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Review

Safety of nanofood: A review

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Introduction of genetically modified (GM) foods generated a lot of controversy few years back, now it is the turn of nanofoods. There has been debate on the safety of foods that have been produced directly or indirectly with nanomaterials. Nanoparticles or nanotechnology procedures may be used to make food products, food additives, seeds and food packaging materials to give rise to a new and novel nanofood. While a lot have been written about the benefits of nanotechnology and nanomaterials in the food system, there is little research into the toxicological and possible hazard of nanofood. In this paper, the concept of nanotechnology, its diverse applications in the food industry and recent safety issues are considered. The paper concluded that it is necessary to do a thorough risk assessment of nanofoods before they are released to the market.

Key words: Nanotechnology, nanofood, nanoparticles, risk assessment.

INTRODUCTION

Nanotechnology and nanofood-background and definition

Nanotechnology was first used in 1974 to describe production technology at ultrafine dimensions by Taniguchi (1974). The prefix ‘nano’ is a Greek word meaning dwarf (FSAI, 2008). Today, nanotechnology has developed into a multidisciplinary research sector with a lot of potential for industrial applications. However, the commercial application of nanotechnology is at the moment more highly developed in areas such as material science, microelectronics, aerospace and pharmaceutical industries unlike in the food industry (Weiss et al., 2006). Dingman (2008) also reported that nanotechnology is used in self cleaning glass and in army uniforms that monitor the health of the wearer to camouflage those changes to match its surroundings

According to FSAI (2008), the major areas where nanotechnology has potential for use in the food sector are encapsulation and emulsion formation, in food contact materials and sensor development but it is expected that this novel technology will be employed in much more areas as the years go by.

National Nanotechnology Initiative (2006) also defined nanotechnology as “the understanding and control of matter at the dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology; nanotechnology involves imaging, measuring, modeling and manipulating matter at this length scale. The International Standards Organization has also recently defined nanotechnology as “under-standing and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nm in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications, where one nanometer is one thousand millionth of a metre” (ISO/TC 229, 2008).

In layman terms, it can be said that nanotechnology is the use of engineered nanomaterial that has been intentionally synthesized or incidentally produced to exploit functional properties exhibited on the nanoscale (FSA1, 2008).

So what is nanofood? According to Garber (2007), a food is termed ‘nanofood’ when nanoparticles, nanotechnology techniques or tools are used during cultivation, production, processing, or packaging of the food. Also, Scrinis (2010) reported that nanofood can be derived after foods, seeds, chemical pesticides and food packaging have been broken down and manipulated at the micro-scale level through nanotechnology.

CURRENT AND FUTURE APPLICATIONS OF NANOTECHNOLOGY IN THE FOOD INDUSTRY

Nanotechnology has diverse applications in the sector at the moment and it may likely change the whole agrifood sector in the nearest future. FSAI (2008) grouped the global applications of nanotechnology into 6 categories which include;

1) Sensory improvements (flavour/colour enhancement and texture modification),
2) Increased absorption and targeted delivery of nutrients and bioactive compounds,
3) Stabilization of active ingredients such as nutra-ceuticals in food matrices,
4) Packaging and product innovation to extend shelf-life,
5) Sensors to improve food safety and
6) Antimicrobials to kill pathogenic bacteria in food.

From the categories stated, it can be inferred that nanotechnology may improve food processing, packaging and safety; it may enhance flavour and nutrition; it may lead to production of more functional foods from everyday foods with added medicines and supplements and it may result in increased food production and cost effectiveness.

In packaging for example, bionanocomposites which are hybrid nanostructured materials with improved mechanical, thermal and gas properties may be used to package the food, increase its shelf and also provide a more environmentally friendly solution because of reduction on reliance on plastics as packaging materials (Perch, 2007; Sozer and Kokoni, 2009). An example of such bionanocomposites is zein, a prolamin and the major component of corn protein. When dissolved in ethanol or acetone, a biodegradable zein films with good tensile and water -barrier properties can be derived (Sozer and Kokoni, 2009). Also, Emamifar et al. (2011) showed that packaging materials made from nanocomposite film containing nanosilver and nano Zinc oxide (ZnO) were significantly able to reduce microorganisms that could cause spoilage in orange juice.

