CURRENT AND FUTURE APPLICATIONS OF NANOTECHNOLOGY IN THE FOOD INDUSTRY

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Abstract

Food technology is regarded as one of the industry sectors in which nanotechnology will play an important role in the future. The usage of nanotechnology in agriculture and food systems will lead to great advancements in the food industry. Specific examples of advancements will likely take place according to the researchers are: i) Increased security of manufacturing, processing and shipping of food products through sensors for pathogen and contaminant detection , ii) Systems that provide integration of sensing, localization, reporting, and remote control of food pro-ducts (smart/intelligent systems) and that can increase efficacy and security of food processing and transportation, iv) Encapsulation and delivery systems. It is commonly distinguished between two forms of nanofood applications: food additives (nano inside) and food packaging (nano outside). Nanoscale food additives may be used to influence product shelf life, texture, flavor, nutrient composition, or even detect food pathogens and provide functions as food quality indicators.

Key words: Nanotechnology, future application, food industry,

I. INTRODUCTION

The definition of nanotechnology is based on the prefix “nano” coming from the Greek word meaning “dwarf”. In more technical terms, the word “nano” means 10^{-9} and/or one billionth of something. For comparison, a virus is roughly 100 nanometres (nm) in size. The word nanotechnology is generally used when referring to materials with the size of 0.1 to 100 nanometres, however it is also inherent that these materials should display different properties from bulk (or micrometric and larger) materials based on their size. These differences include physical strength, chemical reactivity, electrical conductance, magnetism, and optical effects [1,2].

Nanotechnology can assist a wide field of food processing area. The function of nanotechnology in food processing is generally on food preservation and interactive foods. Nanoparticles can be incorporated into existing food to deliver nutrients, increased the absorption of nutrients by the body and also could increase product shelf life. The advantages of nanotechnology in food processing is to develop the texture of food components, encapsulate food components or additives, developing new tastes and sensations, controlling the release of flavours and increasing the bioavailability of nutritional components (Table 1) [3]. On the other hand, the success of these advancements will be dependent on consumer acceptance and the exploration of regulatory issues. Food producers and manufacturers could make great strides in food safety using nanotechnology, and consumers would reap benefits as well [4, 5, 6]

In food and agricultural systems, nanotechnology covers many aspects, such as food security, packaging materials, disease treatment, delivery systems, bioavailability, new tools for molecular and cellular biology and new materials for pathogen detection [7, 8].

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Table 1. Examples of foods, food packaging and agriculture products that contain nanomaterials [3].

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	PrimoMaxx, Syngenta	100nm particle size emulsion	Very small particle size means mixes completely with water and does not settle out in a spray tank

Nanoparticles have tremendous potential for application in agro-food production i.e. processing of pesticides, fertilizers, food additives, cosmetics, feed (e.g. vitamins), packaging and textiles. The spectrum of nanotechnology applications in food science and technology is given in Figure 1 and 2, respectively [4, 6].

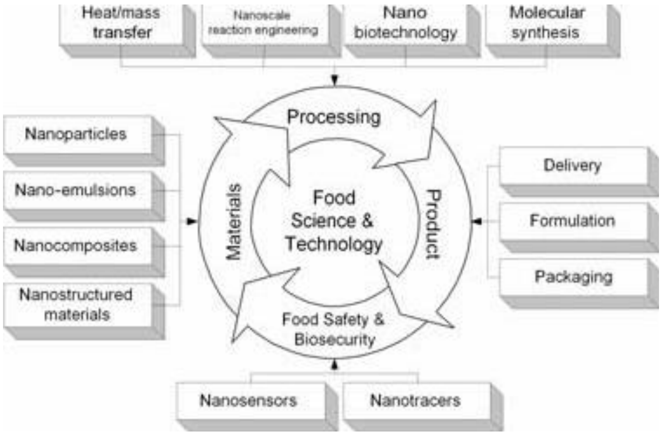

Fıgure 1. Nanotechnology applications in food science and technology.

