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Review Article

Nanomaterials in Food Processing and Packaging, its Toxicity and Food Labeling

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Abstract

Over the past few decades, nanotechnology has increasingly been considered to be attractive technology that has revolutionized the food sector. Nanomaterials, unlike conventional microscale materials, having novel characteristics can improve sensory quality of foods by imparting novel texture, colour, appearance, processability and stability during shelf life. The physicochemical characteristics of a nanomaterial are important as they can affect the outcome of the risk assessment. This paper provides an overview of the application of nanotechnology in the field of food processing and packaging. In addition, this paper also discussed toxic effects of nanomaterials and food labeling. The results of this paper shows that today there is a divided opinion on the use of nanotechnology in food processing and packaging because on the one hand there are the results of the study which reveal that the majority of consumers prefer the use of nanotechnology-based solutions, while on the other hand there is immense public concern regarding the toxicity and environmental effect of these nanoparticles.

Keywords: Nanomaterials; Food Processing; Food Packaging; Toxicity; Food Labeling

Introduction

Nanotechnology is an interdisciplinary study which allows us to develop new materials with new, interesting and useful properties [1]. Nanotechnology plays an active role in trying to solve problems such as food packaging and preservation [2]. Nanotechnology is rapidly developing technology impacts every aspect of the food system from cultivation to food production to processing, packaging, transportation, shelf life and bioavailability of nutrients. Applications of nanotechnology in food packaging sector are related to improve the properties of packaging and to mechanical, thermal and barrier, biodegradable, improve the durability of packed products [3].

Commercial applications of nanomaterials will continue to impact the food industry because of their unique and novel properties. Human exposure to nanomaterials, as a result, is increasing and will continue to increase with time. Therefore, the health impact of nanomaterials in food is of public interest and concern [4].

Moreover, the research carried out by EU-funded NanoPack project in Europe and Asia, showed that majority of consumers preferred the use of nanotechnology-based solutions in the food packaging industry. NanoPack project conducted a detailed research on the acceptance of new active food packaging technologies among consumers and retailers, in order to assess how end-users perceive nanotechnology and its benefits. The research has been carried out in China, Spain, Italy, Denmark and Ireland [5].

New product development, precision processing, smart packaging, nanosensors, tracking devices, targeted delivery of essential components, food safety are all segments of nanotechnology

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which has found its way into the food sector. Nanotechnology has been successfully employed on direct or packaged food products for food quality and food safety (detection of foodborne pathogens or toxic metabolites), food fortification (minerals, vitamins, antioxidants, and essential oils), sensory improvement (enhancement of flavour or colour), shelf life extension, and antimicrobial food packaging [6].

Nanomaterials have dimensions below 100 nm and usually exhibit different chemical and physical properties than macroscopic objects based on the same material [7-9]. Nanomaterials are generally classified as follows: (1) nanoparticles, (2) nanoclays, (3) nanoemulsions, (4) nanolaminates, (5) nanocapsules, (6) nanofibers, (7) nanotubes, and so on, which can be synthesized by a number of methods and have many applications in the food sector.

Nanoparticles (NPs) in foods are not new. In some foods, nano-sized particles occur naturally. For example, casein micelles in milk are nano-sized spheres made of proteins. Based on the application, two different forms of nanofoods are observed: (1) food additives (nanoinside) and (2) food packaging (nanooutside) [10].

Nanofood refers to the food generated by using nanotechnology in processing, production, security, and packaging of food [11].

Nanoscale food additives may be used to influence food product flavour, texture, nutrient composition, or shelf life, and even to detect microbial pathogens and offer functions, such as food quality indicators. In the case of food packaging, nanotechnologies are largely considered to improve food quality and shelf life. Nanomaterials have better properties for encapsulation and release efficiency than traditional encapsulation systems because they possess the ability to penetrate deeply into tissues due to their smaller size and thus allow efficient delivery of active compounds to target sites in the body.

The number of research papers in the field of nanotechnology in food industry had increased in the last ten years. After searching of the keywords “nanoparticles in food processing” on the ScienceDirect is possible to reveal 40237 research articles and for the keywords “nanoparticles in food packaging” 7555. The search for the mention keywords has been done on 18.07.2020. According to these data, the plot has been constructed (Figure 1). These results confirming the growing interest in the research field of application of nanotechnology in food industry.

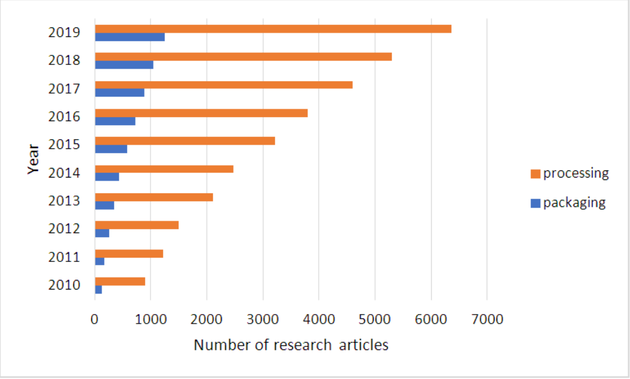

Figure 1: The number of research articles in ScienceDirect for the keywords: a) “nanoparticles in food processing and b) nanoparticles in food packaging.