Novel food packaging technology may in fact be the most promising benefit of nanotechnology in the food industry in the near future and food companies are said to have started producing packaging materials based on nanotechnology that are delaying spoilage and improving microbial food safety (Garber, 2007; Rhim and Ng, 2007; Avella et al., 2005).

Another area of interest to me and equally of great importance for the food industry is food safety and preservation. Food pathogens will be detected with the aid of nanosensors that had been placed directly into the packaging material serving as ‘electronic tongue’ or noses by detecting chemicals release during food contamination and spoilage (Bhattacharya et al., 2007). According to Lilie and Cantini (2011), nanosenser will help to recover even just one *Escherichia coli* bacterium located in ground beef. Another advantage of nanosensor is that it can measure safety at real time and the procedures are quick, sensitive and less labour-intensive (Das et al., 2009).

Food companies especially in the US are already getting ready for the future application of nanotechnology. First among them is Kraft Foods that established Nanotech Consortium (consisting of 15 universities and national research labs) in 2000 (Sanguansri and Augustin, 2006). Their goal was to produce food products that are customized to fit the individual tastes and needs of consumers. Future products, that is, drinks will change colours and flavours to foods that can recognize and adjust to a consumer’s allergies or nutritional needs.

Nestle and Unilever are also reported to be researching on improved emulsifiers that will make food texture more homogeneous (Sanguansri and Augustin, 2006). In other continents such as Australia, nanocapsules are used to add omega-3-fatty acids to one of the country’s most popular brands of white bread. In Asia (joint effort between Mexico and India), researchers are developing non-toxic nanoscale herbicides to attack weed’s seed coating and preventing from germinating (Sanguansri and Augustin, 2006).

Weiss et al. (2006) has also reported that the use nanotechnology in agriculture and food systems will lead to great advancements in the food industry. Specific examples of advancements that will likely take place according to the researchers are:

1) Increased security of manufacturing, processing and shipping of food products through sensors for pathogen and contaminant detection
2) Devices to maintain historical environmental records of a particular product and tracking of individual shipments.
3) Systems that provide integration of sensing, localization, reporting, and remote control of food products (smart/intelligent systems) and that can increase efficacy and security of food processing and transportation.
4) Encapsulation and delivery systems that carry, protect, and deliver functional food ingredients to their specific site of action.

The outcome of Weiss et al. (2006) will lead to a range of benefits to the food industry, that is, there will be range of products with new tastes, textures and sensation and also less use of fat and sugar. Furthermore, there will be enhanced absorption of nutrients, improved packaging, traceability and security of food products (Chaudhry et al., 2007).

Friends of the Earth (an NGO) have also reported that

Table 1. Examples of foods, food packaging and agriculture products that now contain nanomaterials (FOE, 2008).

Type of product	Product name and manufacturer	Nano content	Purpose
Beverage	Oat Chocolate and Oat Vanilla Nutritional Drink Mixes; Toddler Health	300 nm particles of iron (SunActive Fe)	Nano-sized iron particles have increased reactivity and bioavailability
Food additive	Aquasol preservative; AquaNova	Nanoscale micelle (capsule) of lipophilic or water insoluble Substances	Nano-encapsulation increases absorption of nutritional additives, increases effectiveness of preservatives and food processing aids. Used in wide range of foods and beverages.
Food additive	Bioral™ Omega-3 nanocochleates; BioDelivery Sciences International	Nano-cochleates as small as 50 nm	Effective means for the addition of highly bioavailable Omega-3 fatty acids to cakes, muffins, pasta, soups, cookies, cereals, chips and confectionery
Food additive	Synthetic lycopene; BASF	LycoVit 10% (<200 nm synthetic lycopene)	Bright red colour and potent antioxidant. Sold for use in health supplements, soft drinks, juices, margarine, breakfast cereals, instant soups, salad dressings, yoghurt, crackers etc.
Food contact material	Nano silver cutting board; A-Do Global	Nanoparticles of silver	"99.9% antibacterial".
Food contact material	Antibacterial kitchenware; Nano Care Technology/NCT	Nanoparticles of silver	Ladles, egg flips, serving spoons etc have increased antibacterial properties.
Food packaging	Food packaging Durethan® KU 2-2601 plastic wrapping; Bayer	Nanoparticles of silica in a polymer-based nanocomposite	Nanoparticles of silica in the plastic prevent the penetration of oxygen and gas of the wrapping, extending the product's shelf life. To wrap meat, cheese, long-life juice etc
Food packaging	Nano ZnO Plastic Wrap; SongSing Nanotechnology	Nanoparticles of zinc oxide	Antibacterial, UV-protected food wrap.
Plant growth treatment	PrimoMaxx, Syngenta	100nm particle size emulsion	Very small particle size means mixes completely with water and does not settle out in a spray tank

