNA, membranes, proteins, crystalline structures in different starches, cellulose fibrils, molecular building, nanosized plant cell networks, and other biomolecules (Handford et al. 2014; Sozer and Kokini 2009).

Nanoparticles have a large surface area–to–volume ratio, which allows a large fraction of their atoms to be present on their surfaces. This is responsible for their greater stability, strength, and biological and chemical activities, enabling development of new materials with a extensive range of probable applications. Many applications have already been observed in various industries and applications, including sports, cosmetics, medicine, agriculture, food, construction, wastewater treatment, and electronics (Handford et al. 2014; Prasad et al. 2014, 2016, 2017a).

Nanotechnology is an emerging approach in the food industry to ensure the safety of food. The major food safety objective with regard to nanotechnology is to assess risks and safety consequences associated with use of engineered nanoparticles in nanotechnology applications (Prasad et al. 2017b). Food safety risks related to nanotechnology was also introduced in FSMS and considered during risk assessment studies (Panghal et al. 2018a).

9.2 Food Defense

"Food defense" is a term used to define activities and systems that are allied with protection of a country's food supply from intentional and unintentional acts of tampering and contamination (which may also be referred to as "adulteration") (Manning and Soon 2016). It has also been described as actions (mainly related to the safety of human consumers) during the supply of food that protect it from intentional and unintentional contamination, with a focus on safety measures in processed food (Mitenius et al. 2014). Food defense systems also safeguard food and its supply chains from mischievous attacks that could lead to supply failure (Global Food Safety Initiative 2013). Strategies for food defense can be implemented at local or national levels. Manning and Soon (2016) have distinguished between organizational or supply chain management and national risk assessment models. In the USA, the CARVER+ [which stands for “Criticality, Accessibility, Recuperability, Vulnerability, Effect, Recognizability”] shock technique is implemented at the national level.

Intentional food contamination is the one of the global threats of the twenty-first century. Nowadays, food can be used as a tool by terrorists. Threats and fraud in food can have injurious effects on the health of society, consumers, the economy, and national security. Possible threats to the food supply chain are misuse of food for criminal purposes, food shortages due to disruption of the supply chain, and intentional contamination of food with toxic materials that lead to poisoning and death. The US Food and Drug Administration (FDA has developed a personalized food defense plan that includes guidance, tools, and resources in a single application to control food threats and reduce the risk of intentional food adulteration (Manning and Soon 2016).

9.3 Use of Nanotechnology Components in Food Safety and Food Defense

Nanotechnology mainly focuses on operation of biological and nonbiological structures that are smaller than 100 nm. Structures on this scale have distinctive and unique functional properties. Promising advantages of nanotechnology have been identified in different industries, and nanoproducts have been commercially manufactured in the aerospace, pharmaceutical, and microelectronics industries. Development of nanotechnology in industries is determined by research in engineering, materials science, physics, biology, and chemistry. So far, the applications of nanotechnology in the food industry have been limited. However, discoveries and achievements in nanotechnology are becoming more established in the food industry and many related industries, and they have significant influences on various aspects ranging from the safety of food to molecular synthesis of novel food products and their ingredients (Chen et al. 2006). Nanotechnology allows researchers to control, measure, and handle substances at the nanoscale, and to alter their functions and properties in a favorable way.

The unique properties of nanomaterials hold many prospects for the food industry (Cho et al. 2008). Various types of nanostructures are used to build unique structures and establish new functionalities in foods. These include nanoparticles, nanofibers, nanoemulsions, and nanoliposomes. Weiss et al. (2006) described various nanostructures and their potential and actual uses in food processing. Nowadays, nanomaterials used in food applications consist of both organic and inorganic materials. Nanomaterials are classified into three groups: organic engineered nanomaterials (ENMs), inorganic nanomaterials, and surface-functionalized materials (Chaudhary et al. 2008). ENMs are mostly found in nanofood products. Nowadays, nanotechnology is also gaining increased attention in food safety. Nanotechnology-based devices have been reported to enable very quick and specific detection of pathogens to ensure food safety.

9.4 Nanoparticles

The four major categories of nanoparticles are magnetic nanoparticles (MNPs), nonmagnetic nanoparticles, carbon nanotubes (CNTs), and nanowires. They and their applications are discussed further in Sects. 9.4.1, 9.4.2, 9.4.3, and 9.4.4.

