Chapter 15
Prospects and Toxicological Concerns of Nanotechnology Application in the Food Industry

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15.1 Introduction

In the food industry, nanotechnology can be applied to enhance food quality, shelf life, safety, and nutritional benefits [1]. Some nanomaterials used in the food industry are not intended to find their way into the final food product, e.g., those utilized in sensors, packaging, and antimicrobial treatments intended for sterilizing food manufacturing plants. Other nanomaterials are precisely constructed to be integrated into food products, such as nanoparticles used as delivery systems or to

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modify optical, rheological properties. Herein, we focus on the properties and potential safety of ingested nanomaterials since they are most likely to cause health concerns. Nanoscale materials are naturally present in many commonly consumed foods, such as the emulsion micelles in milk or certain organelles found in plant or animal cells [2]. Artificial nanomaterials can be divided into four categories–Carbon-based, metal-based, dendrimers, and composites. Intentionally added to foods (such as nanoparticle-based delivery systems), or they may inadvertently find their way into foods (such as nanoparticles in packaging materials that leach into the food matrix) [3]. Silver is the most common nanomaterial used in products, followed by carbon-based nanomaterials and metal oxides such as TiO_2. Different types of nanoscale materials that may be found in foods and their potential origins are highlighted in Table 15.1.

Few Information concerning the safety of used nanomaterials in food and nutrition industries is available. The British Royal Society report notes that we may face a nanotoxicity crisis in the future. It advises that avoiding nanotechnology in products until there is a comprehensive understanding of the environmental and health risks of exposure to nanoparticles [4, 5].

The main concern regarding human exposure to nanoparticles is that there are different entry routes such as digestion, inhalation, or skin absorption. After absorption, nanoparticles may enter the bloodstream and settle in different tissues such as the brain or trigger immune responses [6]. Despite all these debates, nanotechnology has already been applied in food packaging, agriculture technologies, and food processing, as well as the nature of food, so the public is seeking safety assurances from governments and food producers [7].

Table 15.1 Different types of nanoscale materials that may be found in foods, and their potential origins

Nanoscale material	Origin	Features
Casein micelles	Natural	Protein–mineral clusters
Cell organelles	Natural	Ribosomes, vacuoles, lysosome etc.
Oil bodies	Natural	Phospholipid/protein-coated triglyceride droplets
Lipid nanoparticles	Artificial	Solid particles or liquid droplets coated by emulsifiers
Protein nanoparticles	Artificial	Clusters of protein molecules held together by physical or covalent interactions
Carbohydrate nanoparticles	Artificial	Small solid fragments extracted from starch, cellulose, or chitosan. Clusters of polysaccharide molecules are held together by physical or covalent interactions
Iron oxide	Artificial	Nanoparticles used to fortify foods with iron.
Titanium dioxide	Artificial	Nanoparticles used as whitening agents
Silicon dioxide	Artificial	Nanoparticles used to control powder flowability
Silver	Artificial	Nanoparticles used as antimicrobials in foods, coatings, and packaging

Recently, investing in food industry products was devoted to nanotechnology [8], in agriculture and food processing. Advocates emphasize that this can improve the quality, nutritional value, safety, and quantity of food to meet the needs of a growing population [9]. Herein we describe some of nanotechnology's possible effects on humans and the environment. The use of nanotechnology in food irrespective of its wide benefits confers the possible adverse environmental, social, and health risks as these particles are believed to enter the ecosystem through the delivery of pesticides in agriculture or through application in processed food such as the packaging sector, thus raising the toxicity concerns about their usage [10]. The enhanced risk of artificial nanoparticles is due to the higher reactivity of these nanoparticles and increased bioavailability of smaller particles to our bodies leading to long-term pathological effects.

*Nanomaterials can be introduced to food through***:**

1. Direct incorporation of nanoparticles in novel food as nanoemulsions, nanocapsules, and nano antimicrobial films.
2. By use of nanomaterials in food manufacturing, processing, preservation, and trackings such as the use of nanolaminates, nanosensors, and CNTs.