foods that contain manufactured nanomaterial ingredients are being sold to consumers in supermarkets (FOE, 2008). More than 100 nanofoods or nanofood applications have been shown to be distributed and marketed (FOE, 2008). Also, recently Cushen and Cummins (2012) reported that nanotechnologies have now been applied in the food sector from primary production to stock monitoring at the retail level. Examples of foods, food packaging and agriculture products that now contain nanomaterials are shown in Table 1.

Having discussed the numerous benefits of nanotechnology in the food sector, it is important to consider the possible dangers and safety concerns that may be associated with consumption of nanofood that is, foods that have been produced directly or indirectly with nanomaterials.

HOW SAFE IS NANOFOOD?

Nanofoods will most likely have longer shelf-life, better taste and not cause food borne illnesses because of the advantage of early detection of pathogens as result of the embedded nanosensers. According to Chaudhry and Castle (2001), nanotechnology will make more hygienic food/feed processing (better food and feed safety and quality, reducing food-borne illnesses in developing countries) possible however no one is sure of the problem that may arise if there is a reaction between the cells of the body and the nanomaterials after consuming contaminated food. For example, it has been shown that silver nanoparticles (which exhibit some level of toxicity) that are used in commercial packaging materials can migrate out of the packaging in nanoparticulate form into

Table 2. Areas of concerns of consumption of nanofood[1].

Least concern	Some concern	Major concern
1) Digestion or solubilization of non biopersistent nanofood or nanofood-additives in the gastrointestinal tract.	1) Non biopersistent nanomaterials pass through gastrointestinal tract. 2) Increased bioavailability of non beneficial vitamins and minerals 3) Greater uptake of food colours or preservatives above acceptable daily intake value	1) Nanofood containing insoluble, indigestible, and potentially biopersistent nano-additives (for example, metals or metal oxides

[1]Adapted from Chaudhry and Castle (2011).

the food (Huang et al., 2011; Asharani et al., 2008) Research has also shown that nanoparticles can enter into plants and gastrointestinal tract and trans-membrane segments (FOE, 2008; Bhattacharyya et al., 2011). Some nanoparticles such as gold nanoparticle can cross the materno-foetal barrier (Elsaesser and Howard, 2012).

Nanoparticles equipped with new chemical and physical properties that vary from normal macro particles of the same composition may interact with the living systems thereby causing unexpected toxicity (Das et al., 2009). Also, nanomaterials present different hazards from those of the same material in a micro or macro form (FSAI, 2008). The use of nanoparticles in foods or food contact materials appears at the moment to consist of uncertainties and safety concerns (Cheftel, 2011)

Furthermore, in-depth potential risks of nanomaterials to human health and even to the environment are still unknown (Dowling, 2004). This is because there is little or no scientific information on the effects of nano-technology applications on human, animal health and also the environment (Casabona et al., 2010). Also, on the problems of uncertainty about nanotechnology and food safety, Bosso (2010), wrote that nanoparticles may cause disease and death and that regulators are doing little to respond coupled with this is the obsession with technology innovation and economic growth over safety by the big companies.