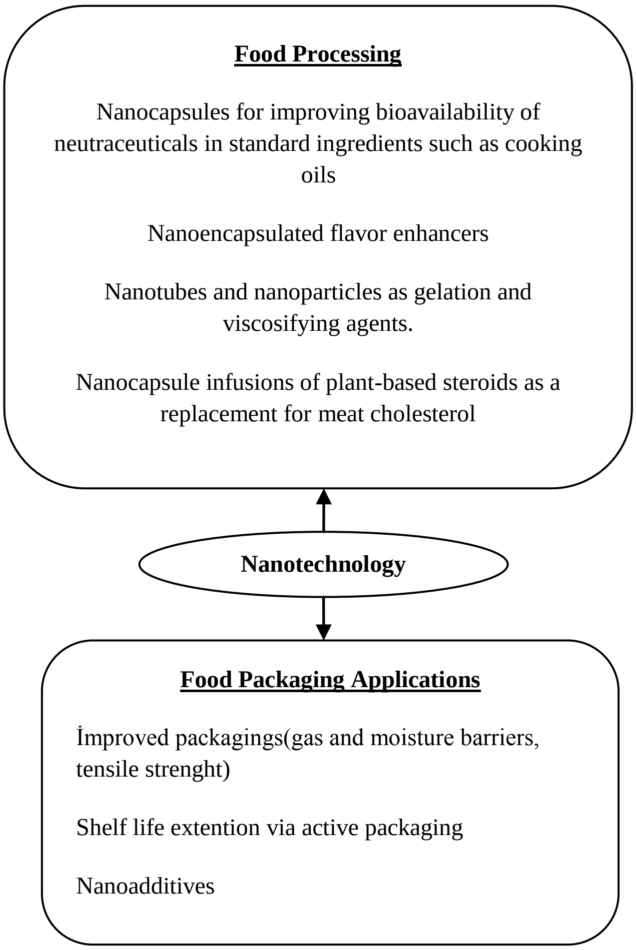

Figure 2. Potential application of nanotechnology in the food and food packaging

Nanoencapsulation of food ingredients and additives

Nanoencapsulation is currently the second largest area for nanotechnology application in the food sector [9]. It is used as a strategy to harness a controlled delivery system for food ingredients and additives in processed food [10]. Food industry claimed that the addition of nanocapsules to processed foods will improve both the availability and delivery of nutrients, thereby enhancing the nutritional status of food [11]. At present, a number of delivery systems are available with a range of encapsulated materials such as food additives (e.g. benzoic acid, citric acid) and supplements (e.g. β-carotene and coenzyme-Q10) used in the food and beverage products [12].

Nanostructured food ingredients and additives

A major focus of current nanotechnology application in food is the processing and formulation of food ingredients to form nanostructures. The mechanisms commonly used for producing nanostructured food products include nano-emulsions, emulsion bilayers and reverse micelles. Some examples of nanotextured food products include spreads, ice-creams, yoghurts, mayonnaise, etc [13]. This category of nanofood was being developed with claims that they offer improved taste, texture and consistency, enhanced bioavailability and allowed mixing of "incompatible" ingredients in food matrix [13,14].

Nanofoods

The term ‘nanofood’ describes food that has been cultivated, produced, processed or packaged using nanotechnology techniques or tools, or to which manufactured nanomaterials have been added [2].

A list of food products currently contain nanoproducts include: Canola Active Oil (Shemen, Haifa, Israel), Nanotea (Shenzhen Become Industry Trading Co. Guangdong, China), Fortified Fruit Juice (High Vive. com, USA), Nanoceuticals Slim Shake (assorted flavors, RBC Lifesciences, Irving, USA), NanoSlim beverage(NanoSlim), Oat Nutritional Drink (assorted flavors, Toddler Health, Los Angeles, USA), and ‘Daily Vitamin Boost’ fortified fruit juice (Jamba Juice Hawaii, USA) and nanocapsules containing tuna fish oil (a source of omega 3 fatty acids) in “Tip-Top” Up bread (Enfield, Australia) [2].

Nanoceuticals

As the concept of “nanoceuticals” is gaining popularity, commercial dairy/food and food supplements containing nanoparticles are available [15,16]. The examples of food-related nanoproducts are:

- carotenoids nanoparticles can be dispersed in water, and can be added to fruit drinks for improved bioavailability;
- canola oil based nanosized micellar system is claimed to provide delivery of materials such as vitamins, minerals, or phytochemicals;
- patented “nanodrop” delivery systems, in the form of encapsulated materials, such as vitamins, transmucosally, rather than through conventional delivery systems such as pills, liquids, or capsules; and Chinese nanotea (nano-based mineral supplements) claimed to improve selenium uptake.
- a wide range of nanoceutical products containing nanocages or nanoclusters that act as delivery vehicles, e.g., a chocolate drink claimed to be sufficiently sweet without added sugar or sweeteners;
- nanosilver or nanogold are available as mineral supplements to prevent the accumulation of cholesterol some of the nutraceuticals incorporated in the carriers include lycopene, beta-carotenes and phytosterols a synthetic lycopene has been affirmed GRAS (“generally recognized as safe”) under US FDA procedures.