9.4.1 Magnetic Nanoparticles

Magnetic nanoparticles are <100 nm in size and are influenced by external magnetic fields (EMFs). Applications of MNPs as biosensors in the clinical and pharmaceutical sectors offer remarkable advantages over conventional detection methods. All biological samples manifest higher sensitivity toward magnetic fields; therefore, even a small amount of a sample can be analyzed through this approach (López-Rubio et al. 2012).

MNPs have been reported to be nontoxic, nonhazardous, environmentally friendly, inexpensive, biocompatible, and physiochemically constant. They also exhibit properties of superparamagnetism (Glynn et al. 2006), which is a form of magnetism that appears in small ferromagnetic or ferrimagnetic nanoparticles (Tarui et al. 2009). In the absence of an EMF, superparamagnetic nanoparticles (SPNs) shows some magnetic properties, which increase with escalations in an EMF. One type of magnetic particle that is commonly used is superparamagnetic iron oxide nanoparticles (SPIONs), which are characteristically applied in immunoassays by surface modification with suitable ligands that may bind with a unique selected target.

9.4.1.1 Nuclear Magnetic Resonance–Based Pathogen Detection

Magnetic nanoparticles possess a nuclear magnetic resonance (NMR) property, which is utilized to detect biomarkers and pathogens. When an EMF is applied, a local magnetic dipole field is generated by the MNPs, which act as proximity sensors, disturbing the stability of the spin–spin relaxation time of adjacent water molecules. The NMR based detection platform exploits this property of MNPs to modulate the spin-spin T2 relaxation time of targeted biological samples. Binding of MNPs to biotic or molecular targets reduces the transverse relaxation time, followed by disturbance of the magnetic resonance. In NMR-based assays, as shown in Fig. 9.1, two detection mechanisms are available. Detection of smaller molecules such as proteins and nucleic acids is achieved by magnetic relaxation switching (MRSw), using the properties of MNPs. This form of detection is less time consuming because there is no requirement for free MNPs. For detection of bacteria, functionalized MNPs are required. Zhao et al. (2017) applied this technique to detect *Listeria monocytogenes* in lettuce, milk, and milk products.

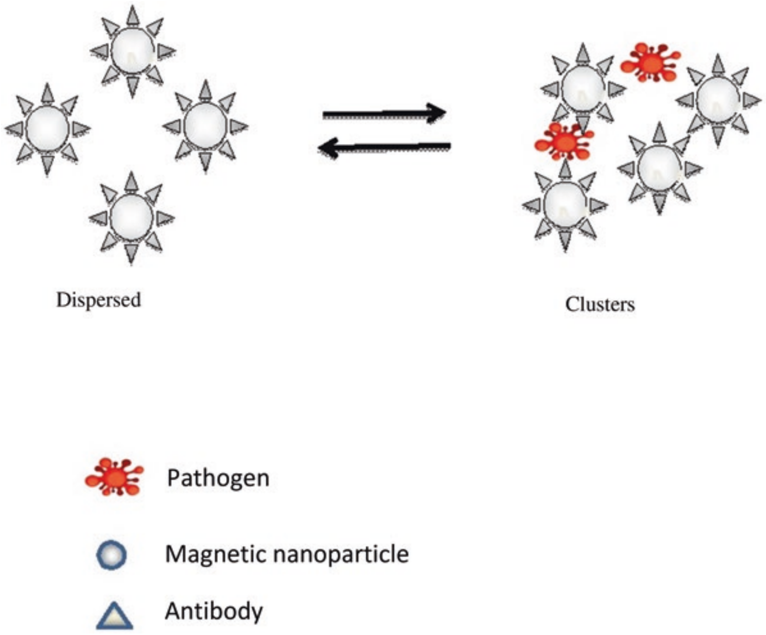

Fig. 9.1 Nuclear magnetic resonance detection platform (Krishna et al. 2018)

9.4.1.2 Search Coil–Based Detection Platform

Magnetic nanoparticles have been reported to possess nonlinear magnetism, and this property is used for immunoassays (Ching et al. 2012; Wang et al. 2014). A coil-based detection system records nonlinear magnetic responses at high and low frequencies. The responses produced are directly proportional to the number of MNPs used. This method has been observed to be better than others, as sample preparation is not required. Orlov (2013) detected toxic shock syndrome toxin (TSST) and staphylococcal enterotoxin A (SEA) in a milk sample with this method, without sample preparation. The sample of untreated milk was filtered via the tip of a pipette for capture of the antigens (i.e., SEA/TSST), followed by cleaning for removal of any free proteins. Finally, specific antibodies, biotinylated antigen, and streptavidin-coated MNPs were distributed in the filter for detection of bound antigens.