The level of human exposure to nanoparticles greatly depends on the specific area where it is used in the food industry and the concentration of usage with exposure risk being higher in the fields where nanomaterials are added directly to food products as carriers of novel food ingredients. Some of the toxic effects of nanoparticles used in food are presented in Table 15.2. The migration of nanoparticles from food

Table 15.2 Some toxic effects of nanoparticles used in food

Nanoparticle	Toxicity	Purpose in food
TiO_2	Little impact as assessed by bacterial respiration, fatty acid profiles, and phylogenetic composition Oxidative stress, DNA damage Suppressed IDO activity and IFN-c production	As food additives (E171-1 and E171-6a)
Nanoclay	Released nanoclays did not show toxicity	Food packaging
ZnO	Cytotoxicity on human pulmonary adenocarcinoma cell line LTEP-a-2 Delay in human neutrophil apoptosis	Food packaging
Ag	Oxidative stress, cytotoxicity endothelial cell injury and dysfunction	Food packaging and coating
NiO	Inflammation and genotoxic effect in lung epithelial cells	Biosensors
FeO	Decrease the cell viability	Enzyme immobilization, protein purification, and food analysis
Silica	Increase ROS, LDH, malondialdehyde oxidative stress, and mitochondrial damage	Packaging, additive (E551)
CuO	Decrease in cell viability, increase in LDH, and lipid peroxidation	Antimicrobial agent in packaging
Al_2O_3	DNA damage	Packaging

packaging materials and the behavior of nanoparticles upon entering the body are still being evaluated at an extensive level [11].

Food, by its nature, is a pool that presents enormous possibilities for biochemical interactions, and the incorporation of a highly reactive species of nanoparticles into food may trigger different reactions. The interaction of nanoparticles with such functional ingredients and other constituents is unclear and needs to be explored. Besides a lot of advantages of nanotechnology to the food industry, safety issues associated with the nanomaterial cannot be neglected. Safety concerns associated with nanomaterial emphasizing the possibility of nanoparticles migrating from the packaging material into the food and their impact on consumer's health are discussed by many researchers [12, 13]. The physicochemical properties in nanostates are completely different from that are in macrostate. Moreover, the small size of these nanomaterials may increase the risk for bioaccumulation within body organs and tissues [14]. For instance, silica nanoparticles which are used as anti-caking agents can be cytotoxic in human lung cells when subjected to exposure [15]. There are a lot of factors that affect dissolution including surface morphology of the particles, concentration, surface energy, aggregation, and adsorption. Since every nanomaterial has its individual property, therefore, toxicity will likely be established on a case-by-case basis [16]. Further, regulatory authorities must develop some standards for commercial products to ensure product quality, health and safety, and environmental regulations. The transparency of safety issues and environmental impact should be the priority while dealing with the development of nanotechnology in food systems and therefore compulsory testing of nano foods is required before they are released to the market.

15.1.1 Is Nano Safe in Foods?

Credits to nanotechnology, plenty of new products, and nanomaterials for food can be developed. Nano-iron, for example, could be added to foods to fight anemia and nano-packaging methods can be developed to improve the shelf life of products. In principle, nanoparticles in packaging may leach into food products and therefore be ingested as part of the human diet.

Are there specific health risks from nanoproducts? Out of three human studies, only one showed a passage of inhaled nanoparticles into the bloodstream. Materials which by themselves are not very harmful could be toxic if they are inhaled in the form of nanoparticles. The effects of inhaled nanoparticles in the body may include lung inflammation and heart problems.

What are the possible dangers of nanotechnology?

- Nanoparticles may damage the lungs.
- Nanoparticles can get into the body through the skin, lungs, and digestive system.