Nanomaterials in food processing

In food processing are used anticaking agents, nano-additives and nutraceuticals which improve nutritional value of food, gelating agents to improve food texture and nanoencapsulation and nanocarriers. Encapsulation may be defined as a process of entrapping one substance within another substance, thereby producing particles with diameters of a few nm to a few mm. The entrapped material is usually a liquid, but may be a solid or a gas. Nanoencapsulation packs substances into nanocarriers and provides final product functionality that includes controlled release of the core materials. The main reason of using encapsulation is the fact that some nutrients do not remain in the food for a significant amount of time or may react with the other food components causing undesirable effects [12-16].

A majority of bioactive compounds such as lipids, proteins, carbohydrates, and vitamins are sensitive to high acidic environment and enzyme activity of the stomach and duodenum. Encapsulation of these bioactive compounds not only enables them to resist such adverse conditions but also allows them to assimilate readily in food products, which is quite hard to achieve in non-capsulated form due to low water-solubility of these bioactive compounds [17].

The utilization of nanomaterials with antimicrobial activity has been offered as a new defense against multiple drug-resistant infectious organisms [18]. Instead of interfering with a particular biochemical process like what conventional antibiotics do, nanoparticles are likely to interrupt multiple processes in microbial cells in a less specific manner. It was reported that silicon dioxide (SiO_2) and titanium dioxide (TiO_2) were allowed as food additives in bulk quantities (E551 and E171, respectively) [19].

Edible nano-coatings (~ 5 nm thin coatings) can be used in meat, fruits, vegetables, cheese, fast food, bakery goods, and confectionery products, in which they serve as gas and moisture barriers. Nanofilters have been used to remove colour from beetroot juice while retaining the flavour and the red wine, and to remove lactose from milk so that it can be substituted with other sugars, making the milk suitable for lactose-intolerant patients.

The shelf life of tomato has been increased by the bionanoencapsulated quercetin (biodegradable poly-D,L-lactide), and this approach should be extended to increase the shelf life of other vegetables and fruits [20]. Nanogreen tea, Neosino capsules (dietary supplements), Canola active oil, Aquanova (micelle to enhance the solubility of vitamins (A, C, D, E, and K), beta-carotene, and omega fatty acids), Nutralease (fortifying nanocarriers to carry nutraceuticals and drugs) are the common commercialized nanotechnology-based products in the market. Similarly, fortified fruit juices, oat nutritional drinks, nanoteas, nanocapsules containing tuna fish oil in breads, and nanoceuticals slim shakes are few commercially available nano-processed foods in the market which are widely sold in the USA, Australia, China, and Japan [11,21].

Nanomaterials in food packaging

In food packaging are used nanoparticles to improve physical performance of food, nanoparticles as antimicrobial agents and nano-biosensors for pathogen detection.

The application of nanoparticles is not limited to antimicrobial food packaging but nanocomposite and nanolaminates have been actively used in food packaging to provide a barrier from extreme thermal and mechanical shock extending food shelf-life. In this way, the incorporation of nanoparticles into packaging materials offers quality food with longer shelf-life. Nanomaterials, used as filler to the packaging polymer matrix, act as an impermeability barrier, and the impermeable property gets increased significantly due to larger surface area of the nanomaterials. The demand of nanoparticle-based materials has been increased in the food industry as many of them contain essential elements and also found to be non-toxic [22]. They have been also found to be stable at high temperature and pressures [23].

Generally, nanoparticles are used in the form of nanoemulsions, nanocapsules, or nanocomposites in foods. Nano-scale control of food molecules may lead to the modification of many macro-scale characteristics, such as texture, taste, some sensory attributes, processability and stability during shelf life. Particle size may directly affect the delivery of any bioactive compound to various sites within the body as it was noticed that in some cell lines, only submicron nanoparticles can be absorbed efficiently but not the larger size micro-particles [24].

Among all metal oxide nanoparticles such as silver oxide (Ag_2O), titanium dioxide (TiO_2), magnesium oxide (MgO), copper and copper oxide (CuO), zinc oxide (ZnO), cadmium selenide/telluride, chitosan, and carbon nanotubes (CNTs) [25-29], silver nanoparticles (AgNPs) are the most potent broad spectrum antimicrobials [30]. Recently, [31] have synthetized green silver nanoparticles from orange peel extracts with possible antimicrobial effects. According to Han and Li [32], common antibiotics eradicate only 5–6 disease-causing microbial pathogens, while silver molecules can kill more than 650 pathogens in 6 min of contact.