Concerns that may arise as a result of consumption of nanofoods have been grouped into three major areas; least concern; some concern and major concern. According to Chaudhry and Castle (2011), area of least concern is where processed food with nanomaterials that are not biopersistent are digested or solublized in the gastrointestinal tract. Where food products contain also non biopersistent nanomaterials but carry across the gastrointestinal tract are areas of some concern. Other areas of some concern are increased bioavailability of vitamins and minerals may not always be beneficial for consumer health. Also, a greater uptake of food colours or preservatives could take the application outside of the conditions under which the acceptable daily intake (ADI) value was set for the additive. The areas of major concern however are where foods include insoluble, indigestible, and potentially biopersistent nano-additives (for example, metals or metal oxides), or functionalized nanomaterials. Such applications may pose a risk of consumer exposure to 'hard' nanomaterials – the adsorption, distribution, metabolism and elimination (ADME) profile and toxicological properties of which are not fully known at present (Chaudhry and Castle, 2011). Another concern raised by Mukul et al. (2011) is that most nanomaterials used in foods are organic moieties and may contain and carry other foreign substances into the blood through the nutrient delivery system. ZnO is an example of organic moieties that is, it has zinc moiety and oxygen moiety.

Powell et al. (2010) has also reported that it is possible under certain conditions, for very small nanoparticles to gain access to the gastrointestinal tissue via paracellular transcytosis across tight junctions of the epithelial cell layer. However, whether there are realistic situations of nanoparticle exposure that lead to significantly abnormal reactive oxygen species (ROS) and inflammasome activation responses *in vivo* in the gut have not been established.

It is important at this junction to state that all the negative assumptions about the risk and dangers of nanomaterials in food may not be true but it is ethically necessary to fill the present knowledge gaps through more research and thorough risk assessment of nano-foods and nanopackaging materials. FSAI (2008) reported on the lack of knowledge regarding the effect on pharmoacokinetics and bioavailability of changes in the physicochemical properties of normally inert and non-biodegradable materials such as inorganic particles, for example, titanium dioxide, and biological polymers in moving to the nanoscale. It is of great concern because changes may occur with potential cascade effects on cellular homeostatis when they get into the body system (FSA1, 2008).

Some areas of concerns regarding consumption of nanofood are shown in Table 2.

THE NEED FOR RISK ASSESSMENT

Nanotechnology has become important development and innovation in the food industry. Promising results and applications will be achieved especially in the areas of food packaging and microbial food safety. Although there are concerns, it will be out of place to be totally against the use of nanomaterials in foods as being suggested by some pressure groups. What should be done is for a proper risk assessment framework to be provided. However, it is sad that limited toxicological/safety assessments have been carried out for a few nanoparticles; hence, studies relevant to oral exposure risk assessment are required for particles to be used in food (Das et al., 2009). Sozer and Kokini (2009) also suggested that governments should set down regulations and appropriate labeling that will help to increase consumer acceptability. Labeling and legislation will be a good development because skeptical consumers will have a choice not to buy nanofood.

Furthermore, it has been recommended that nanomaterials should only be used in the food industry after they have been proven following vigorous testing (Dowling, 2004). The importance of risk assessment of food containing nanomaterials has also been canvassed by the food safety authority of Ireland (FSAI, 2008).

The risk assessment of silver nanoparticles used as antimicrobial agents and the effect on the environment have been carried out according to Blaser et al. (2008), however, what is necessary is the risk assessment of nanotechnology in food and the effect on humans and animals. There is also the need for more research into the toxicological impact and possible hazard of food-nanoparticles to human health and environment (Elsaesser and Howard, 2012)

CONCLUSION

The benefits of nanotechnology and nanofoods can never be overemphasized. Nanotechnology has come to stay. It has been estimated that nanotechnology market will grow to USD 1 trillion by 2015 (Bhat, 2003). However, it is important that safety becomes the key word when trying to implement it in the food industry. It must be recognized that the presence of nanoparticles in food is not a new trend. According to FSAI (2008), "People have always been exposed to very fine particles (nanoparticles) in their diet, without harmful effects, since many food and feed ingredients are comprised of proteins, carbohydrates and fats with sizes extending from large biopolymers (macromolecules) down to the nanoscale. Even when food is consumed predominantly as macromolecules, the natural digestive processes of the body reduce these to the nanoscale in order to utilize the energy contained in the molecules for the maintenance of physiological processes". Furthermore, it is not actually nanoparticles in food that should be a cause for concern but rather hazardous nanoparticles. Materials such as silver or silicon that may be harmful to human and animals at macro scale should be subjected to thorough risk assessment if it must be used as nanoparticles in foods or packaging materials. Further work or investigation is urgently needed to fill the wide knowledge gap in the area of nanotoxicity because this will help to improve risk assessment.

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