9.4.1.3 Giant Magnetoresistance Nanosensors

Magnetic sensors using the giant magnetoresistance (GMR) effect are used to detect the local magnetic dipole field generated by MNPs. The GMR effect is usually examined in multilayers consisting of alternating ferromagnetic and nonmagnetic

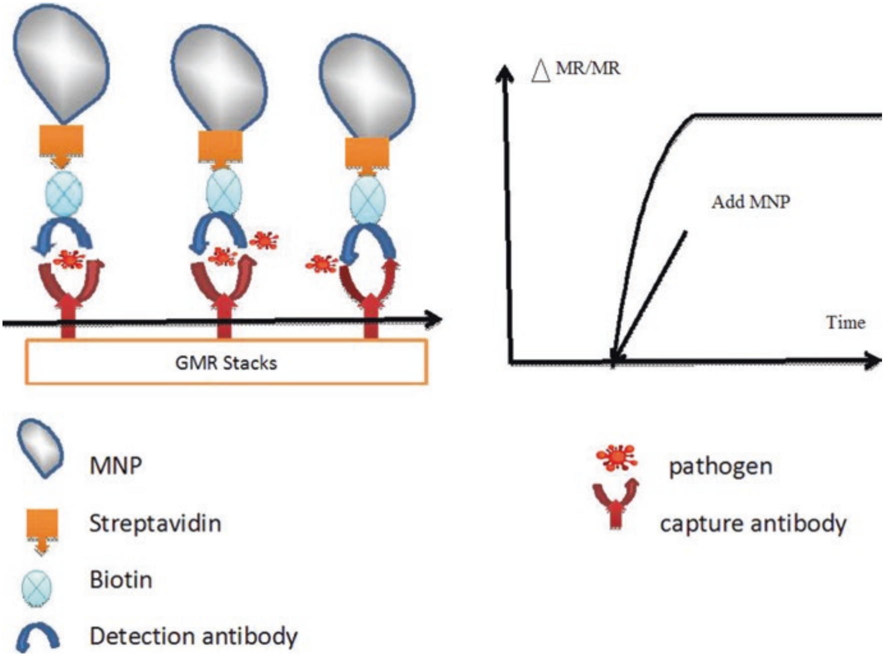

Fig. 9.2 Giant magnetoresistance (*GMR*) sensor surface showing the sandwich structure and time signal change (Wu et al. 2018). MNP magnetic nanoparticle, MR magnetic resonance

conductive layers. Depending on the magnetization alignment of the ferromagnetic layers, the electrical resistance changes; usually, more resistance is present when the layers are in an antiparallel alignment than when they are in a parallel alignment, since electrons are more scattered in the former alignment than in the latter. In standard GMR structures, the magnetic direction of a ferromagnetic layer is in a stationary phase during the deposition and annealing process, and another ferromagnetic layer moves freely under the impact of an applied field. On the basis of this effect, MNPs are used to detect various biological compounds. As shown in Fig. 9.2, the surface of the sensor is functionalized with captured antibodies; MNPs and target antigens are attached with detection antibodies. The number of MNP-tagged antibodies that bind to the antigens is directly proportional to the number of antigens that are present on the surface of the sensors. When affected by an EMF, the magnetic dipole field generated by the MNPs present on the bound antibodies is detected by the GMR sensors, resulting in resistance variation that is directly proportional to the concentration of the antigens (Fig. 9.2). In comparison with other sensing methods, GMR is low in cost, has high sensitivity, and is capable of real-time signal detail. Moreover, it can be used to detect multiple analytes simultaneously.