15.2 Factors Affecting the Gastrointestinal Fate and Toxicity of Food-Grade Nanoparticles

A major factor that has been frequently ignored in the studies of the biological fate of ingested food nanoparticles is their interactions with various components within complex food matrices and GIT. These interactions may occur within the food itself, or during the passage of the food nanoparticles through the GIT. The interaction of a food or GIT component with nanoparticles may alter their physicochemical properties in the GI tract and therefore their biological fate and function. Indeed, the results of many previous studies have been highly limited because they used unrealistic test systems that ignored food matrix and GIT effects [3, 17].

15.2.1 Food Matrix Effects

Prior to ingestion, nanoparticles are typically dispersed within food matrices that vary considerably in their compositions, structures, and properties. The physicochemical and structural properties of nanoparticles may therefore be changed considerably when they are dispersed in food products, which would play an important role in determining their subsequent GIT fate and toxicity. For example, the interfacial composition and properties of food-grade nanoparticles changes appreciably when they are added to foods or when they enter the GIT because of the adsorption of surface-active molecules from the surrounding environment [18]. Moreover, it has been reported that certain flavonoids in foods can be tightly bound to the surface of inorganic nanoparticles [19]. The interaction between these food components and nanoparticles may significantly alter the biological fate of these nanoparticles. Although knowledge of food matrix effects is critical for understanding the gastrointestinal fate of food nanoparticles, this important factor is currently ignored in most studies. Consequently, this should be an important focus for future research in this area.

15.2.2 GIT Effects

After ingestion, nanoparticles travel through the complicated environment of the GIT before they are absorbed or exhibit their toxic effects [20] (Fig. 15.1). If the nanoparticles are not absorbed in the upper GIT, then they will reach the colon (pH 6–7) where they will encounter colonic bacteria and undigested food components. If the nanoparticles are originally trapped within a food when they are ingested, then they may be released into the GIT fluids as the food matrix is disrupted and digested [21]. The GIT region where they are released will therefore depend on the composition and structure of the food.

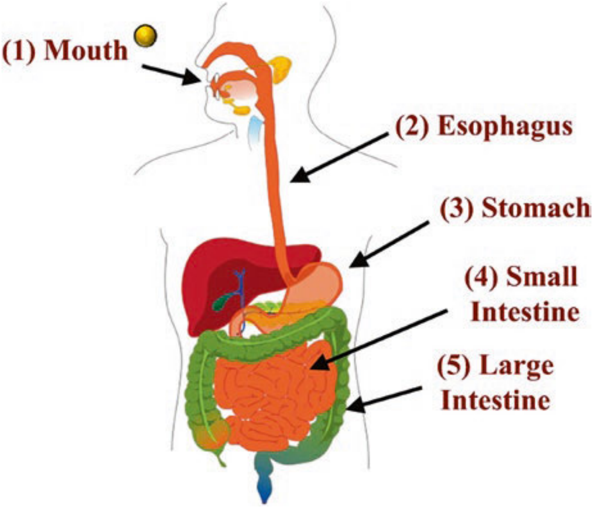

Fig. 15.1 Nanoparticles travel through the complicated environment of the GIT before they are absorbed or exhibit their toxic effects

***Some of the most important properties of GIT fluids that may alter nanoparticle characteristics are emphasized here*:**

(a) **PH and ionic strength**: The pH and ionic composition of the gastrointestinal fluids depends on the nature of the food consumed and the specific GIT region (mouth, stomach, small intestine, or colon). These parameters determine the surface potential and electrostatic interactions of nanoparticles, which influences their aggregation state and interactions with other components.

(b) **Surface-active components:** Gastrointestinal fluids contain surface-active components that may arise from the ingested food or the GIT, such as surfactants, proteins, bile salts, phospholipids, and FFAs. These surface-active components may adsorb to nanoparticle surfaces and alter their interfacial properties and subsequently their biological fate [22].

