Chapter 12
Toxicological Studies and Regulatory Aspects of Nanobased Foods

Asaithambi Kalaiselvi, Ravichandran Rathna, and Ekambaram Nakkeeran

Abstract Nanotechnology is a major breakthrough technology that expanded its wings in several dimensions of life. Nanoscale materials found to have a wide range of applications in food sectors by enhancing the palatability, flavor, taste, micronutrient protection and shelf life of the food products. The market of nano-based food products are increasing at an immense rate but uncertainty on safety and risk is also emerging. The current regulatory framework for nano-based food products developed by Europe, United States, and Asia are eager to capture nanotechnology food products. In this chapter, toxicity studies of nanomaterials and knowledge gap between nanoscience and nanotechnology in the food sector are discussed. An overview of nanostructures, potential risk and future perspective of nanomaterials in food sciences is also discussed.

Keywords Nanomaterials · Risk assessment · Toxicity · Food stores
Nanoparticles

12.1 Introduction

One of the major breakthroughs in applied biosciences is nanotechnology, opened up new arrays of prospects and opportunities that serve as the cradle for the industrial sector (Singh et al. 2016). In recent decades, nanosciences and nanotechnology have progressed to the next generation phase by elaborating its wings in several dimensions of life, from nanomaterials to smart nanotechnology such as RFID - Radio-frequency identification barcodes (Chaudhry and Castle 2011). Nanotechnology is already in reality in various fields such as electronics, medicine (Aslan et al. 2005), textile (Yetisen et al. 2016), communication (Dressler and Kargl 2012), energy production (Guo 2011), defense (Glenn 2006) and food industries

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S. M. Roopan, G. Madhumitha (eds.), *Bioorganic Phase in Natural Food: An Overview*, https://doi.org/10.1007/978-3-319-74210-6_12

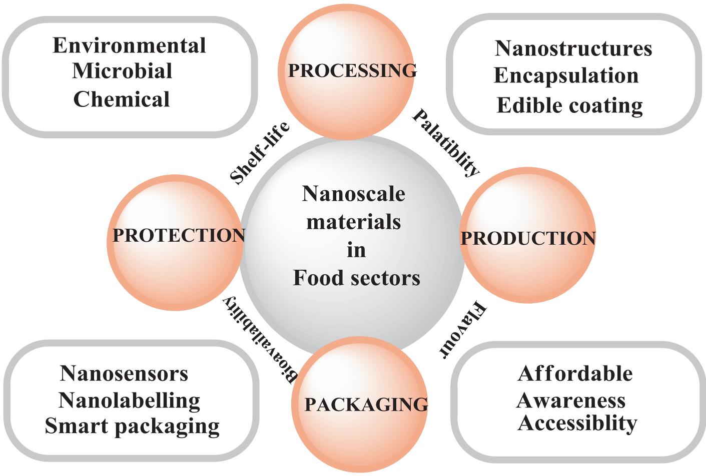

Fig. 12.1 Applications of nanoscale materials in food sector

(He and Hwang 2016). The application of nanotechnology in food sectors is regarded as a new frontier technology that has its mere impact in future (Pradhan et al. 2015; Ravichandran 2010). According to Plunkett Research 2016, the global food and agricultural industry was about an $8.0 trillion market which is almost 10% of the world's GDP. It becomes obvious to generate food sector revenue, the agriculture and food industries continue to progress rapidly for exploring novel products by determining consumers requirements (Ravichandran 2010). Nano-related foods are gaining momentum in developing food science research and offer a wide range of benefits to the industries and consumers (Ravichandran 2010). Nanoscale materials are used in the food sector to enhance several applications in food processing, production, packaging, and protection which is illustrated in Fig. 12.1. Thereby, consumer's procurement and consumption of nano-based food were augmented to intensify the texture, palatability, bioavailability and shelf life (Sekhon 2010).

Nanomaterial incorporated consumer products have been raised much interest in global market compared to last few years (Chaudhry and Castle 2011). Nano-based food and health fitness products have formed the largest category of goods procurement followed by electronics and home appliances. This application based process is initiated from particulate synthesis process from past decade through extensive research. In 1997, about $432 million was supported by the research and development of nanotechnology and the contribution was increased in nine folds in 2005 which is around $4.1 billion (Roco 2007). In 2006, The Institute of Food Science and Technology from the United Kingdom conducted a worldwide survey, estimated and identified that more than 200 companies majorly involved in various applications of nanotechnology (Buzby 2010). Countries like United States, Japan, European Union and China are mainly contributing their research and development in food applications. In 2008, Cientifica reported that about 400 companies involved and initiated their use nano applications in food processing industries (Chaudhry et al. 2008). The nanotechnology research group estimated in 1996 reported that nano-based food products would reach the international market more than $1 trillion by 2015 (Buzby 2010). A study revealed that the global market on food and beverage packaging products sector would alone raise almost six-fold in the period of 2 years from $150 to $860 million in the year 2002 to 2004 (Buzby 2010). In 2016, 20 participating Federal departments, independent agencies, and commissions requested about $1.5 billion to brief the development of nanoscale science, engineering, and technology (nano) research and development (R&D) (Bhushan 2015). According to Persistence market research 2014 estimates a compound annual growth rate of 12.7% would reach about $15 billion in 2020 (Bumbudsanpharoke and Ko 2015).

Researchers initially focused on developing nanovesicle to enhance the bioavailability of bioactive compound at the targeted site in a low dosage form (Watkins et al. 2015). Taking this into account, researchers developed vital nutrient fortification to overcome individual's daily nutritional needs by considering the permissible limit. Primarily food endures bio-mitigation during its processing that affects its chemical and physicochemical nature (Ravichandran 2010). In order to prevent this, nanomaterials with unique structural properties were used to influence the product from initial stability to final biotransformation in the human body when ingested (Özer et al. 2014). The unique physical, chemical and biological properties of the nanostructures which are significantly different from its original bulk form, and make it ideal for its potential application in the food sector (Armentano et al. 2014). Nanostructured materials like nanocomposite, nanoemulsions, and nanoencapsulation help in improving the shelf life, color, taste, flavor, safety level and nutritional values of the food products (He and Hwang 2016). These nanomaterials are extensively used in food packing due to its barrier properties, mechanical properties (flexibility, durability), heat and moisture resistant properties and biodegradability (Yang 2007). Nanomaterials are also used to enhance antimicrobial effects, prevent and detect food spoilage via nanosensors and labeling (He and Hwang 2016; Ravichandran 2010).

The rapid advancement in nanotechnology in food sector has led to the development of innovative novel process and products for human society but considerably suffers from health, safety, and regulatory issues (Ravichandran 2010). Thereby, the major challenge is to formulate and produce the nano-based product that is economically feasible and safe for human consumption. There are regulatory bodies in the world to formulate the rules and regulations for nano-based materials that have consequences for use in food items (Chaudhry and Castle 2011). Moreover, toxicological studies, pharmacokinetics profile and potential risk of the nanomaterials used in the food sector is in its infancy stage (Chaudhry and Castle 2011; Sekhon 2010) and standardized validation test/procedure for detection and characterization of nanomaterials in food on living cells are currently unavailable (Chaudhry and Castle 2011; Ray et al. 2009). Therefore, there exists a knowledge gap between nanoscience and nanotechnology in food that needed further research.

12.2 Agency and its Regulations in Use of Nanotechnology in Food Sectors

The use of novel materials and methodology in various fields of food sector as food additives and food contact materials, potential risk assessment should be followed to quantify, identify and to overcome human health complications and to prevent the flora and fauna based environment from discarded nanomaterials (Viswanath and Kim 2016). The novel applications that are incorporated with nanotechnology in food sector must be thoroughly assessed, assured and regulated for safe commercialization and consumer use (Sekhon 2010). Till date, there are no proper standard international regulations framed on nanotechnology/ nano-based products. Only few government agencies/ organizations from various developed countries have come forward to define the usage of nanotechnology by establishing regulated standards. The regulations that are established by representatives of several countries are represented in Table 12.1.

In Food and Drug Administration (FDA), Special regulations were not framed initially on the use of nano additives, nanocontact materials during the entry phase of nanotechnology in the food sector. In 2004, FDA regulated nano-based food by its nano range of the particulate source material but failed to focus on their methodology of preparation and its applied technology (Weiss et al. 2006). Nevertheless, there are several other government agencies with various goals and mission set to assess the risk of nanotechnology to solve environmental related problems and to treat diseases with improved technology (Boverhof et al. 2015).