9.4.2 Nonmagnetic Nanoparticles

9.4.2.1 Localized Surface Plasmon Resonance

This detection method is used for Label free biological sensing. In this method, a beam of light, which is monochromatically polarized, is delivered via a prism and reflected from a film of thin metal on a glass slide, followed by interaction with a test liquid. The surface plasmon resonance (SPR) is attained when the frequency of photon strikes on the metal film matches the normal occurrence of electron fluctuations on the metal surface. A swing of the resonance frequency occurs, which is directly proportional to the concentration of the species adsorbed on the metallic surface; actual measurements of the binding may be attained by obtaining the alteration in the visual reflectivity with respect to time (Yu and Yang 2017). However, although SPR technology is moderately well established, the instrumentation used in this technique is costly and complicated to operate (Krishna et al. 2018).

9.4.2.2 Nanoparticle-Assisted Colorimetry

The simplest method for detection of biological targets is colorimetric testing. The presence of a target analyte can be easily determined either by visualization, by a colorimeter, or by employing a chemical reaction that involves color change. However, the efficacy of color conversion in a normal colorimeter is comparatively low, which lowers the device sensitivity. Kuswandi and Heng (2017) designed nanoparticle-assisted colorimetry to resolve the aforementioned problem. The surface area on which the color precursor molecules are situated is increased considerably by bringing nanoparticles into the sensing matrix.

A sandwich structure was formed on a plate by immobilizing capture probe, during hybridization between capture probes, target sequence and a detection probe by means of functionalized AuNPs. Luo (2014) detected the *invA* gene of *Salmonella* species using a combination of polymerase chain reaction (PCR) and DNAzyme probe self-assembled gold nanoparticles. In the presence of hemin, the detection probe was formed as G-quadruplex/hemin complex, which performed as a catalyst for the oxidation reaction, facilitated by H_2O_2, leading to an intense variation in color. The detection limit was 3×10^3 colony-forming units (CFU) per milliliter. For recognition of *Salmonella typhimurium*, AuNPs have been combined with antibodies (Banerjee et al. 2017).

9.4.2.3 Quantum Dots

Quantum dots (QDs) are widely employed in detection of traditional fluorescence with organic fluorescent dyes, showing corresponding emission peaks and high sensitivity to photobleaching. QDs are nanosized crystalline particles with good resistant properties against chemical degradation and photobleaching (Shao et al. 2012).

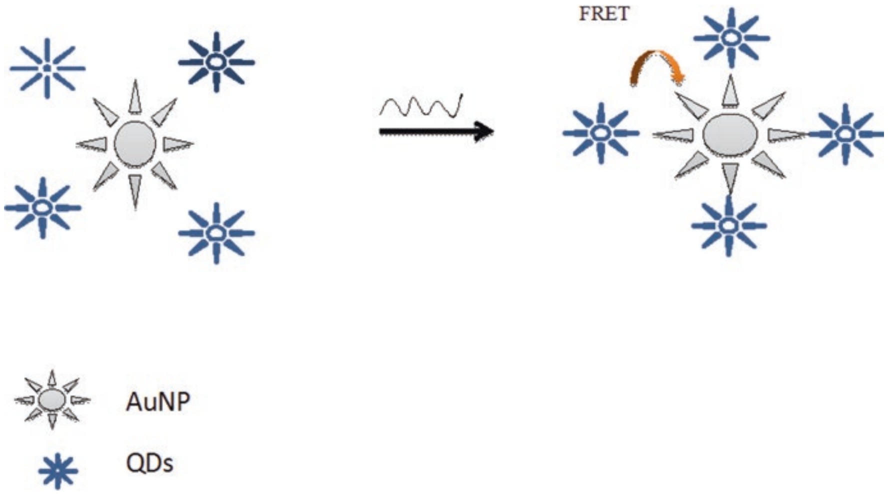

Fig. 9.3 Fluorescence resonance energy transfer (*FRET*) between graphene quantum dots (*QDs*) and gold nanoparticles (*AuNP*). Graphene QDs conjugated with capture probe and AuNPs conjugated with reporter probe (Krishna et al. 2018)

The QD bandgap energy is inversely proportional to their size, resulting in tunable and narrow emission bands, independent of the excitation wavelength (Wu et al. 2015). QDs are available in various sizes with a wide variety of emission wavelengths that allow their use in multiplex analysis. QDs coupled with immunomagnetic separation (IMS) are used to detect *Salmonella enteritidis* and *Escherichia coli* (Landeghem et al. 2009). Magnetic beads and QDs coated with the corresponding antibodies bind the targeted antigens by using a magnet, as shown in Fig. 9.3.