(c) **Enzyme activity:** Gastrointestinal fluids contain digestive and metabolic enzymes that may change the properties of certain types of nanoparticles. For example, nanoparticles containing starches, proteins, or lipids may be digested by amylases, proteases, or lipases. Consequently, the properties of the nanoparticles reaching specific regions within the GIT may be very different from those of the ingested nanoparticles.

(d) **Biopolymers**: Gastrointestinal fluids contain biopolymers that may also alter the properties of nanoparticles. These biopolymers may arise from the ingested food or be secreted by the GIT, e.g., proteins, polysaccharides, and glycoproteins. Biopolymers may adsorb to nanoparticle surfaces and change their interfacial properties, or they may alter their aggregation state by promoting or opposing flocculation [23].

(e) **Mechanical forces**: Ingested nanoparticles are contained within gastrointestinal fluids that are subjected to various kinds of mechanical forces as they pass through the GIT which may alter the properties of the nanoparticles. Mechanical forces may alter the aggregation state of nanoparticles by breaking down weakly flocculated systems.

As a result of these factors, the properties of nanoparticles are changed appreciably as they pass through the GIT, which will alter their GIT fate and potential toxicity. For example, there may be changes in the composition, dimensions, surface properties, physical state, and aggregation state of nanoparticles, which should be considered when establishing their potential toxicity. The interfacial properties of inorganic (magnetite) nanoparticles co-ingested with bread were altered in a way that promoted their uptake by intestinal epithelium cells [24]. The presence of a digested food matrix enhanced the absorption of silver nanoparticles by intestinal epithelium cells [25]. These findings demonstrated that the characteristics of the nanoparticles inside the GIT may be appreciably different from those of the original nanoparticles, which is often ignored in biological fate and toxicity assessments of food nanoparticles potentially leading to unrealistic and misleading results.

15.3 Mechanisms of Action of Nanoparticle Toxicity

This section highlights some of the most important mechanisms of nanoparticle toxicity. Ingested nanoparticles may cause toxicity due to numerous physicochemical and physiological mechanisms depending on their compositions, structures, and properties.

The direct contact of nanomaterials used as food additives/functional/nutritional ingredients may pose threats to human health. The production of reactive oxidative species (ROS) acts as one of the main toxicological mechanisms causing cellular damage and death [26]. Overproduction of ROS can lead to autophagy [27], neuron damage [28], and severe damage to DNA [29], and potentially mutagenesis, carcinogenesis, and aging-related diseases in humans. Allergic reactions and damage from metal ion release from nanomaterials are also possible adverse outcomes upon exposure to food nano-products [30]. Additionally, the accumulation of nanomaterials in the edible parts (seeds) of plants [31] and the human body [32] may cause severer problems at a higher concentration and long-term interactions.

15.3.1 Interference with GIT Normal Function

The small size of nanoparticles means they have a high specific surface area, which offers a large area for adsorption of any surface-active components in the GIT. Consequently, high levels of nanoparticles could reduce the rate or extent of starch, lipid, or protein digestion within the GIT. For example, digestive or metabolic enzymes could adsorb to nanoparticle surfaces thereby altering their normal GIT function. Many globular proteins are denatured after adsorption to particle surfaces due to the change in their thermodynamic environment, which could lead to a reduction in the catalytic activity of some enzymes.

The concentration of inorganic nanoparticles in the small intestine is likely to be a fraction of a percent, and so this effect is only likely to be important for relatively large lipid droplets at relatively low concentrations. In addition, the effect of a nanoparticle is likely to be difficult to be predicted for several reasons: first, the inorganic nanoparticles may aggregate in the GIT; second, the lipase molecules may adsorb more strongly to the lipid droplet surfaces than to the inorganic nanoparticle's surfaces; third, there may be other surface-active substances in the GIT that compete with the lipase for the surfaces of the inorganic nanoparticles.