In 2005, a suggestion was passed by the Institute of Food Science and Technology (IFST) stating that if nano-based particle or material used in any form as food additives or food contact formulations, the concerned food product should be labeled with the conventional E-numbering system with subscript "n" before it is into commercial use (Weiss et al. 2006). Later in 2006, the British government accepted the suggestions made by IFST that any nano ingredients added in or in contact with the food material must be subjected to a complete safety assessment prior to use in food products (Chau et al. 2007).

In 1963, Codex Alimentarius has created to monitor the food regulations with a set of regulatory standards for characteristics, practices, handling, recommendations and marketing of the food product. This agency initially updated its standard protocols to the World Health Organization (WHO) and the United Nations Food and Agriculture Organization (UN-FAO) that was followed to maintain nanofood production and use of nanotechnology in promoting food and agriculture sectors (Bumbudsanpharoke and Ko 2015). Later in 2008, WHO and UN-FAO initiated to hold their own committee with expert consultations in the field of food sector to maintain and identify in-depth applications of nanotechnology, which can minimize the health risk at present and future with potential measures taken on food safety sector. Further, they can pave way for exploring future research (Rashidi and Darani 2011).

Table 12.1 List of the regulatory agencies around the World

Country	Regulating agency	Year of establishment	Head quarters
Australia	Food Standards Australia and New Zealand (FSANZ)	1991	Wellington
	Friends of earth (FoE)	1975	Melbourne
	CSIRO Manufacturing and Materials technology (CMMT)	1945	Canberra
Canada	Canadian Food Inspection Agency (CFIA)	1997	Ottawa
	Public Health Agency of Canada (PHAC)	1993	Ottawa
	National Institute for Nanotechnology (NINT)	2001	Alberta
China	Chinese Academy of Sciences	1949	Beijing
	National Center for Nanoscience and Technology (NCNST)	2003	Tianjin
European Union	European Food Safety Authority (EFSA)	2002	Parma
	Federal Agency for the Safety of the Food Chain (FASFC)	2000	Brussels
	Community Research & Development Information Service (CORDIS)	1990	Luxembourg
	European Nanotechnology Gateway	2003	Greece
	European Nanobusiness Association (ENA)	2002	Belgium
France	French Research Network in Micro and Nano Technologies (RMNT)	1998	Cedex
	ANSES - French Agency for Food, Environmental and Occupational Health & Safety	2010	Maisons-Alfort
	Centre National de la Recherche Scientifique (National Center for Scientific Research) (CNRS)	1939	Paris
Germany	Federal Ministry of Education and Research (BMBF)	1955	Heinemannstraße
	German Federal Institute for Risk Assessment (BFR)	2002	Berlin
India	Food Safety Standard Authority of India (FSSAI)	2011	New Delhi
	Department of Science and Technology (DST)	1971	New Delhi
	Department of Biotechnology (DBT)	1986	New Delhi
Iran	Nanotechnology Committee of Food and Drug Organisation	2006	Tehran
	Iran Nanotechnology Initiative Council (INIC)	2003	Tehran
Ireland	Food Safety Authority of Ireland	1999	Dublin

(continued)

Table 12.1 (continued)

Country	Regulating agency	Year of establishment	Head quarters
Italy	Joint FAO/WHO Expert Committee on Food Additives (JECFA)	1956	Rome
Japan	Ministry of Health, Labour, and Welfare	2001	Tokyo
	Nanotechnology Researchers Network Center (NANONET)	2012	Tokyo
	Rikagaku Kenkyusho (RIKEN)	1917	Tokyo
	Ministry of Education, Culture, Sports, Science and Technology (MEXT)	2001	Tokyo
	National Institute of Health Sciences (NIHS)	1874	Tokyo
	National Institute for Environmental Studies (NIES)	2001	Onogawa
	National Institute of Advanced Industrial Science and Technology (AIST)	2001	Tokyo
	Japan Society for the Promotion of Science (JSPS)	1932	Tokyo
Korea	Korean food and Drug Administration (KFDA)	1998	Chungcheongbuk-do
	Korean Agency for Technology and Standards (KATS)	1883	Chungcheongbuk-do
	National NanoFab Center (NNFC)	2002	Chungcheongbuk-do
	National Center for Nanomaterials Technology (NCNT)	2003	Gyeongsangbuk-do
	Center for Nanostructured Materials and Technology (CNMT)	2009	Seoul
Russia	Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing (Rospotrebnadzor)	2004	Moscow
Switzerland	Swiss Federal Office of Public Health (FOPH)	2006	Bern
	Federal Office for the Environment (FOEN)	1971	Bern
Taiwan	NanoTechnology Research Center (NTRC)	2002	Hsinchu
	National Science and Technology Program for Nanoscience and Nanotechnology	2003	Taipei
USA	Government Accountability Office	1921	Washington, D.C.
	Food and Drug Administration (FDA)	1906	Maryland
	Institute of Food Technologists (IFT)	1939	Chicago
	Environmental Protection Agency (EPA)	1970	Washington, D.C.
UK	Institute of Nanotechnology (IoN)	1994	Ottilia Saxl
	Department for Environment, Food and Rural Affairs (DEFRA)	2001	London

Source: Chau et al. 2007; Bhattacharya et al. 2012

The Directorate-General of Health and Consumer Protection in the European Union structured a Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) in 2010 (Grobe et al. 2008). Emerging environmental and health related risks are assessed regarding the consumer safety and public health by comprehensive risk assessment exclusively on nano-based technologies that fit into the food sector profile.

The Swiss Center for Technology Assessment (TA-Swiss) recently found that nano food additives were in commercial use for many years in Switzerland such as micelles, carotenoids, silicon dioxide, etc., when a study was conducted by TA-Swiss, no indications was found that the nanoparticles used in food products in Switzerland were not dangerous to human health. In major cases, to understand the risk of nanoparticles consumption no specific tests are available in food and health sector (Vishwakarma et al. 2010). Therefore, a regulatory system was introduced as "positive principle" to identify the registered positive nano food additives using E-numbering system such as silicon dioxide (E 551), silver (E 174), gold (E 175), Iron oxide (E 172), titanium oxide (E 171) and aluminium (E173) (Ravichandran 2010).

In Japan, the government agencies along with Ministry of Education, Culture, Sports, Science and Technology (MEXT), Ministry of Economic, Trade, and Industry's (METI), Ministry of Health, Labor and Welfare (MHLW) and Ministry of Environment (MOE). MEXT promotes research and development along with academic and industrial sector and creates a platform for nanotechnology, material science and extensively supports the development of nanotechnology in various fields of applications. The standardization protocols of testing methods and nanoparticles safety are evaluated by METI (Thomas et al. 2006). The health impacts of nanomaterials and its route causative agents are assessed and evaluated by MHLW. Therefore, regulation of science academic are worked by METI, MHLW, MOE and the sole responsible for the researcher's performance to public acceptability was evaluated and maintained by MEXT. Further, during the development of nanomaterial using nanotechnology information support was given by National Institute for Materials Science (NIMS) which was established by the Nanotechnology Researchers Network Center (Nanonet).

In 2009, Australian Government launched The National Enabling Technologies Strategy (NETS) in its four-year plan of Federal Budget to explore advanced technologies such as nanotechnology and biotechnology. In this budget, NETS was funded $38.2 million over 4 years. Food Standards Australia New Zealand (FSANZ) is a statutory authority that develops comprehensive safety assessment for nano-related products in Australia and New Zealand.

In 2003, Chinese Academy of Sciences (CAS) and Ministry of Education founded the National Center for Nanoscience and Technology (NCNST) in China. It has several divisions of laboratories which have established a platform to the public about the basics, technology and applied research in the field of nanosciences. In 2005, NCNST established the Commission on Nanotechnology Standardization along with its affiliation. It has the responsibility of developing a technology which should fulfill safety requirements including termination protocol of any processing, materials, bio-mediated products, medicine that are produced with nanotechnology. Any protocol generated should be based on the china national standards. The commission provides the necessary guidance, governs assessment risk and handles accreditation of nano products which promotes the industries to enhance quality, sustain safety by reducing health risks and to fasten the development of the products.