NANO - FOOD MARKET

The worldwide sales of nanotechnology products in the food and beverage packaging sector increased from US$ 150 million in 2002 to US$ 860 million in 2004 and are expected to reach to US$ 20.4 billion by 2015. The consulting firm Cientifica, has estimated the then (2006) food applications of nanotechnologies at around $410 million (food processing US$100 million, food ingredients US$100 million and food packaging US$210 million). There is a large potential for growth of the food sector in developing countries. Today, many of the world’s leading food companies including H.J. Heinz, Nestle, Hershey, Unilever, and Kraft are investing heavily in nanotechnology research and development [17, 18, 19, 20]. As of March 2006, over 200 ‘‘nano’’ consumer products are currently available, and about 59% and 9% of the products are categorized as ‘‘Health and Fitness’’ ana ‘‘Food and Beverage’’ products, respectively [4] . The estimated world market for nanofoods is rapidly growing and is estimated at $ 20 billion in 2010 and 1 trillion by 2015 for the entire nanotechnology production.

More than 200 companies are actively involved in research and development [21]. USA is the leader followed by Japan and China [22]. There is a large potential for growth of the food sector in developing countries. Today, many of the world's leading food companies including H.J. Heinz, Nestlé, Hershey, Unilever, and Kraft are investing heavily in nanotechnology research and development [17, 18,19, 20].

APPLICATION IN FOOD PACKAGING

Food packaging is considered to be one of the earliest commercial applications of nanotechnology in the food sector. About 400-500 Nano-packaging products are estimated to be in commercial use, while nanotechnology is predicted to be used in the manufacture of 25% of all food packaging within the next decade. The significant purpose of nano-packaging is to set longer shelf life by improving the barrier properties of food packaging to reduce gas and moisture exchange and UV light exposure [23].

By 2003, over 90% of nano-packaging was based on nanocomposites, in which nanomaterials were used to improve the barrier properties of plastic wrapping for foods and dairy products. Nano-packaging can also be designed to release antimicrobials, antioxidants, enzymes, flavours and nutraceuticals to extend shelf life [24]. The most active area of food nanoscience research and development is packaging: the global nano-enabled food and beverage packaging market was 4.13 billion US dollars in 2008 and has been projected to grow to 7.3 billion by 2014, representing an annual growth rate of 11.65% [9]. Nano packaging applications as Food Contact Materials (FCMs) are anticipated to grow from a $66 million business in 2003, to over $360 million by 2008 [11].

Applications for food contact materials (FCMs) using nanotechnology is as follow:

- FCMs incorporating nanomaterials to improve packaging properties (flexibility, gas barrierproperties, temperature/moisture stability, light and flame resistant, transparency, mechanical stability).
- ‘‘Active’’ FCMs that incorporate nanoparticles with antimicrobial or oxygen scavenging properties.
- ‘‘Intelligent’’or “smart” food packaging incorporating nanosensors for sensing and signaling of microbial and biochemical changes, release of antimicrobials, antioxidants, enzymes, flavours and nutraceuticals to extend shelf-life.
- Biodegradable polymer–nanomaterial composites by introduction of inorganic particles, such as clay, into the biopolymeric matrix and can also be controlled with surfactants that are used for the modification of layered silicate [10,17, 20, 25, 26, 27, 28].

Smart Packaging and Active Packaging

One of the most promising innovations in smart packaging is the use of nanotechnology to develop antimicrobial packaging. Packaging that incorporates nanomaterials can be “smart,” which means that it can respond to environmental conditions or repair itself or alert a consumer to contamination and/or the presence of pathogens [29]. Scientists at big name companies including Kraft, Bayer, and Kodak, as well as numerous universities and smaller companies, are developing a range of smart packaging materials that will absorb oxygen, detect food pathogens, and alert consumers of spoiled food. These smart packages, which will be able to detect public health pathogens such as *Salmonella* and *E. coli*, are expected to be available within the next few years. According to industry analysts, the current US market for “active, controlled and smart” packaging for foods and beverages is an estimated $38 billion—and will surpass $54 billion by 2015. The following examples illustrate nanoscale applications for food and beverage packaging [29].

Nano silver, Nano magnesium oxide, nano copper oxide, nano titanium dioxide and carbon nanotubes are also predicted for future usage in antimicrobial food packaging [10, 20, 30]. Kodak company is developing antimicrobial packaging for food products that will be commercially available in 2005 and ‘active packaging,’ which absorbs oxygen [21]. Other companies include FresherLongerTM Miracle Food Storage Containers’’ and ‘‘Fresher LongerTM Plastic Storage Bags’’ from Sharper Image® USA, ‘‘Nano Silver Food Containers’’ from A-DO Korea, ana ‘‘Nano Silver Baby Milk Bottle’’ from Baby Dream® Co. Ltd. (South Korea). Oxygen scavenging packaging using enzymes among poly ethylene films have also been developed [26]. An active packaging application could also be designed to stop microbial growth once the package is opened by the consumer and rewrapped with an active-film portion of the package [27]. Zinc oxide quantum dots were utilized as a powder, bound in a polystyrene film (ZnO-PS), or suspended in a poly vinyl prolidone gel (ZnO-PVP) as antimicrobial packaging against *Listeria monocytogenes, Salmonella enteritidis, ana Escherichia coli* O157:H7 [31].