Recently, Biswas., *et al*. [33] have shown that green nanotechnology may be useful in the food industry. They studied the nature of physiological changes of coconut liquid endosperm along with the interaction of its DNA with green route synthesized Ag nanoparticles (AgNPs) using *Garuga pinnata* leaf, an important ethnomedicinal plant. Coconut water is one of the universally appealing drinks for proper health and metabolism owing to the presence of plentiful naturally occurring bioactive enzymes, such as, simple sugars, amino acids, electrolytes, vitamins and others. But the major drawback of this drink is with regard to its shelf-life for commercialization as functional food item in packets and bottle. It has the chances of microbial contamination, as can be seen via observation of low pH value with elapsed time. They found that the pH of the endosperm was found to decrease from 6.31 to 4.01, following an exponential decay trend and giving a decay constant of ~8.8h.

Further investigation, with more focused goal is needed to assess the exact AgNP-DNA interaction both in wet lab as well as in silico study. Hence AgNPs which are also earlier known to be good anti infectant can be smoothly used in packaging of coconut drinks.

Moreover, they are going to extend their future research on the impact of implementation of the metal nanoparticles on the nutraceutical value of the tender coconut water is a major interest during development of coconut based functional foods.

Due to biocompatibility, SiO_2 nanoparticles are used in direct food contact applications, packaging, in the clearing of beers and wines. Nanosized TiO_2 are often incorporated into the packaging materials for photocatalytic sterilization. Among various antimicrobial nanomaterial agents, TiO_2 and Ag have gained attraction as they highly generate reactive oxygen species (ROS) preventing foodborne pathogens and food spoilage [34].

Birgit Gaiser was a postdoctoral research fellow at Heriot-Watt University in the UK who gave a statement for „The environmental Magazine" in 2012 that "Some nanoparticles are present in the human diet, for example titanium dioxide in food products and cosmetics, and silver, which is sold as a nutritional supplement. There is evidence that a small percentage of these particles, or particle components like silver ions which can be released in stomach acid, can move on from the intestinal tract into the blood, and reach other organs. This is why we believe it is important to assess the risk of even small amounts of particles in the human body and ensure that the types of particles present in the human diet and cosmetics, as well as the amounts ingested, can be considered safe" [35]. In figure 2 is shown the foods containing nano titanium dioxide.

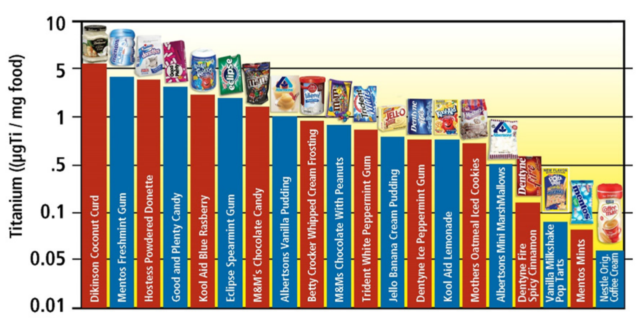

Figure 2: Foods containing nano titanium dioxide [35].

Toxic effects of nanomaterials

Regardless of the remarkable advantages of nanoparticles in the dairy and food industries, there is immense public concern regarding the toxicity and environmental effect of these nanoparticles.

Nanoparticles may enter into the body through inhalation, ingestion or cutaneous exposure [36]. Once they penetrate into the biological environment, NP will inevitably come into contact with a huge variety of biomolecules (proteins, sugars, and lipids) which are dissolved in body fluids such as the interstitial fluid between cells, lymph or blood [37]. Few reports points out toward the genotoxicity and carcinogenicity of NPs. ZnO nanoparticles displayed genotoxicity in human epidermal cells, even if the bulk ZnO is non-toxic, implying the role of particle diameter [38]. Out of few reports, inhalation of very high doses (10 mg/m^3) of nano-TiO_2 has been associated with incidence of lung tumors [39]. There are scientific evidences which indicate that free-engineered nanoparticles can cross cellular barriers and can lead to increased production of oxyradicals, which cause oxidative damage to cells [40,41]. Moreover, the efficiency of silver as an antimicrobial agent in fabrics may be limited or even negated after washing in oxidizers containing solutions. However, Echegoyen and Nerín [42] reported that the migration of silver was observed for all samples of three commercial nanosilver plastic food containers, with the total silver migration values ranging between 1.66 and 31.46 ng/cm^2. Modern techniques reveal that nanoparticles are characterized by greater reactivity and ability to cross membrane barriers and capillaries; hence, they can lead to different toxicokinetic and toxicodynamic properties. According to [43], as the particle size decreases, the toxicity level increases.