Singapore has set up Agency for Science, Technology, and Research (A*STAR) in 2006 with the goal to promote nanotechnology research and development and commercialization. In 2010, the Singapore Institute of Manufacturing Technology (SIMTech) organized the first nanotechnology Manufacturing Round Table Discussion (MRTD) to accelerate the adoption of nanotechnology.

Indian government endeavored systematically to promote research in the frontier of nanotechnology since 2001 (Beumer and Bhattacharya 2013). National Institute of Pharmaceutical Education and Research (NIPER) has entered into licensing agreement with Windlas Biotech limited for development and commercialisation of nanocrystals for drug delivery. NIPER is also working on regulatory approval guidelines and standards for toxicological study in nano-based drug delivery systems. In the Twelfth Five Year Plan (2012–2017), a total cost of Rs. 650 crore is approved for the Mission on Nano Science and Technology (Nano Mission). In India, government mainly focuses on the development of infrastructure, skill development and strong institutional base for achieving success in the field of nanoscience and nanotechnology (Beumer and Bhattacharya 2013). Though Indian government does not have specific regulation for nanotechnology but there are checks and balances at places (Beumer and Bhattacharya 2013).

12.3 Nanomaterials in Food

Nanomaterials are structures that fall under nanometer scale with properties different from its bulk materials (Maurice and Hochella 2008). Generally, nanomaterials are categorized into 4 forms based on its structural dimensions as shown in Fig. 12.2.

These nanostructural materials are found naturally in milk proteins and casein, incidentally formed in the byproducts of welding and intentionally produced as nanofibres (Tarafdar et al. 2013). Nanostructures exist in different sizes and shapes as illustrated in Fig. 12.3. The most notable nanostructured materials used in food systems are nanocomposite, nanoemulsions, nanoencapsulations and nanoparticles (NPs) represented in Fig. 12.4.

12.3.1 Nanocomposites

Nanocomposites are defined as a multiphase component acquired from a combination of two or more constituents to form the unique properties than the bulk composite with a nano-sized dimension less than 100 nm in size (Roy et al. 1986).

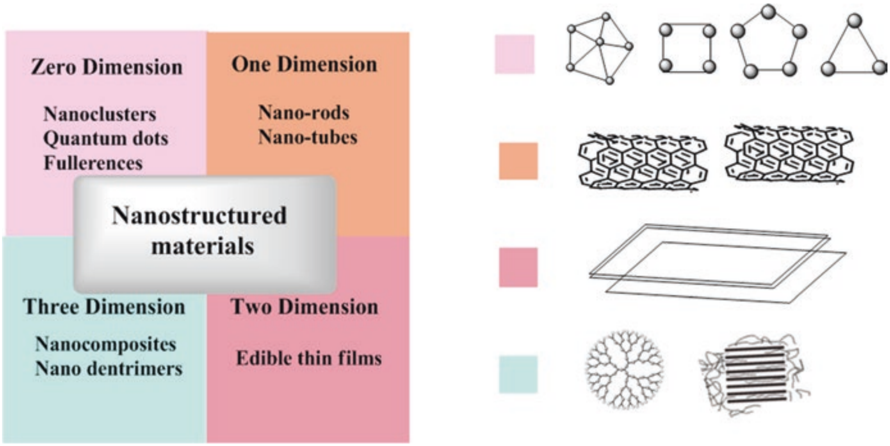

Fig. 12.2 Forms of nanostructured materials

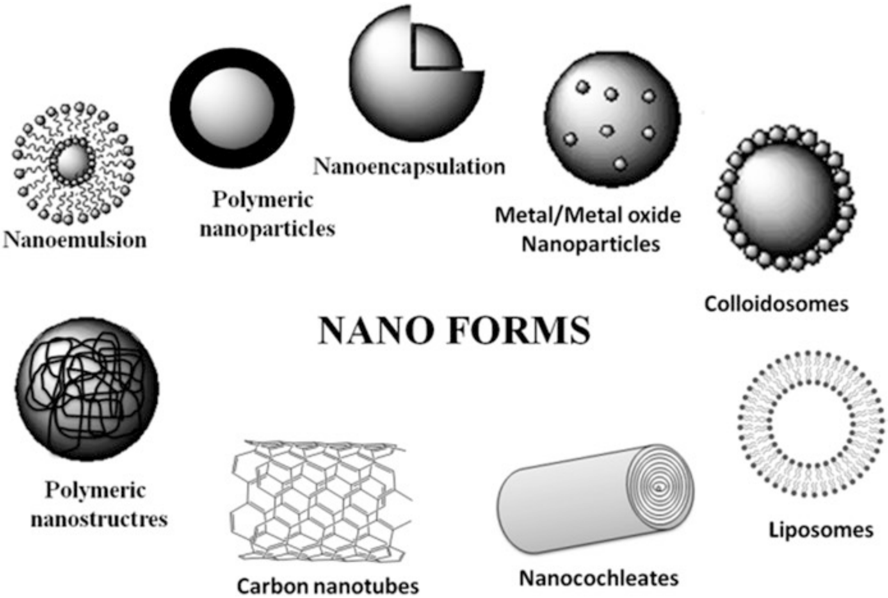

Fig. 12.3 Various nano forms

It is broadly classified into polymeric nanostructures and nanoclays based on the materials used. These nanocomposites are mainly used in food packing as alternative conventional packaging materials due to its advanced functional properties and economic feasibility (Pathakoti et al. 2017).

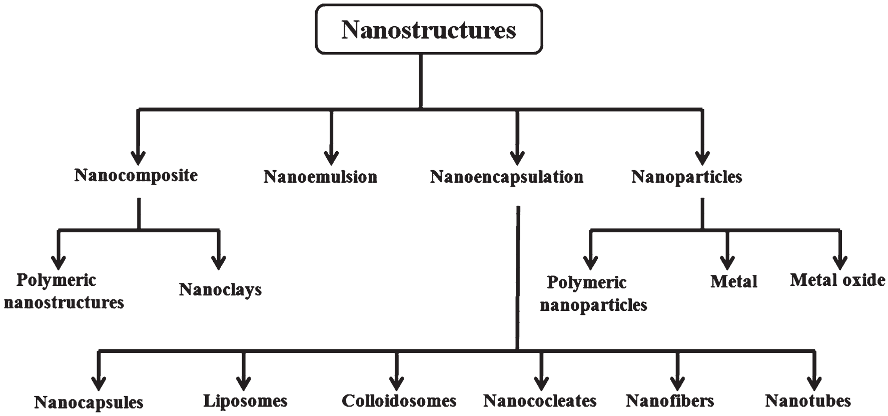

Fig. 12.4 Categories nanostructures

12.3.1.1 Polymeric Nanostructures

Polymeric nanostructures/nanocomposites are materials consisting of two or more phase separated materials, the polymer as its major phase in one or more dispersed phase in nanoscale size. This polymer nanocomposite can be used as a nanocoating material to act as a specific surface gas barrier (Cui et al. 2016). When the polymeric nanocomposites are layered with minerals like silicates, it enhances the physical and mechanical properties in terms of tensile strength (Jumahat et al. 2012), permeability to gas (Beyer et al. 2002), resistance to thermal stress and moisture (Paul and Robeson 2008), etc. The polymeric nanostructure packaging system helps in improving the stability of color, flavor, and palatability and avoids food spoilage (Weiss et al. 2006). The polymer used for preparing nanocomposites can be derived from plant (eg. starch, cellulose), animals (eg. proteins) or microbial (e.g. polyhydroxybutyrate, bacterial cellulose) source.