9.4.3 Carbon Nanotubes

Carbon nanotubes are allotropes of a carbon compound with a cylindrical nanostructure. Usually, CNTs measure up to a few millimeters in length, with a diameter of up to few nanometers. These carbon molecules have attracted significant interest because of their exclusive mechanical and electronic characteristics, which make CNTs a capable contender to increase the performance of electrochemical biosensors (Park et al. 2016). Immobilization of ligands for molecular recognition is permitted by the large surface area of CNTs. They function as a sensing component, which allows communication between the conjugated antigen–antibody complex and the underlying electrode.

Single-walled CNTs (SWCNTs) enclosing monoclonal antibodies of *Salmonella* can be applied to modify a surface electrode of glassy carbon (GC) for use as a nanosensor to detect *Salmonella* at a very low concentration (Park et al. 2016). This type of immunosensor results in formation of antigen–antibody multiplexes by estimating changes in the electrical and chemical properties of the sensor Afforded by the insulating properties of bacterial cell membrane.

9.4.4 Nanowires

In addition to having a large surface-to-volume ratio, nanowires have great electrical conductance sensitivity to variations on the surface of an electrical field. As a result, they are used in research (Star 2006).

To detect *L. monocytogenes*, TiO_2 nanowire bundles were developed by Wang et al. (2008). Monoclonal antibodies were immobilized on the exterior of the TiO_2 nanowire bundles to capture *L. monocytogenes*. The cell wall of *Listeria* has a neutral pH with a negative charge on its surface; therefore, specific binding of the TiO_2 nanowire bundle and the *Listeria* cell produces substantial changes in the electrical conductance. A TiO_2 nanowire–based activity immunosensor has the capability to detect *L. monocytogenes* at a low concentration (4.7×10^2 CFU/mL) with a detection time of 50 min. For detection of the foodborne pathogen *Bacillus cereus,* Pal et al. (2007) used polyaniline nanowire–based direct-charge transmission biosensors. The working principle is binding of the antigen to its similar antibody, which disturbs the movement of the electron charge in the polyaniline nanowire, resulting in increased resistance. The detection limit for this pattern is specified as 10^1–10^2 CFU/mL, with a detection time of 6 min.

ZnO nanowires are mostly used to detect breast cancer and uric acid levels in patients with Parkinson's disease (Yue et al. 2014). Silicon nanowires are used to detect cancer risk biomarkers, cardiac troponin I (cTnI), and circulating tumor cells.

9.5 Nanotechnology Applications in the Food Supply Chain

Applications of nanotechnology in food contact materials (FCMs) account for the greatest market share of the current and short-term forecasted benefits of nanotechnology in the food sector (Chaudhry et al. 2008). Various characteristics of food and agricultural systems are influenced by nanotechnology. The science and engineering of food and agricultural systems have some important links with nanotechnology—for example, food security, delivery of medical treatments, different tools for use in cellular and molecular biology, pathogen detection with new materials, and environmental protection (Prasad et al. 2014, 2017a, b). Momin et al. (2013) reported that the USA leads the nanofood product sector, followed by Japan and China, although the largest future market for nanofood products may be the Asian countries, which are led by China. An application matrix of nanotechnology is presented in Fig. 9.4.

Examples of nanotechnology as a tool used for accomplishing further improvements in the food industry are:

- Sensors for detecting contaminants and pathogens to increase food security during manufacturing, processing, and distribution of products
- Tracking of individual products to maintain historical records, along with environmental data, with the help of devices