There has been little research in this area, and so it is difficult to assess any potentially harmful effects associated with this mechanism. At the worst, one might expect that there would be a reduction in the rate of lipid, protein, or starch digestion, but that these components would eventually be fully digested due to the bodies' ability to secrete additional enzymes and other digestive components when needed. Due to the relatively low levels of inorganic nanoparticles normally ingested, the authors do not anticipate that this mechanism will be a major health concern.

Some types of inorganic nanoparticles may also be able to physically disrupt important structures within the GIT, such as the tight junctions or microvilli, thereby altering normal nutrient absorption and the protective function of the epithelium cells [33]. The presence of nanoparticles in the GIT may also stimulate an immune response, which could have adverse effects on human health, and so this possibility should be tested for food-grade nanoparticles [34].

15.3.2 Accumulation Within Specific Tissues

Certain types of ingested nanoparticles are absorbed within the GIT and accumulate in numerous tissues [35]. Apparently, these nanoparticles travel across the mucus layer and are then absorbed by active or passive transport mechanisms. After they have been absorbed into the cells, the nanoparticles may be metabolized, transferred out of the cells, or accumulate within the cells. The accumulation of nanoparticles within specific tissues may lead to long-term problems if they exhibit toxic effects above a certain accumulation threshold. This mechanism of action is likely to be most important for inorganic nanoparticles that are biopersistent.

15.3.3 Cytotoxicity and Cellular Malfunction

Nanoparticles may produce toxicity in cells through a variety of different mechanisms, depending on their composition and structure [33]. One of the most important factors contributing to the toxicity of inorganic nanoparticles is their ability to generate ROS, such as singlet oxygen, superoxide, hydrogen peroxide, and hydroxyl radicals [36]. These ROS may then cause damage to cell membranes, organelles, and the nucleus by interacting with lipids, proteins, or nucleic acids [37, 38]. As a result, many biochemical functions required to maintain cell viability, such as ATP production, DNA replication, and gene expression, may be adversely affected [39]. Several studies have reported the ability of inorganic nanoparticles to increase the generation of ROS in cells and to produce cytotoxicity, including silicon dioxide nanoparticles, [40] ZnO nanoparticles, [41] and silver nanoparticles [35]. Some inorganic nanoparticles produce toxicity by generating ions (such as Ag + from silver nanoparticles or Zn 2+ from zinc oxide nanoparticles) that interact with the normal functioning cellular components (such as proteins, nucleic acids, or lipids) required to maintain biochemical processes. These mechanisms of action are most likely to be important for inorganic nanoparticles that are absorbed by the intestinal cells since most organic nanoparticles are digested before being absorbed. However, it is still unclear about the extent to which inorganic nanoparticles would produce cytotoxicity when they are consumed as part of a complex diet under normal conditions.

15.3.4 Altered Location of Bioactive Release

The encapsulation of bioactive agents within nanoparticles may alter the location of their release and absorption within the GIT. For example, a bioactive agent that is normally released in the mouth, stomach, or small intestine could be released within the colon. As a result, the physiological response and biological impact of the bioactive agent may be altered by nanoencapsulation, which could have potentially adverse health effects. For example, the encapsulation of digestible lipids within nanolaminated dietary fiber coatings may inhibit the rate and extent of lipid digestion in the upper GIT, [42] so that high levels of undigested lipids reach the colon. These lipids may then be fermented by the colonic bacteria, which could cause gastrointestinal problems. Alternatively, an antimicrobial agent may be encapsulated within a nanoparticle that is not digested within the upper GIT, so that it reaches the colon, where it could alter the nature of the colonic microflora, which could again have adverse health effects. These effects are likely to be highly system-specific, depending on the nature of the encapsulated bioactive and nanoparticle used, and would therefore need to be established on a case-by-case basis.