12.3.1.2 Nanoclays

Nanoclays are crystal lattice structure of layered inorganic mineral which occurs in nanoscale size. Based on the chemical composition, nanoclays are categorized into several classes like montmorillonite, bentonite, kaolinite, hectorite, and halloysite (Nazir et al. 2016) as shown in Fig. 12.5. Nanoclays are extensively implemented in food contact surfaces and food packing application because of their enhanced barrier and mechanical properties over the synthetic packaging materials (Majeed et al. 2013). Food and beverages industries use multilayered nanoclay for the bottling of beer and carbonated drinks (Huang et al. 2015; Othman 2014). These nanoclay composites are reported to be used in pharmaceutical products as excipients and active agents (Aguzzi et al. 2007). Bentonite, considered as the most commonly

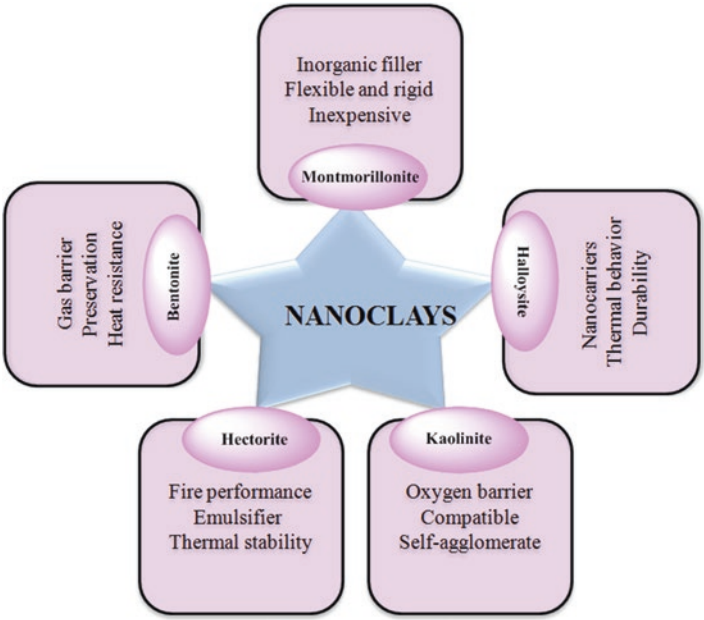

Fig. 12.5 Classifications of nanoclays and its physico-chemical properties

used nanoclay composite with high gas barrier properties which is relativity low cost and availability (Liu et al. 2014). The performance of the nanoclay depends on the polymer used for the preparation of nanoclay which determines its use in food and pharmaceutical packaging applications.

12.3.2 Nanoemulsions

Nanoemulsions are a colloidal dispersion of lipid in the aqueous phase to produce droplets ranging in nanoscale. Nanoemulsions act as a potential carrier of lipophilic (soluble in lipids or oils) compounds which are extensively used in pharmaceutical industries as drug delivery system (Jaiswal et al. 2015). Hence, this concept was recently explored in the food industry to improve the bioavailability of functional compounds like antioxidant (α-Tocopherol, Curcumin, β-carotene, lycopene, lutein, coenzyme Q10), essential fatty acids (omega-3), vitamins (A, D3 and E) and phytosterols in the fortification of food. Nanoemulsions of phytosterols act as an excellent food additive (Garti et al. 2005). They are extensively used to shield the flavor during the processing and increase the shelf life by protecting the food materials from an environmental condition such as oxidative stress and enzymatic hydrolysis (Silva et al. 2012). Commercially available nanoemulsion-based food products are flavored oils (Rao and McClements 2011), bottled beverages (Mirhosseini et al. 2009) and drinking water (Gu et al. 2005), fortified milk (Joung et al. 2016), sweeteners (Coupland and Hayes 2014), ice-creams (Kumar et al. 2016), food colourants (Yin et al. 2009) and other processed food items (Silva et al. 2012).

12.3.3 Nanoencapsulations

Nanoencapsulation is a technique to protect the active compound in nanoscale range and augment its functionality and stability with controlled release of the active compound. This technique is used in pharmaceutical as particulate carrier system (Reis et al. 2006). They are employed as a tool to improve the pharmacokinetics, bioavailability and to facilitate controlled drug release at targeted site (Diab et al. 2012). This technique is widely used to deliver culinary balance in processed food products and to enhance the flavor and color release and retention in food sample (He and Hwang 2016; Nakagawa 2014). Functional ingredients and additives like vitamins, probiotics, preservatives, antioxidants, peptides, lipids, carbohydrates, etc., are incorporated into the nanovesicles as nano encapsulated bioactive material (Nakagawa 2014). Based on its structure nanoencapsulation is categorized as Nanocapsules, Liposomes, Colloidosomes, Nanocochleates, Nanofibres and Nanotubes.

12.3.3.1 Nanocapsules

Nanocapsules are a nanoscale-sized shell made up of the external polymer layer with internal polymeric matrix capable of holding bioactive compounds. This nanosystem is extensively used for delivering functional compounds by protecting against catalyze oxidation and hydrolytic degradation in food, beverage and nutraceutical industries. Nanocapsules are formed by polymerization of monomers or crosslinking of polyelectrolytes or biomaterials like chitosan, zein, etc. (Chauhan et al. 2017; Patel and Velikov 2014). They have the special property to get expanded and bind with specific chemical receptors of particular cells and the bioactive compounds are released in a controlled manner (Pradhan et al. 2015). Nanocapsules are exclusively used in self-degrading packaging and encapsulate lipid compounds in food products (Sekhon 2010). Nanocapsules has huge potential in the packaging of food and beverage sector but there is a need for further research to reduce the cost and potential risk of the consumer to open up the market for nanoproducts (Sekhon 2010).

12.3.3.2 Liposomes

Liposomes are spherical bilayer vesicles formed with phospholipids. Food industries initiated usage of encapsulated liposomes to increase the bioavailability of functional ingredients (Mozafari et al. 2008). More recently antimicrobial properties of liposomes are explored; it has an ability to integrate food microbes and increases the protection and shelf life of the food products (Mozafari et al. 2008). Its unique properties such as nano size range and interfacial surface area make it ideal for the controlled delivery of nutraceuticals at the specific target site.

12.3.3.3 Colloidosomes

Colloidosomes are self-assembled colloids oil-in-oil emulsion to form microcapsules. This encapsulated topology was found in accordance with liposomes (Thompson et al. 2010). It has gained importance in various felids of science, food, medicine and cosmetics due to their solid hollow structure, computability and physicochemical structure. It is found to be ideal carrier for lipophilic compounds, vitamins, antioxidants and coloring agents with controlled functionality (Lopes et al. 2013).

12.3.3.4 Nanocochleates

Nanocochleates are nano coils the particles by wrapping the micronutrients to stabilize and secure the extended range of micro or macro nutrients by enhancing the bioavailability and nutritional value of the processed food (Lopes et al. 2013). These nanomaterials also have an ability to microencapsulate water soluble cationic drugs/peptides within its lipid bilayer space by interacting with lipids that are negatively charged. Either peptides or drugs, they act as inter-bilayer bridges with multi cations instead of metal ions (Pawar et al. 2015). These nanocochelates are incorporated into bakeries products such as cookies, cakes, and muffins as a carrier for micronutrients, phytosterols etc., without varying the taste and odor of the particular food product (Lopes et al. 2013). This nano cochleate's paves way for the concept of super foodstuffs found to improve mood, energy, immunity, cognitive functions and alleviates depression

12.3.4 Nanofibers

Nanofibers are nanoscaled fibers fabricated using electrospinning process with the very large surface area and high porosity (Vasita and Katti 2006). Honey/Chitosan nanofibers found to be an attractive matrix for wound care with bacericidal effect

(Sarhan et al. 2016). Due to its structural organization it is widely used in food industries for clarication (beer and wine) and food contact materials (Ravichandran 2010). It is also used for enzyme immobilization (Jia 2011), scaffold geometry of bioreactor (Hardick et al. 2015), delivery of bioactive compound (Hrib et al. 2015), the concentration of fruit juice (Bélafi-Bakó and Koroknai 2006) and scaffold to remove bacteria in milk (Fahim et al. 2016). Edible biopolymers are used in the preparation of nanofibers that has its potential application in encapsulating the bioactive compound for its use in food and nutraceutical sectors (Azeredo et al. 2012). Food and beverage industries use nanofiber membranes/composites as an alternative membrane system for purification and concentration of the desired compounds with higher flux, rejection rate and anti-fouling characteristics.

12.3.5 Nanotubes

Nanotubes are cylindrical fullerenes representing buckytubes structure used in sports, medicine and food industries for its novel mechanical properties. Carbon nanotubes are used in food sector to improve the shelf life of the food produced from microbial deterioration (Honarvar et al. 2016). Further, self-assembled alpha-lactalbumin nanotubes from partial enzyme hydrolysis of the milk protein were used as thickening and gelling agent in food sector (McClements et al. 2009). It is also used to encapsulate matrix to protect and promote the stability of the food ingredients. Improved mechanical strength and resistance to environment stress of nanotubes paves the way in processing and packaging technologies in food industries (Honarvar et al. 2016).