Recently, Australian researchers [44] have investigated the impact of food grade TiO_2 on gut microbiota of mice when orally administered via drinking water. They found that TiO_2 had minimal impact on the composition of the microbiota in the small intestine and colon, but TiO_2 treatment could alter the release of bacterial metabolites *in vivo* and affect the spatial distribution of commensal bacteria *in vitro* by promoting biofilm formation. They also found reduced expression of the colonic mucin 2 gene, a key component of the intestinal mucus layer, and increased expression of the beta defensin gene, indicating that TiO_2 significantly impacts gut homeostasis. Their findings collectively show that TiO_2 is not inert, but rather impairs gut homeostasis which may in turn prime the host for disease development.

The key point for hazard identification is that nanomaterials may show typical "small particle" behaviour, and thereby can exhibit biological properties different from the corresponding non-nanomaterial [45].

Monitoring the behaviour of nanomaterial in terms of biodistribution, speciation and quantification is crucial for hazard assessment (i.e. through toxicological and toxicokinetic studies). The physicochemical characteristics of a nanomaterial are important as they can affect the outcome of the risk assessment (e.g. different sizes, shapes, crystal structure (phase) and surface properties of nanomaterials of the same chemical composition may show different toxicokinetic behaviours or toxicities). Nanosized particles of the same elemental composition may be present with different shapes, sizes, crystal structures (phases) and/or surface properties, for example as a consequence of a different production process. For each distinct nanomaterial, the applicant must undertake a separate physicochemical characterization and risk assessment as described in EFSA Guidance [45].

By keeping modern food regulations, any new specific nanotechnology regulation, information transparency and a willingness to provide the public with information in mind, the safety of nanomaterials in the food industry can be assured [46].

Nanofood labeling

Nanofood is food that has been cultivated, produced, processed or packaged using nanotechnology techniques/tools or to which engineered nanomaterials have been added [47]. There is rapid growth of the use of nanotechnology in consumer products [48] and an increasing trend in its use in the agricultural and food sectors with the development of products and applications that could impact food quality and food safety. According to the PEN inventory, 117 manufacturer-identified nanofood products were on the market by July 2014 (PEN, 2014). Interestingly, none of these products, had to be labeled as a nanofood at that point in time. Major impediments to labeling have been disagreements on the definition of nanofoods for regulatory purposes [49] and the lack of appropriate risk assessment. On this latter point, uncertainty exists regarding the risks of nanotechnology which include the potential toxicity of nanoparticles and their effect on humans and the environment [50].

Engineered Nanoscale Materials (ENMs) are atomic- to molecular-scale sized organic (e.g. starch based) and inorganic (e.g. metal oxides) materials incorporated into consumer and industrial products because the ENMs exhibit chemical and physical properties of commercial interest. For example, nano-titanium dioxide makes candy coatings shinier and, when incorporated into a food packaging polymer, can extend the shelf life of whatever is wrapped. ENMs, particularly those that persist in the human body, may pose risks to health about which there is research, if not scientific consensus [51].

The economic effects of labeling food nanotechnology products were studied by Tran., *et al*. 2019 [52], using an analytical framework of heterogeneous consumers and imperfectly competitive suppliers. Labeling results in increased costs for nanofood producers (the cost effect of the labeling policy), reduced consumer uncertainty regarding the nature of the food product (certainty effect), and can affect consumer attitudes towards nanofoods by being perceived as a warning signal (stigma effect). In this context, nanofood labeling can change the perceived quality differences between nanofoods and their conventional and organic counterparts, with such changes being more salient when the stigma effect is large, when consumers have low awareness of food nanotechnology in the absence of labeling, and/or when competition among nanofood suppliers is more intense. Despite its empirical relevance, the impact of a labeling policy on consumer preferences (and the economic ramifications of such impact) has largely been ignored by the theoretical literature on the economics of labels. Their analysis shows that it matters. Specifically, their study shows that the market and welfare effects of labeling are case-specific and dependent on consumer awareness of, and attitudes towards food nanotechnology before and after the introduction of the policy as well as the relative magnitude of the cost, certainty and stigma effects of nanofood labeling. Their analytical findings also suggest that the effects of nanofood labels on consumer welfare are asymmetric with certain groups of consumers benefiting even when labeling has a stigma effect on nanofoods.

Conclusion

Novel nanopackaging systems have potential to serve as an important tool to overcome existing packaging challenges with consumer and industrialist satisfaction. The scientist who research and develop new nanomaterials with its application in food processing and packaging need to ensure parallel monitoring of the behaviour of nanomaterials in terms of biodistribution, speciation and quantification is crucial for hazard assessment.

In the coming period, consumers should be more and better informed about the advantages and disadvantages of using nanotechnology in the food industry and thus remove all doubts when it comes to food labeling.

Conflict of Interest

Author declare no conflict of interest for this manuscript.

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