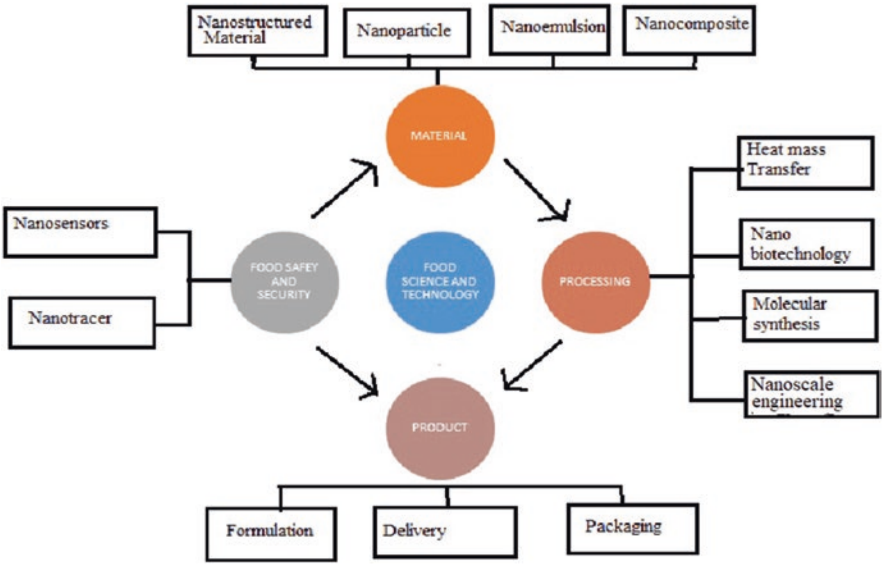

Fig. 9.4 Nanotechnology application matrix in food science (Weiss et al. 2006)

- Increased effectiveness and security of food processing and distribution through remote control of food products with a combination of sensing, localization, and (intelligent) reporting systems
- Protection of functional food ingredients with conservation of their specific modes of action by encapsulation and delivery systems
- Upgraded biosecurity and food safety methods and equipment design, with new product development, microscale and nanoscale processing, and new functional material development, enabling further advancements in the main areas of food production with the help of nanotechnology

9.5.1 Nanotechnology in Food Processing

Nanotechnology has been deployed in food production units and processing areas to increase food quality and food safety. Nanosieves and nanosensors are two basic approaches used in processing units. Nanosieves are a tool by which contaminants are separated from food products, and nanosensors are designed for detection of microorganisms during packaging of food. Silver has been reported to control the growth of bacteria during storage and is widely used in packaging materials (Geys et al. 2008), although an important safety concern is migration of nanoparticles into the food. Inert nanoparticles are used as a system for nanodelivery, in which nanocapsules are prepared that contain bioactive compounds and nutrients. The advantage of this delivery system is that desired active compounds (e.g., pesticides or medicines) can be delivered to their target sites. The use of this system leads to increased absorption and bioavailability (Geys et al. 2008).

9.5.2 Nanoparticles as Food Additives

Chemical reactions occurring in food products, as a result of interaction between food components and outer atmospheric conditions, are the major cause of food spoilage. In the reported literature, numerous nanomaterials have been originated and applied for prevention of these undesirable activities in food (Manke et al. 2013). Pool et al. (2012) studied preparation of polymeric nanoparticles with encapsulation of two bioactive compounds—quercetin and catechin—and their controlled release in food products. Their study indicated that use of poly(lactic-*co*-glycolic acid) (PLGA) encapsulation effectively enhanced the antiradical and chelating characteristics of these bioactive compounds and could be a constructive tool for prolonging the shelf life of lipid-based food. Nanotechnology has also proved to be an effective way to enhance food safety and the nutritional and sensory properties of food products. Rojas-Graü et al. (2009) observed that incorporation of active ingredients into edible coating solutions and films increases the functionality of fruits, and these components work as antimicrobial, antioxidant, antibrowning, and nutraceutical agents. Furthermore, nanoparticles have been reported to improve food characteristics such as appearance and color, but only to a limited extent. The US FDA's permitted limit for TiO_2 coloring additive ingredients is 1% (w/w). Mehrad et al. (2018) reported use of SiO_2 as an anticaking agent, an aroma transmitter, and a means of maintaining the flow properties of dried powder. However, despite their positive attributes, nanomaterials and their metal oxides have been reported to cause generation of reactive oxygen species (ROS), which can result in genotoxicity, inflammation, fibrosis, and carcinogenesis (Manke et al. 2013).