12.3.6 Nanoparticles

Proteins and polysaccharides produce food grade biopolymeric nanoparticles in the nanoscale range (He and Hwang 2016). Polylactic acid is used as one of the major component due to its biodegradable properties. These biopolymeric polylactic NPs are used regularly in the delivery of bioactive micro and macro nutrients to the targeted site through encapsulation (Pathakoti et al. 2017). Polysaccharides based starch like NPs prevents oxidation of lipids and improves the stability and prevents the food degradation (eg. α- tocopherol and sodium caseinate stabilized lipid-based nanostructures) (Pathakoti et al. 2017).

To overcome the adverse effect of chemically synthesized metal nanoparticles, various secondary derivatives were used as a reducing agent to produce biologically mediated nano particles. Example silver nanoparticles from *Annona squamosa* (Kumar et al. 2012) and *Cocos nucifera* (Elango et al. 2016), etc. Silver nanoparticles have increased utility in food industries to retained aroma and sensory characters. Several nano-based color additives are extensively studied and manufactured in food industries. Customer's personal and psychological characters are highly influenced by the color to select the particular food products. TiO_2 is a major metal oxide used in food additives and SiO_2 and Al_2O_3 are traces used. SiO_2 nanomaterials are used as vesicle for flavors, fragrance and as an anti-caking agent in food products (Martirosyan and Schneider 2014). The US FDA approved the use of TiO_2 not exceeding its permissible limits more than 1% w/w and for SiO_2 and Al_2O_3 not exceeding 2% of the total (Kuznesof and Rao 2006). The European Union indicated the least containing of SiO_2 in food additive products are widely certified and registered as E551 within the permissible limits.

12.3.7 Nanolaminates

Apart from nanodispersions and capsules, the most important technique used commercially in the food sector is nanolaminates (Ravichandran 2010). This nanomaterial consists of two or more layers in nano dimensions. The size of laminates ranges about 1–100 nm/layer thin films that are extremely food grade. These edible thin film nanolaminates have several advantages in the preparation of various fruits, vegetables, meat, chocolate, candies, french fries and bakery products and protect deterioration by acting as a barrier to moisture, lipids, and gasses (Weiss et al. 2006; McClements et al. 2009). It serves as nanocarriers by enhancing the color, flavor, nutrient availability, textural property, antioxidant and antimicrobial properties and increases the shelf life of the food materials (Ravichandran 2010). Presently, edible lipid-based nanolaminates are commercially used due to its moisture resistant property but have a certain resistance to limited gasses compared to polysaccharide and protein based edible nanolaminates (Ravichandran 2010; Pradhan et al. 2015).

12.4 Categories of Nanotechnology Used in Food Sectors

There are two categories of nanotechnology in the food sector, one involves in the production of nano-based technologies for food processing. Nano products such as nano-sieves to filter bacteria and food packaging materials incorporated with nanosensors to detect food deterioration caused by microorganisms (Bouwmeester et al. 2007). Two is to introducing nanostructured material into the food items with the idea of maintaining and to increase the shelf life of food (He and Hwang 2016). In this category, whole diversity of inert nanoparticles and nanocapsules are used for various purposes in the food chain production such as soil cleaning and water purification process based on nanotechnology, in storage of food and to increase its period of duration, nanoscale quantity of lanthanum particles and iron powder, intellectual food packaging systems are carried out frequently with silver, magnesium, zinc oxide, silica nanoparticles (García et al. 2010). Hence, consumers remain riskless that inert nanoparticles remain bound within the packaging material than the particles are directly exposed or migrated inside food substances (House of Lords 2010). However, the nano-based drug delivery system such as nanocapsules promotes a way to deliver desired active compound to its target in its desired way in the human biological system by reducing the size and dosage of the desired bioactive compound (Singh and Lillard 2009). These nanocapsules are used as active compounds in the production of nutraceuticals and medicines to increase the absorption and bioavailability of the lead bioactive compound (Sekhon 2010; Nair et al. 2010). Table 12.2 represents the commercial nano-based products available in the market.

12.5 Strategies of Engineered NPs in Food

An extensive research and special attention are needed in a forthcoming generation since the majority of food industries on the globe initiated to advance their food products, production, and protection with novel ideas using various applications of exposed and unexposed fields of nanotechnology. Therefore, detection of these engineered nanoparticles in food matrices is found to be difficult at present due to lack of methodologies to determine the actual amount of nanoparticles present in the food in a consumable form (De Jong and Borm 2008). It is advisable to consider and evaluate the nutritional implications of nanoparticles when ingested along with the food. Bioactive compound when ingested along with the food, such as nanocapsules, which has the capability to increase the bioavailability even to contaminants that are normally present in the food matrix (Viswanath and Kim 2016). Further, these nano-based particles with an active charge on their surface can easily absorb biomolecules when they pass through the gastrointestinal (GI) tract. This effect is also called as "Trojan Horses" effect due to the transportation of toxins in the intestinal mucosa, which leads to intestinal cellular line exposure and damages the cells (Bouwmeester et al. 2007). It is possible and feasible that the nanoparticles are measured and assessed according to its permissible limits before it enters into the food matrix at pilot scale production of the particular food chain process. However, protocols are currently available only to detect and assess conventional chemicals but not for the nanoparticles present in the food matrix. This area should be pivoted; more importance should be given because functionalities of nanoparticles get modified from one biological matrix to the other depending on thermodynamic conditions that occur in each matrix. Relying on producer's information can be an alternative approach to understanding exposure of NPs as an initial assessment to predict health effects. A scrutinized primary data that is lacking behind should be assessed and maintained by novel governance.

Table 12.2 Nanotechnology based commercial FoodProducts

Product name	Nanomaterial used	Uses	Company name	Country
Canola Active Oil	Nanoencapsulation	Fortified phytosterol	Shemen	Israel
Nanotea	Selenium nanoparticle	Micronutrient	Shenzhen Become Industry Trading Co.	China
Fortified Fruit juice	Nanoencapsulation	Nutritional supplements	High Vive.com	USA
Nanoceuticals slim shake	Nanoencapsulation of cocoa	Assorted flavour	RBC Life Sciences	USA
NanoSlim beverage	Nano diffuse technology	Diet supplements	Nanoslim	Canada
Oat Nutritional Drink	Iron nanoparticles	Assorted flavour	Toddler Health	USA
Daily vitamin boost	Nanoencapsulation	Nutritional supplements	Jamba juice	USA
Nanocapsule – Tuna fish oil	Nanocapsules	Omega fatty acid protection	Tip-Top Up bread	Australia
Low-Fat Cottage Cheese	Titanium dioxide	Pigment properties	Daisy	USA
Coffee Creamer	Titanium dioxide	Pigment and anticaking agent	Albertsons	USA
Greek Plain Yogurt	Titanium dioxide	Pigment	Dannon	France
Eclipse Spearmint Gum	Titanium dioxide	Anticaking agent	Eclipse	Canada
Whipped Cream Frosting	Titanium dioxide	Anticaking agent and pigment	Betty Crocker	USA
Cereal	Titanium dioxide	Anticaking agent	Fiber One	USA
Chocolate Syrup	Titanium dioxide	Pigment	The Hershey Company	USA
Breathsavers Mints	Titanium dioxide	Anticaking agent and pigment	The Hershey Company	USA
Kool-Aid Lemonade	Titanium dioxide	Anticaking agent	Kool-Aid	Mexico
Silk soy milk	Titanium dioxide	Anticaking agent	Silk Vanilla Soy drink	USA
Roasted Garlic	Titanium dioxide	Anticaking agent and pigment	Betty Crocker Mashed Potatoes	USA
Oreos chocolate biscuit	Titanium dioxide	Anticaking agent	Oreos	USA

(continued)

Table 12.2 (continued)

Product name	Nanomaterial used	Uses	Company name	Country
Antibacterial Pet products	Silver nanoparticles	Antibacterial agent	Nano Care Technology Ltd.	China
ASAP health max 30	Silver nanoparticles	Nutrient supplements	American Biotech Labs	USA
BlueMoonGoods™ fresh box silver nanoparticle food storage containers	Silver nanoparticles	Packaging	Blue Moon Goods, LLC	USA
Utopia silver supplements®	Advanced colloidal silver	Healing	Utopia	USA
Lypo- Spheric Vitamin C	Liposome	Nutrient supplement	LivOn Labs	USA
Colour emulsion	Nanoemulsion	Coloring agent	Wild Flavors	USA
Bioral Omega 3	Nanocochelates	Food additives	Bioral	USA

Sources: Pradhan et al. 2015; Rao and McClements 2011; Sekhon 2010; Silva et al. 2012

12.6 Consumer Consumption and Exposure Assessment

From various standardized food baskets utilized to obtain the consumption data of nano-based food using various sources from pre-marketing to households. The individual dietary survey was assessed with post-marketing studies (Bouwmeester and Marvin 2010). It is found that no additional information was given regarding the usage of nano additives or nano-based substances. Hence, usage of NPs in food which is generally lacking should be reframed along with consumption databases to maintain prominent assessment on evaluating food supplements those are frequently incorporated into nanoparticles.