15.3.5 Enhancement of Oral Bioavailability

One of the most widely studied applications of nanotechnology in the food industry is for the encapsulation and delivery of hydrophobic bioactive agents, such as certain nutrients and nutraceuticals [43]. Numerous *in vitro* and *in vivo* studies have shown that delivering these bioactive agents within nanoparticles can greatly increase their bioavailability. For illustration, nanoemulsions have been shown to increase the bioavailability of carotenoids, curcumin, coenzyme Q10, ω-3 fatty acids, and fat-soluble vitamins [43, 44]. There are a few different physicochemical mechanisms that may be responsible for this improvement.

In particular, the nanoparticles may increase the bioaccessibility, chemical stability, and/or absorption of the encapsulated bioactive agents [45]. In general, nanoparticles tend to be digested or dissolved more rapidly in the GIT and/or release any encapsulated components more rapidly because of their small size and high surface area. A change in the exposure level of bioactive agents within the blood could have potentially adverse health effects. The biological effects of many bioactive agents depend on their exposure levels in the blood and specific tissues. If the exposure level is too low, then the bioactive agent will have a little biological impact. If the exposure level is too high, then it may be toxic. Thus, the concentration should be within a certain intermediate level to have the most beneficial biological effects. This effect is likely to be highly system-dependent. It will depend on the toxicity profile of the bioactive agent. Some bioactive agents can be consumed at relatively high levels and have little toxicity, and therefore the ability of nanoparticles to boost their bioavailability should not have any adverse consequences. On the other hand, boosting the bioavailability of some bioactive agents could cause health problems. Vitamin E (a mixture of tocopherols and tocotrienols) is essential for maintaining human health and performance. However, the consumption of high doses of vitamin E may increase the risk of various chronic diseases [46]. Much of the studies establishing the upper limits for the adverse health effects of bioactive agents have not considered the nature of the delivery systems used. Consequently, the level where toxic effects are observed could be appreciably lower in cases where nanoparticle delivery systems greatly increase the bioavailability of the bioactive agents being tested.

Nanoparticles may increase the bioavailability of bioactive agents through two different approaches: delivery systems or excipient systems [40]. In both cases, the delivery or excipient system is specifically designed to increase the bioavailability of the bioactive agents by increasing the bioaccessibility or absorption, or by modulating any transformations (such as chemical or biochemical reactions) of the bioactive agents in the GIT.

15.3.6 Interference with Gut Microbiota

Nanoparticles that reach the colon may interact with colonic bacteria and alter their viability, thereby changing the relative proportions of different bacterial species present [33]. The type of bacteria populating the human colon is known to play a major role in human health and wellbeing [47]. Consequently, any change in the gut microbiota due to the presence of food-grade nanoparticles could have adverse health effects. This is an important area that requires further research to determine the impact of specific nanoparticle characteristics on the gut microbiota and the resulting health implications.

15.4 Toxicity Measurement of Nanoparticles Used in the Food Industry

Nanomaterials have unique properties such as high surface area, which make them more chemically active than bulk material so they could participate in most biological reactions that may have a harmful effect on human health or the environment. Nanostructures in nutrition or related industries must not create any direct or indirect damage to human health. Some features of nanoparticles are more important in unintentional side effects observed.

15.4.1 Size

Size is an important characteristic of the irreplaceable properties of nanoparticles. Size determines the surface area of nanoparticles. The effect of surface area on the respiratory response has been shown [48]. It has been reported that the size of particles is an important factor in observed dermal-cell *in vitro* cytotoxicity [49]. Absorbed nanoparticles in different absorption routes could trigger an immune system response [50]. The small size of these particles allows them to pass through different biological barriers and settle in tissues like the central nervous system [51]. The size of the nanoparticles in different routes of exposure should be considered in assessing the safety of nanomaterials that are to be used in food and food-related industries.

15.4.2 Chemical Composition

During the production of nanoparticles, many reagents are used that could be toxic. Some may remain in the final product and result in exposure to toxins that are unrelated to the nanomaterials themselves. For instance, some observed toxic effects of carbon nanotubes and semiconductor nanoparticles are related to residual reagents during synthesis. The remaining reagents and impurities may hinder our understanding of the possible side effects of carbon nanotubes. Iron ions and impurities can accelerate oxidative stress in cells [52]. Crystallinity is another important aspect of chemical composition. Titanium oxide has three different levels of crystallinity that each has different cytotoxic effects [53].

