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Applications of Nanotechnology in the Food Industry: An Overview

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ABSTRACT

Nanotechnology deals with the capability to image, measure, model, control and manipulate matter at dimensions of roughly 1–100 nanometer. The potential benefits of nanotechnology have been recognized by many industries and commercial products in many fields based on fundamental and applied research in physics, chemistry, biology, engineering and material science. In contrast, applications of nanotechnology within the food industry are rather limited. However, achievements and discoveries in nanotechnology are beginning to impact the food industry and associated industries.

This article provides an overview of some developmental efforts in the area of nanotechnology as it applies to food systems and industry. Such applications include the following: nanoemulsions, nanoparticles, nanolaminates, nanocomposites, nanofibers, nanoprecipitation, nanodispersion, nanocapsules. Furthermore, nanotechnology can be applied to produce novel nutraceutical, functional foods and unique milk protein. Identification of pathogens in food, oil and fat industry, food packaging and Atomic Force Microscopy (AFM) as a nanotechnology tool in food science are all promising applications discussed in the present article.

Keywords: nanolaminates, nanocomposites, nanofibers, nanotubes, nanoparticles, nanoprecipitation, liposomes, microemulsions, nanoemulsions, cubosomes, nanosensores, nutraceuticals, functional foods, oils & fats, pathogens, nanopackaging, milk protein, AFM.

INTRODUCTION

The National Nanotechnology Initiative (NNI, 2006) defined nanotechnology as the understanding and control of matter at 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 matters at this scale.

The point of interest is that nanotechnology is considered as a drawing inspiration from native. Atoms and molecules are organized in hierarchical structures and dynamic systems that are the results of millions of years of Mother Nature's experiments. Tenth nanometer diameter ions such as potassium and sodium generate nerve impulses. The size of vital biomolecules – such as sugar, amino acids, hormones, and DNA is in the nanometer range. Membranes that separate one cell from another or one subcellular or organelle from another are about 5 times bigger. Most protein and polysaccharide molecules have nanoscale dimensions. Every living organism on earth exists because of the presence, absence, concentration, location, and interaction of these nanostructures (Weiss *et al.*, 2006).

The real breakthrough that eventually led to the flourishing of the fledgling area in research laboratories did not occur until mid-1980, when some key analytical tools such as scanning tunneling microscopy and atomic force microscopy were developed. Discovery of new materials such as fullerenes and carbon nanotubes and the characterization of their unique physical and chemical properties were essential in understanding that their properties were governed by quantum mechanics rather than Newtonian mechanics (Chen *et al.*, 2006).

Many of the principles, applications and techniques that are included in the term "nanotechnology" are the same or fairly similar to those that have already been widely understood and utilized. In particular, there are major areas of overlap between nanotechnology and the more traditional disciplines of colloid, interfacial and polymer science. However, one of the defining features of nanotechnology appears to be the emphasis on building structures on the nanoscale rather than on just understanding their properties. Nanotechnology should probably best be understood as a conceptual and intellectual complex macroscopic structure using nanometer scale building blocks (Weiss *et al.*, 2006).

Because applications with structural features on the nanoscale level have physical, chemical, and biological properties that are substantially different from their macroscopic counterparts, nanotechnology can be beneficial on various levels. It is worth to mention that certain industries such as microelectronics, aerospace, and pharmaceuticals have already begun manufacturing commercial products of nanoscale size. Even though the food industry is just beginning to explore its applications, nanotechnology exhibits great potential (Tarver, 2003).

As a matter of fact, food undergoes a variety of postharvest and processing-induced modifications that affect its biological and biochemical makeup, so nanotechnology developments in the field of biology and biochemistry could eventually also influence the food industry. Ideally, systems with structural features in the nanometer length range could affect aspects from food safety to molecular synthesis (Chen *et al.*, 2006).

Applications of nanotechnology in food science and technology

Nanotechnology has the potential to impact many aspects of food and agricultural systems. Food security, disease-treatment delivery methods, new tools for molecular and cellular biology, new materials for pathogen detection and protection of the environment are important links of nanotechnology to the science and engineering of agriculture and food systems (Chen *et al.*, 2006).

Further achievements of nanotechnology in the food industry may be exemplified as follows:

- Increased security of manufacturing, processing and shipping of food products through sensors for pathogen and contaminant detection.
- Devices to maintain historical environmental records of a particular products and tracking of individual shipments.
- 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.
- Encapsulation and delivery systems that carry, protect and deliver functional food ingredients to their specific site of action. Figure (1) shows application matrix of nanotechnology in food science and technology.