9.5.3 Nanobiosensors for Foodborne Microbial Pathogens

Prokaryotic microorganisms have a hugely dominant influence on the earth and survive in almost all environmental conditions. Microbial pathogens and/or the toxins they produce can contaminate food and cause illness in those who consume it; thus, foods may need to be treated with pasteurization. A vast number of food- and waterborne diseases can ensue when microbial contamination occurs (Malhotra et al. 2014). Microbial analysis can be accomplished with advanced analytical methods such as gas chromatography with mass spectrometry (GC-MS) and high-performance liquid chromatography (HPLC), but these techniques are costly and require technical proficiency to perform (Lee et al. 2012; Valdés et al. 2009). The aforementioned limitations may possibly be overcome with the help of nanotechnology-based biosensing. The many techniques that can produce and manipulate materials in a size range of 1–100 nm are referred to as nanotechnology, which is one of the most promising technologies of the twenty-first century. Microorganisms such as *Salmonella* spp., *Listeria* spp., and *E. coli* are detectable with nanobiosensors. *S. typhimurium* concentrations as low as 1000 CFU/mL can be detected with the use of pathogen-specific antibodies and aptamer-functionalized magnetic particles in an enzyme-linked antibody–aptamer sandwich (nano-ELAAS) assay (Wu et al. 2014).

9.5.4 Nanoparticles in Packaging Materials

Nanotechnology has been reported to have wide applications in the food packaging industry. Incorporation of nanoparticles into packaging materials leads to improvements in their mechanical and heat resistance characteristics, with greater water and gas resistivity (Youssef 2013). Laoutid et al. (2009), Lizundia et al. (2016) reported that nanocomposite polymers covered with silicates have more flame and ultraviolet resistance. Nanotechnology-based packaging materials have been reported to be environmentally friendly because of their biodegradable nature. Rashidi and Khosravi-Darani (2011) described preparation of composite polymers consisting of potato starch and calcium carbonate, and found that this form of packaging was an effective replacement for polystyrene packaging of fast food.

9.6 Limitations of Nanotechnology in Food Safety and Defense

Silver nanoparticles have been reported to affect fibroblasts in the human lung by increasing ROS creation, reducing adenosine triphosphate (ATP) content, and damaging mitochondria and DNA (Kim et al. 2007). Incorporation of nanoparticles into food packaging materials has been reported to cause effects on the skin and lungs (Mills and Hazafy 2009). Morones (2005) verified that nanoparticles could be toxic to plankton and that aluminum nanoparticles could inhibit plant growth. However, the particles present on the equipment or the packaging material directly comes in contact with the food substance that are expected to migrate into food in small amount, these particles are removed from the regulation as food additives if they satisfy certain criteria (US Food and Drug Administration 2014). All these types of pacaking materials thoughout the food suppy chain should be assessed and taken care during food safety studies (Panghal et al. 2018b). Chawengkijwanich and Hayata (2008) reported that different nanoparticles that are known to be harmful to human well-being are employed in food defense nanotechnology.

Cioffi et al. (2005) stated that minerals, proteins, polysaccharides, phospholipids, and surfactants are the most important components of nanoemulsions. Nanoemulsions are made from surfactants and solvents, which can lead to hazardous effects after ingestion at higher concentrations (Cushen et al. 2012). Fujishima et al. (2000) observed that ingestion of large amounts of lipid-containing nanoemulsions can cause obesity and cardiovascular diseases. DNA or RNA can be delivered through the intestinal wall by cochleates, which are lipid-based encapsulates; therefore, a virus or other hazardous components could be transferred through the intestinal wall and cause contamination, which could be a bigger risk factor. There may be some risk associated with the presence of these constituents. Nanosized crystals of lycopene have a tendency to dissolve faster than natural crystals, which could be hazardous. Emulsions containing nanosized components are less stable than those containing larger components; thus, they are absorbed and broken down very quickly (Boom 2011).

Greater knowledge is needed in order to determine the carcinogenicity of these substances, their migration inside the food product through packaging materials and their impact on environment. Determination of the migration patterns of other polymer–nanomaterial compounds resulting from biopolymers requires further research (Chhikara et al. 2018).