Evaluating a number of nanoparticles and its conventional chemicals that are integrated into the consumption of food is the final step performed for exposure assessment (Contado 2015). To integrate the exposure data one among the three approaches are followed such as point estimation, simple distribution, and probabilistic analyses (Arisseto and Toledo 2008). Using this analysis, consumer exposure to particular nano-based food is compared with a toxicological reference value, such as recommended daily allowances, tolerable permissible value, a minimal referral doses, and the upper safe level of intake. Currently, these type reference values regarding NPs are lagging which should be established to provide a healthier lifestyle for humans.

12.7 Potential Risks Assessments

Using nanotechnology, the nano range materials brings several benefits and prospects in midst of consumers in the global market (Beumer and Bhattacharya 2013). In spite, due to some biopersistent (insoluble or hard NPs) used in food and beverages for human consumption (Laux et al. 2017). It is more concerned when NPs enter inside the human body, they have large reactive surfaces and crosses biological barriers and enters another biological system of the body. This large particulate material initiates its unknown reaction in the new biological matrix, where NPs entry is restricted. Therefore, the knowledge gaps should be assessed in understanding thermodynamic properties and behavioral effects of biopersistent NPs used in food application to prevent the raise of any special health concerns (Laux et al. 2017). Case by case assessment is needed to avoid risk on consumer consumption. Natural foods with nanostructures are considered as soft nanoparticles are known well to be digested and degraded in the GI tract (Estelrich et al. 2014). Detailed evaluations for soft NPs are not required compared to hard NPs.

It is minimally considered about the food products that contain natural food structures that are not biopersistent. They are easily digested and absorbed in GI tract. Some areas are more concerned though food nanocarriers are not produced with biopersistent material. This nano encapsulated food carriers when crosses the GI tract, the materials present in nanocarriers may be different from the conventional bulk equivalents (Chaudhry and Castle 2011). Moreover, due to enhanced bioavailability, the vitamins and minerals than recommended permissible limit may not benefit consumers health. Major concerns are given on potentially biopersistent, insoluble, indigestible food products (Chaudhry and Castle 2011). Nano-additives / nano-functionalized materials produced from hard materials with poor ADME (adsorption, distribution, metabolism and elimination) profile and several toxicological properties that are not completely explored at present may cause risk when food and agriculture products exposed to consumption (Singh et al. 2016).

Nanotechnology derived packaging material can raise some potential health risk depending on migrating behavior from the intact pack (Honarvar et al. 2016). On the basis of the packaging system, few modeling and experimental studies reported that likelihood of migration behavior of NPs is very low or nil (Wyser et al. 2016). Based on the model, it is predictable that any NPs that is migrated from the polymer matrix will be minimal because only nano range quantity are incorporated with low dynamic viscosity but further research should be proceeded to determine the behavior of migration patterns of polymer composites as well derived biopolymers (Noonan et al. 2014).

It is noted that in relation to risk assessment of nanotechnology applications in the food sector, it is unlikely that knowingly acute biopersistent toxic materials are used in food products. The usage of NPs should mainly concern of consumer safety. Several transformations occur in nano-based food, due to aggregation, agglomeration, adhesion with other components of food, its binding reactions with enzymes, acids and many other biotransformations in the human GI tract system may lead to losing actual characteristics of the nanomaterials (Martirosyan and Schneider 2014). Currently, there is some understanding on the safety of nano food products and its biotransformation nature/ impact.

12.8 Entry of Nanoparticles into Human Body

Nanoparticles in food when consumed, they can be easily translocated from one to the other organ due to its particles size (nano range) can cause its own reaction and risk (Oberdörster et al. 2005). Only limited data information is available on handling nanomaterials and its risks. Therefore, a stringent control is essential and it should be strictly implemented until adequate knowledge is available on handling nanomaterials. Inhalation, ingestion and dermal exposure are the three possible routes for NPs to enter the human system as shown in Fig. 12.6.

12.8.1 NPs through Dermal Exposure

The entry of NPs depends on their ability to penetrate the skin from dermal hair, outer protective layers of the epidermis to the dermis (Chau et al. 2007). In the case of healthy intact skin, epidermis provides excellent protection from nanostructured particles (Filon et al. 2015). The keratinized dead cells that are composed and glued with lipids known as Stratum corneum, acts as a rate limiting to chemicals, soluble molecule, water and ionic compounds (10 mm) from entering in the cutaneous layer (Riviere and Monteiro-Riviere 2005). There are few NPs such as fine fluorescent microspheres or dextran beads (±1 mm) can reach epidermis by penetrating stratum corneum (Filon et al. 2015). The NPs very rarely get translocated in lymph to regional lymph nodes by penetrating dermis layer (Oberdörster et al. 2005).

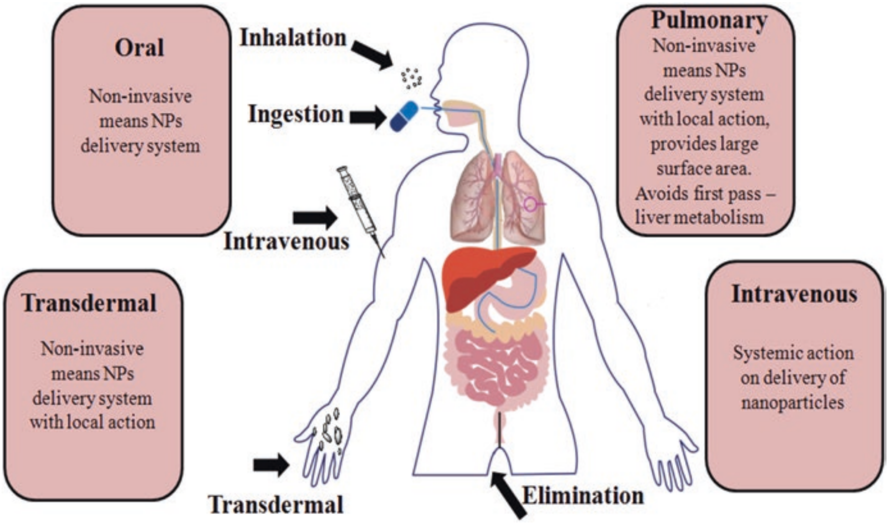

Fig. 12.6 Ways of entry for nanoparticles into human body

Titanium dioxide (20 nm) can interact with the immune system if particles penetrate into the skin and they possibly involve photogeneration of hydroxyl radicals and oxidative damage occurs (Bhattacharya et al. 2009; Wakefield et al. 2004). Only few information is available on hazards of NPs exposure to skin. Therefore, NPs mechanisms of interaction and possible health consequences are still speculative.

12.8.2 NPs through Inhalation

The aerodynamic ambient diameter of 10 μm has a chance of 50% probability to penetrate into the alveolar region through nasal cavity and lungs (Brown et al. 2013). As the size ranges in nano meters, NPs can travel deeper into the lungs (Politis et al. 2008). The pulmonary toxicity and its adverse pathogenic effects of inhaled NPs are determined from the shape (Stoehr et al. 2011), size (Taylor et al. 2012), surface coating (Suresh et al. 2012), chemical composition (Limbach et al. 2007), and surface charge (Schlinkert et al. 2015). The low-solubility ultrafine particles indicate more toxic than large particles. Titanium dioxide, carbon tube gets accumulated in the lungs, induces chronic diseases such as pulmonary inflammation, pneumonia, pulmonary granuloma, and oxidative stress (Forbe et al. 2011). If the nanoparticles are efficient to cross blood brain barrier system, they can evade and translocate out easily even from specific defense mechanisms through different pathways (De Jong and Borm 2008). Based on the size of NPs alone the potential toxicity cannot be determined to reach the possible generic conclusions.