15.4.3 Surface Structure

There are many factors in the surfaces of nanostructures that could affect their cytotoxicity. Hydrophobicity, charge, roughness, and, most importantly, surface chemistry are factors that could change the toxicological effects of absorbed nanoparticles in the human body [54]. The coating of nanoparticles with hydrophilic polymer-like polyethylene glycol decreases the toxic effects of bare particles [55]. Evidence indicates that positively charged nanoparticles are more toxic than negative or neutral nanoparticles [56]. Different types of coatings or functionalization groups on the surface of nanoparticles are referred to as surface chemistry. Surface chemistry is one of the most important factors affecting the interaction of nanoparticles and biological systems [57].

15.4.4 Solubility

Solubility is also important in the toxicity of nanoparticles. For instance, soluble (hydrophilic) titanium oxide nanoparticles are more toxic than insoluble titanium oxide nanoparticles [58]. Some soluble nickel compounds are recognized as carcinogenic agents [59]. A detailed report on the solubility of the oxide nanoparticle's toxicity has been published [60]. Thus, understanding the toxicity and biological activity of nanoparticles requires an understanding of these factors and many others that must be considered in applying nanotechnology in food and related industries. In other words, all factors regarding the toxicity and environmental activity of nanoparticles should be investigated. Nanoparticle uptake routes and pathways are also important and must be considered in nanosafety investigations [61].

15.5 Harmful Effects of Nanoparticles on Humans

The use of nanotechnology in food irrespective of its wide benefits confers the possible adverse environmental, social, and health risks as these particles are believed to enter the ecosystem through the delivery of pesticides in agriculture or through application in processed food such as the packaging sector, thus raising the toxicity concerns about their usage [10].

The level of human exposure to nanoparticles greatly depends on the specific area where it is used in the food industry and the concentration of usage with exposure risk being higher in the fields where nanomaterials are added directly to food products as carriers of novel food ingredients. The migration of nanoparticles from food packaging materials and the behavior of nanoparticles upon entering the body are still being evaluated at an extensive level [11]. Nanoparticles can cause oxidative stress to human body cells and can traverse from lungs to blood, cell nuclei, and central nervous system leading to the inflammation of the gastrointestinal tract, Parkinson's syndrome, Alzheimer's disease, as well as the impairment of the DNA. Adverse effects on the kidney, liver and other vital organs have been reported due to long-term exposure to nanoparticles [62].

15.6 Prospects in Nanotoxicology Research

As one of the main characteristics of a nanoparticle is the enhancement of its reactivity, it is quite possible that, when a nontoxic nanoparticle is incorporated in food, it may get converted to a harmful form or vice versa.

Food has different roles in the body and the composition of the food is important with respect to that role. A food may contain a functional ingredient that is specific to that food; for instance, beef contains vitamin B12. During the processing of such food, the main aim is to reduce the loss of such functional ingredients. Food, by its nature, is a pool that presents enormous possibilities for biochemical interactions, and the incorporation of a highly reactive species of nanoparticles into food may trigger different reactions. The interaction of nanoparticles with such functional ingredients and other constituents is another area of research that needs to be explored.

15.7 Conclusion

The transparency of safety issues and environmental impact should be the priority while dealing with the development of nanotechnology in food systems and therefore compulsory testing of nano foods is required before they are released to the market. The main role of nanotoxicology is to provide clear guidelines and roadmaps for reducing risks in the optimal use of nanomaterials. Exposures routes in industrial workers and consumers of food products that contain nanomaterials must be studied carefully. With a precise understanding of the properties of nanomaterials such as size, dose, surface chemistry, and structures, we will have useful and safe food products.

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