Engineered nanosensors are being developed by Kraft along with Rutgers University (U.S.) with in packages to change colour to warn the consumer if a food is beginning to spoil, or has been contaminated by pathogens using electronic ‘noses’ and ‘tongues’ to ‘taste’ or ‘smell’ scents and flavours [5, 11, 17, 21]. Nestlé, British Airways, MonoPrix Supermarkets are using chemical nanosensors that can detect colour change [32].

Nano-coatings

Waxy coating is used widely for some foods such as apples and cheeses. Recently, nanotechnology has enabled the development of nanoscale edible coatings as thin as 5 nm range in width, which are invisible to the human eye. Edible coatings and films are currently used on a wide variety of foods, including fruits, vegetables, meats, chocolate, cheese, candies, bakery products, and French fries [33, 34, 35].

Nanolaminates

Nanotechnology provides food scientists with a number of ways to create novel laminate films suitable for use in the food and dairy industry. A variety of different adsorbing substances could be used to create the different layers, including natural polyelectrolytes (proteins, polysaccharides), charged lipids (phospholipids, surfactants), and colloidal particles (micelles, vesicles, droplets). It would be possible to incorporate active functional agents such as antimicrobials, antibrowningagents, antioxidants, enzymes, flavors, and colors into the films. These functional agents would increase the shelf life and quality of coated foods [28].

Nanosensors

Packaging equipped with nano-sensors is also designed to track either the internal or external conditions of food products, pellets and containers, throughout the supply chain. For example, such packaging can monitor temperature or humidity over time and then provide relevant information of these conditions, for example by changing colour. Opal, which makes Opal film incorporating 50nm carbon black nanoparticles was used as biosensor that can change colour in response to food spoilage [36].

Nanosensors in plastic packaging can detect gases given off by food when it spoils and the packaging itself changes color to alert you. Nanosensors are being developed that can detect bacteria and other contaminates such as salmonella on the surface of food at a

packaging plant. There are also nanosensors being developed to detect pesticides on fruit and vegetables
[17].

The Scientists at Kraft, Rutgers University ana the University of Connecticut, are trying to exploit the "electronic tongue" to detect pathogens and other substances in parts per trillion with the help of embedded nanosensors in the packaging materials using nanotechnology. The sensors trigger colour changes in the package when the dairy and food products began to spoil [37]

APPLICATIONS IN FOOD PROCESSING

Nanofrying

The US based Oilfresh Corporation has marketed a new nanoceramic product which reduces oil use in restaurants and fast food shops by half because of its large surface area [17, 32].

Novel foods

Kraft Foods and NanoteK consortium have plans to incorporate the electronic tongue (which is chemical change based biosensor) into foods to release accurately controlled amounts of the suitable molecules for the customized tailor-foods [19, 38].

A Hungarian company has developed an ice gel for soft drinks or ice-cream containing CO_2 bubbles of 1-10 nm in diameter for effervescence (http://files.nanobio-raise.org/ Downloads/ Nanotechnology-and-Food-fullweb.pdf). Nanotech spray is available in which Nanodroplets 87 nm are used to enhance the uptake of vitamin B_{12} and other supplements for usage in foods [39].

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Nanofiltration

Nano Filtration separating materials of less than 0.001 microns (10 angstroms) in size and rejects divalent ana multivalent ions [40, 41]. It has application in desalination, milk, whey and juice filtration, demineralization, color removal, concentration of products, waste water treatment and water purification [30, 38, 40, 41, 42, 43].

REGULATIONS CONCERNING THE SAFETY OF NANOPRODUCTS

There are currently no special regulations for the application or utilization of nanotechnology in foods in the United States (FDA) and Europe (EFSA) [44]. The European Union regulations for food and food packaging have recommended that for the introduction of new nanotechnology, specific safety standards and testing procedures are required [45].

In the United States, nanofoods and most of the food packaging are regulated by the USFDA [46], while in Australia, nanofood additives and ingredients are regulated by Food Standards Australia and New Zealand (FSANZ), under the Food Standards Code [47]. In India food safety regulations are introduced but not adequate for the monitoring safety of nanoparticles.

Existing laws are inadequate to assess risks posed by nano based on foods and packaging because:(1) Toxicity risks remain very poorly understood (because of their unique properties); (2) are not assessed as new chemicals according to many regulations (3) Current exposure and safety methods are not suitable for nanomaterials and (4) many safety assessments use confidential industry studies Up to now, there is no international regulation of nanotechnology or nanoproducts [10, 20].

CONCLUSION

The scientific and technical advances needed to continue the application of nanotechnology to foods, regulatory considerations (including safety/toxicology and environmental impact), economics and consumer acceptance of nanotechnology will ultimately dictate its success in food applications.

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