12.8.3 NPs through Ingestion

Based on toxicological perspective, material characteristics of particle size and surface area are considered to be more important. The nano-based material entering the human system particularly through oral ingestion is given more importance because NPs can prolong their retention period dramatically in GI tract by interrupting the intestinal clearance mechanisms (Posocco et al. 2015). This promotes surface availability to increase the interaction by penetrating deeply through fine capillaries into the tissues and efficiently delivers the compound to the targeted sites in the human system. The NPs either directly ingested or inhaled through various forms are cleared via mucociliary escalator and ends up in GI tract (Oberdörster et al. 2005). A study was experimentally proved that intestinal mucus barrier acts as a barrier system, the particles were unable to pass through if the size was larger than 1 mm (Hoet et al. 2004). The particle translocation study was evidentially performed with female Sprague-Dawley rats to study the uptake of polystyrene spheres nanoparticles in GI tract (Jani et al. 1990). The rats were fed with polystyrene spheres (50 nm- 3 mm) by gavage for 10 days, the results revealed that about 26 to 34% of NPs (50 to 100 nm) was absorbed and NPs that are larger than 300 nm was not present in blood, lung and heart tissues (Jani et al. 1990; Chau et al. 2007). Another observation study was conducted using gel penetration action by using hydrophobic latex nanospheres (14 and 415 nm) which penetrated the mucus gel layer which is of 30–50 μm in thickness in 2 and 30 mins (Chau et al. 2007). Therefore, it was concluded that the smaller particles would be able to penetrate faster across the mucus barrier systems.

12.9 Kinetics of Toxicology Studies

From the available information on experimental data, it indicates that the physicochemical characteristics of NPs such as size, charge on the surface and its functionalizations are involved in influencing the properties of Absorption, metabolism, distribution and excretion (ADME) of the nano-based food matrix (Shin et al. 2015). The various exposure routes along with kinetics of NPs reveal that the oral exposure of NPs from the food matrices that directly affects the characteristics of ADME and also an emphasis on special NPs based agro-food.

12.10 Behavior and Fate of nanomaterials Used in Food

The nano-based food that contains NPs is ingested by the consumers in the form of food and beverages. The food consumed along with nano incorporated material further undergoes various physiological changes. Some of the NPs directly absorbed by the biological system or along with the food components. These NPs predispose themselves across the biological barrier of GI tract depending on their size, structure, and shape. They maintain and reside in GI certain period either bounded or unbounded form inside the GI tract. At this period, NPs are either beneficially or adversely interact with biomolecules (Kumar et al. 2015). Depending on the interaction of biomolecules and its physicochemical features, NPs are eliminated from the body by using different modes (Kumar et al. 2015). Some of the engineered nanomaterials that are specifically designed for an important purpose raise problem during their elimination process from the body relying on the type of material and fabrication methodology used.

The elimination of nanofabricated quantum dots (QDs) was investigated with in vivo studies, which resulted that the behavior of quantum dots is based on surface chemistry and size of the particles (Choi et al. 2007). In particular, the QDs of 5.5 nm diameter size and QDs with cysteine were eliminated from kidneys (Choi et al. 2007). However, QDs with various dimensions with altered surface chemistry need to be extensively investigated. Opsonization plays a vital role in eliminating the foreign materials (Owens and Peppas 2006); NPs based materials and pathogens depending on size and surface charge (Donaldson et al. 2005).

12.11 Toxicokinetics Involved in Clearance of NPs

The nano-based materials that are administered orally through food and supplements are absorbed, crosses GI tract and get distributed in respective targeted parts and organs of the body. NPs are maximum get eliminated from the body along feces or urine (Kumar et al. 2015; Hemalatha and Madhumitha 2015). The entry and clearance of NPs from the human system are illustrated in Fig. 12.7.

Nanomaterials with high concentrations are eliminated through the hepatobiliary pathway and excreted through the kidney (Zhang et al. 2016). The exposure of carbon nanotubes to neural and neuronal cell lines, cells were well grown and differentiated better (Jan and Kotov 2007). In the alveolar zone, the nanomaterials are cleared by macrophages using phagocytosis mode of engulfing action by enhancing the chemotactic attraction (Gustafson et al. 2015). Clearance of nanomaterials gets initiated when it reaches the circulatory system or targeted organs in the body involving the live macrophages and phagocytic process (Gustafson et al. 2015).

In food and pharmaceuticals industries, nanomaterials such as polysorbate 80 are coated with poly(n-butylcyano-acrylate) and pegylated polylactic acid (PEG-PLA) immune nanoparticles (Kumar et al. 2015). These NPs are intravenously administered which moves through the blood-brain barrier and accumulates in the brain tissues. Due to their respective physiological features, brain tissues results in neurotoxicity. Zinc oxide (ZnO) NPs when administered in the chorioallantoic fluid of chicken egg (50 µg/g wet of egg), the embryonic hepatic tissue was reached by ZnO

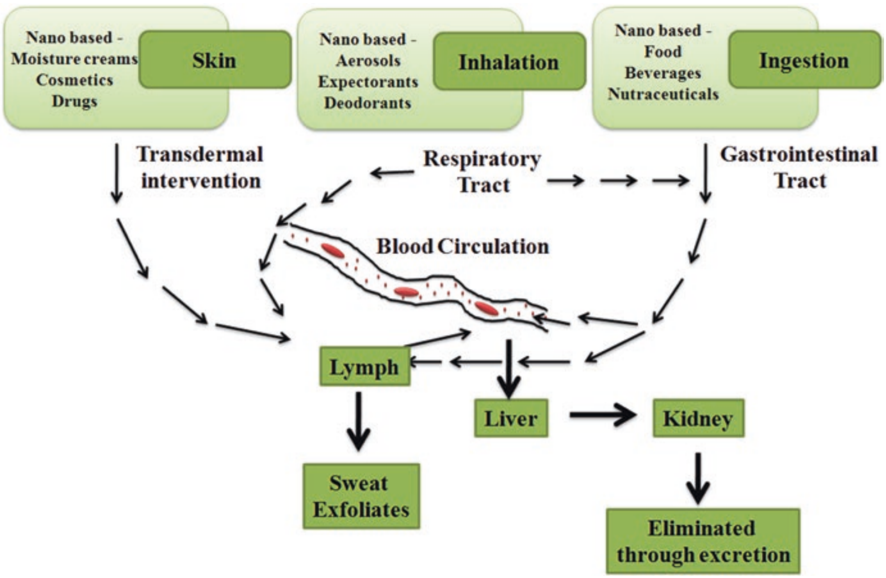

Fig. 12.7 Entry and metabolic routes involved in clearance of NPs in humans

NPs within 24 to 48 h (Pardeshi et al. 2014). On the 18/19 incubation day, the human RBCs exhibited viability and hemolytic response against ZnO NPs (20, 30, 40 μg/mL) (Clift et al. 2011).

Oral administration of ZnO NPs ranging size of 20, 70 nm was fed to male and female rats in dose-dependent pattern, within 24 h of the concentration of ZnO NPs was found increased in the blood, plasma, lungs, liver and kidneys (Baek et al. 2012; Elango et al. 2015; Madhumitha et al. 2016). Elimination degree of renal was very less than fecal elimination comparatively. The study exhibited that ZnO NPs are absorbed unevenly from the GI tract. Sprague-Dawley rats were studied to evaluate the excretion of TiO_2 and ZnO NPs with 1041.5 mg/Kg for 13 days (Cho et al. 2013). The concentrations were estimated considering various biological samples, such as blood, liver, spleen, brain, feces and urine. TiO_2 in tissues was absorbed very less compared to ZnO NPs but the concentration was found low in brain and spleen compared to TiO_2 NPs. Renal excretion was found to be low in TiO_2 NPs but the amount of ZnO NPs excretion was greater in urine and feces than TiO_2 NPs (Cho et al. 2013).

In the human biological system, the intestinal goblet cell secretion pathway is one of the important pathway models to eliminate NPs from the body (Zhao et al. 2014). This particular pathway was investigated using activated carbon NPs by injecting 30–200 nm sized NPs in Zebrafish yolk and resulted that NPs injected was excreted in the lumen as hepatobiliary pathway mode was not preferred (Zhao et al. 2014).