9.7 Regulation of Nanotechnology

To date, there has been no regulatory body to formulate specific regulations for use of nanotechnology in food processing. However, the European Parliament and nongovernmental organizations (NGOs) including several stakeholders have suggested some guidelines. The need for such guidelines to evaluate possible risks and provide recommendations for safe use of nanomaterials has been recognized, and numerous bodies are now active in this field, such as the Organization for Economic Co-operation and Development (OECD), the European Union (EU) Scientific Committees and Agencies, the International Standards Organization (ISO), and the US FDA. The input of the EU, the USA, and Australia (which are different jurisdictions) should be sufficient to “capture” the applications of nanotechnology in the food sector within the current framework for food and FCMs. General product safety, water quality, FCMs, chemical safety, specific health claims, novel foods, food additives, and other specific regulations related to general food safety within these jurisdictions cover the use of some chemicals in food production/preservation—for example, pesticides, biocides, and veterinary medicines. For more information on the regulatory features of nanotechnologies, see Chaudhry et al. (2008) and Marchant et al. (2009).

9.8 Future Needs for Nanotechnology

Different nanosystems are being established as capable components of applications in the food industry. Diligent efforts are being made to improve the efficiency of nanocarriers with enhanced bioavailability without affecting the organoleptic properties of food products. Detectors have been designed with incorporation of

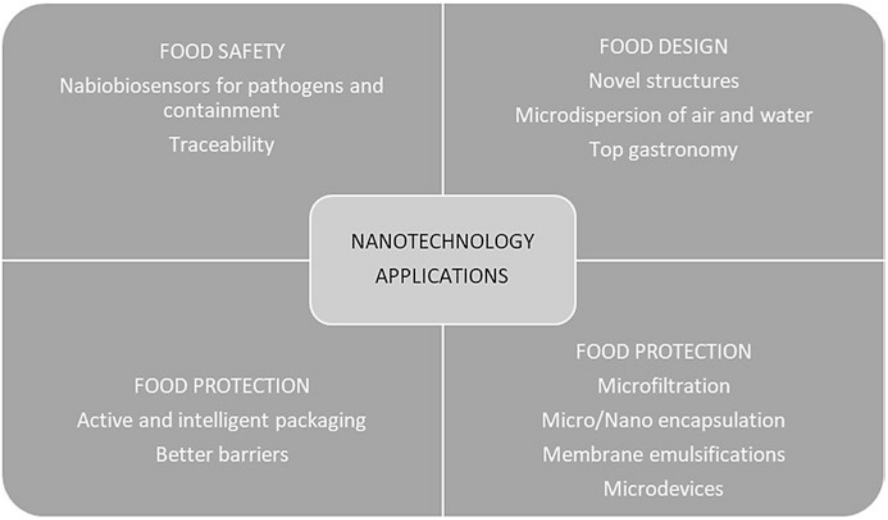

Fig. 9.5 Future needs for nanotechnology applications in the food industry (Rossi et al. 2014)

specific antigen markers to examine the presence of specific microorganisms (Graveland-Bikker and Kruif de 2006). The smart-packaging idea is gradually becoming more appreciated, and research is being done to produce antigen-specific biomarkers for use in food packaging and to create polymeric nanocomposite films containing nanoparticles (Cho et al. 2008). Use of the radiofrequency identification (RFID) concept has also been introduced into the distribution of fast food products with a short shelf life (Farhang 2009).

The field of nanotechnology in product development and commercialization is still lagging behind in India, because the Indian scenario is different from those of developed countries, but it is slowly following world trends and devising new methods. The Indian government has set up a national Institute of Nano Science and Technology for development of nanofoods with use of nanotechnology during cultivation, processing, and packaging of food to improve food safety and food defense.

In the future, nanotechnologies will be used to improve various characteristics of food products, with the use of so-called soft nanomaterials (such as vesicles and micelles) to encapsulate nutrients and deliver them to specific locations in the gastrointestinal tract and to improve the flow and behavior of powdered foodstuffs. Future needs for nanotechnology applications in the food industry are shown in Fig. 9.5.

9.9 Conclusion

Nanotechnology offers pervasive applications in various different areas of the food industry, such as in production, processing, packaging, storage, transportation, traceability, and food security. Numerous advances in nanotechnology in food systems—for example, in food processing and distribution—have been observed in many countries. Nanotechnology also has potential to innovate technology for improvement of functional foods, nutrient delivery systems, food packaging, food hygiene, water decontamination, and shelf life extension. Finally, nanotechnology will enable us to change the existing food system and processing to ensure food safety, construct a healthy food culture, and improve the nutritional quality of food products. However, there is need for better regulations in many countries to ensure proper safety evaluation of products involving nanotechnology in order to protect consumers.

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