Nanomaterials that are present in circulation stream in our biological system are cleared by the action of reticuloendothelial cells and NPs that degrade in slow phase will have a low degree of renal clearance, further NPs that are not eliminated get accumulated in liver and spleen (Lee et al. 2010). The elimination of NPs primarily depends on the size of the NPs: example 5 nm in blood circulation have increased the degree of renal clearance and NPs 10–20 nm are cleared by the liver cells, 200 nm NPs are picked by sinusoidal spleen and Kupffer cells. The exempted nanomaterials by the above cells and organs are taken care of by macrophages, opsonins by phagocytosis mechanism (Yu and Zheng 2015; Longmire et al. 2008). Therefore, the nanomaterials in all three forms when entering the biosystem of the human body specific pathway are designed to eliminate the NPS irrespective of the nature and features of nanomaterials immediately after completion of its specific intended purpose.

12.12 Future Perspective

"The Convergence of Information and Communication Technology (ICT), nanotechnology and biological sciences are on the horizon. India is even better placed to exploit this revolution than any other nation", says the Missile man of India, India's Former President Dr. APJ Abdul Kalam. In his vision for 2020, agriculture, stem cell research and nanotechnology hold the future India. Prof. CNR Rao, chairman of the Scientific Advisory Committee says to the Prime Minister, “We missed the semiconductor revolution in the early 1950s. We had just gained independence. But with nanoscience and technology, we can certainly be on an equal footing with the rest of the world”.

Nanotechnology can promise myriad opportunities for innovations in the field of food sector from its processing to packaging. The future prospects of nanotechnology in the food sector are far from certain reasons because it can meet the needs of current and future generations through its scientific principles and foreseeable applications (Roopan et al. 2014; Elango and Roopan 2016). Even in twenty-first century, it is difficult to have a breakthrough technology without any craze, hype, and controversy because similar things happened to biotechnology and information technology in the past. Consumer acquires the scientific information primarily via television, social networks, newspaper, magazines and online sites (Duncan 2011). If these media, amplifies the consumer’s risk perception of new and existing technologies without a level-headed debate, then there exist a distrust which could foster consumers opposition to it. In UK and Europe, acceptance of GMO (genetically modified organism) foods was partly influenced by mass media (Duncan 2011). Nanotechnology food products also suffer from a similar problem because negative aspects are mainly focussed. As a result, consumers acceptance for nanotechnology-based food products is reducing in Australia, America, Europe, etc. and creates a great challenge for government and industries (Duncan 2011). For an effective future flight, nano-based food products should mainly focus on the regulatory gap, promotion of good laboratory practice (GLP) in the industries and safety/ethical issues for consumers acceptance/confidence.

Nanotechnology can support distinctive edge for products developed by food processing sector in innumerable ways. Nano-based food and packing are current interest by the major food corporations globally. Over past 8 years, European government has funded £1.7 billion for nanotechnology in food research. Kraft, a food company is working on developing ‘programmable food’ by considering the consumer’s vision for their desired food. They are currently developing food items that are mainly disliked by children by appetizing flavor – e.g. chocolate taste cabbage, milk taste like cola beverage. The main idea is to develop colorless, flavorless drink which could be customized according to the satifisfaction of the customers. This could be achieved by nanocapsules, which is activated by programmed microwave transmitter. Further breakthroughs in the future food world is to design and produce food products by manipulating the shape and structure of the food matrixes in its molecular/atomic level with precision by strictly considering the permissible limits of nanomaterials involved (Ravichandran 2010). Nano-modification helps to remove excess fats and sugar content from processed food. Food nanotechnology mainly emphasized on improving the solubility nature, stability, bioavailability effect, facilitates sustained release and fortifies micronutrients in food. In future, nutritional assert can be brought in processed food as per customer interest through nano food fortification. Smart foods developed using nanotechnology would detect the compounds present in the food that causes an allergic reaction and could to be occluded. Specific dietary needs of the consumer could be detected and released into the food using nanotechnology. Nanotechnology would also help to determine the chemical contaminants and harmful microorganism in food products that could augment food safety level.

Based on nanotechnology literatures, India ranks third next to China and USA. The main goal of the Indian government is foster, assist and develops nanoscience and nanotechnology in all facets for the betterment of the country. In India, the National Nanoscience and Nanotechnology Initiative (NSTI) was launched under the Department of Science and Technology of the Ministry of Science and Technology to develop nanofood products. Nano Mission primarily focused on developing infrastructure, skilled manpower and academia-Industry partnerships for nanotechnology projects. Indian food processing sector needs nanotechnology that bestows flavor, taste, mouth sensation, appetite, color, and nutrients to keep ahead in the market. Therefore, nanotechnology would revolutionize future food products and food industries. However, there is a need for comprehensive potential risk assessment system to manage the menace associated with nano-based food before commercialization.

12.13 Conclusion

The perspective of nanotechnology has inexhaustible potential applications that would change and improve the food sector in the economy. Nanotechnology has its application in all facets of food industries from raw materials production to processing to storage to packaging. It is typically implemented to benefit and enhance the quality of food produced from nano-related methodologies and instrumentations with standard and acceptability. Yet, its application in food industries still clawed back due to its safety issues. Consumers perceive that nano-based food products constitute enormous environmental and health related risks which have to be eliminated carefully with new technologies. There is currently no definite data or evidence indicating that food incorporated with nanomaterials will become a serious threat or irreversible damage. Scientific committees have extensively reviewed the applications of nanomaterials in food products and deduced that proactive approach is required while customers are more likely to benefit from this technology. Public acceptance to nano food packing is more on board than nano-based foods. Lack of scientific certainty on the safety evaluation of nanomaterials shall not be a reason for the postponement. We are at the beginning stage of development of nanotechnology in food sector; we have the chance to get utmost benefit from nano foods with negligible risk to human health.

The most important characteristic of nano foods is to enhance the food products quality, desirability, and acceptability as per consumer's demands. Though issues of using nanomaterials in food products may foster distress in customer, it is highly necessary to apprise them about the benefits and risks associated with the product. In the current scenario, nano-based foods are still on the drawing board due insufficient scientific exploration, knowledge gap and awareness about the technology. Many scientific types of research state that nanomaterials are toxic in nature but none explained the cause for toxicity. Therefore, the nature of the interaction of nanomaterials with its surrounding system is still unknown. More researches are required to completely determine the potential cause of human health on exposure to nanoscale materials available in the food products.

The novel functional properties of nanomaterials make them attractive could potentially lead to health complications. The literatures sttes that nanomaterials ingested into humans gets accumulated in several organs like lungs, brain, liver, bones and spleen. The toxicological studies published on nanomaterials have focused on in-vitro cell culture which is different from animal studies (Ray et al. 2009). Hence, analytical methods are required to study the interactions of nanomaterial with biological components available in the human body to understand the basic relationship of physicochemical properties and mechanistic information. Biomedical field is currently involved in studying the nanomaterials ingested/injected into the living system through in vivo imaging which shortens the gap on how living system respond to these nanomaterials. Advances in information technology leads to the development of computational models that predicts the potential toxicity of nanomaterials through quantitative structure-activity relationships.

The fundamental for toxicity profile assessment of nanomaterials depends on the morphology, chemical constituents, size, mass, concentration, surface modification, agglomeration nature and biotransformation when exposed to the biological matrix (Oberdörster et al. 2005). For the effective application of nanomaterials in food products, basic mechanisms of interaction and reactivity of nanomaterials with biomolecules have to be studied. Therefore, for the realistic implications standardized protocols are needed to study the toxicity of the nanomaterials.

In the present scenario, nanotechnology has the ability to produce novel food products and processes that have the ability to stand high in this competitive market. Future food industries would involve in customizing the products and produce food items by modifying its atomic structures by enhancing its quality and safety level. The existences of strict and rigid regulatory systems in countries that consider nanotechnology as a big push in the future provides reassurances that only safe products will be available in the market. However, there is a need for standardized procedures and novel approaches to test the toxicology/safety profile of nanomaterials used in food products. With no doubt, in mere future smart foods and programmable foods with the aim to customize the product as the individual's concern. The first step in progress would be the development of advanced regulations, toxicological studies and potential risk assessment concerning the impact of nanomaterials used in food products on human health and environment to assure food safety.

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