Food processing is a multitechnological manufacturing industry involving a wide variety of raw materials, high biosafety requirements, and well-regulated technological process. Four major areas in food production may benefit from nanotechnology:

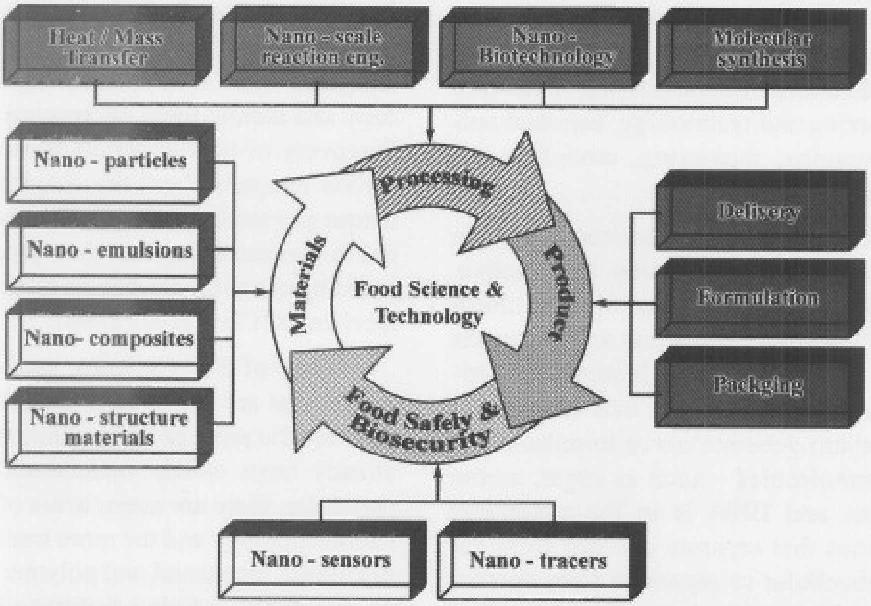

Fig. 1: Application matrix of nanotechnology in food science and technology

Source: Moraru and Chithra (2003)

development of new functional materials, microscale and nanoscale processing, product development, and methods and instrumentation design for improved food safety and biosecurity (Charych *et al.*, 1996, Augilera, 2005). The applications of nanotechnology in the area of food science and technology can be reviewed under the following main headings:

1- Nanolminates

Nanotechnology provides food scientists with a number of ways to create novel laminate films suitable for use in the food industry. A nanolaminate consists of two or more layers of materials with nanometer dimensions that are physically or chemically bonded to each other. One of the most powerful methods is based on the layer by layer (LbL) disposition technique, in which the charged surfaces are coated with interfacial films consisting of multiple nanolayers of different materials (Decher & Sehlenoff, 2003). Similar to the preparation of multiple emulsions, electrostatic attraction causes polyelectrolytes and other charged substance to be deposited onto oppositely charged surfaces. This LbL technology allows precise control over the thickness and properties of the interfacial films, which in this case enables the creation of thin films (1 to 100 nm per layer).

Nanolaminates can give food scientists some advantages for the preparation of edible coatings and films over conventional technologies and may thus have a number of important applications within the food industry. Edible coatings and films are currently used on a wide variety of foods, including fruits, vegetables, meats, chocolate, candies, bakery products and French fries (Morillon *et al.*, 2002, Cagri *et al.*, 2004, Cha & Chinnan, 2004, Rhim, 2004). These coating or films could serve as moisture, lipid and gass barriers. Alternatively, they could improve the textural properties of foods or serve as carriers of functional agents such as colour, flavour, antioxidants, nutrients and antimicrobials.

Nanolaminates are more likely to be used as coatings that are attached to food surfaces, rather than as self standing films, because their extremely thin nature makes them very fragile (Kotov, 2003). The object to be coated with a nanolaminate would be dipped into a series of solutions containing substances that would adsorb to the surface of the object (McClements *et al.*, 2005). Alternatively, the solutions containing the adsorbing substances could be sprayed into the surface of the object. The composition, thickness, structure, and properties of the multilayered laminate formed around the object could be controlled in a number of ways. The driving force for adsorption of a substance to a surface would depend on the nature of the surface and the nature of the adsorbing substance. The force usually governing the two phases is the electrostatic attraction of oppositely charged substances.

It is possible that nonuniform laminates could be formed that contain microscopic and macroscopic pores that could negate the barrier function of the laminate. Consequently, this would necessitate the formation of a second base biopolymer layer on the food product to form a more uniform substrate surface, followed by deposition of the layer containing the functional ingredient (McClements *et al.*, 2005).

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). The choice of the type of adsorbing substances used to create each layer as well as other related factors will determine the functionality of the final films. In addition, the aforementioned procedure could be used to encapsulate various hydrophilic, amphiphilic, or lipophilic substances within the films by incorporating them in oil droplets or associated colloids. As a result, it would be possible to incorporate active functional agents such as antimicrobials, antibrowning agents, antioxidants, enzymes, flavours and colours into the films. These functional agents would increase the shelf-life and quality of coated foods. These nanolaminated coatings could be created entirely from food grade ingredients (proteins, polysaccharides, lipids) by using simple processing operations such as dipping and washing (Weiss *et al.*, 2006).

2- Nanocomposites

The most widely studied type of polymer-clay nanocomposites, a class of hybrid materials composed of organic polymer matrices and organophilic clay fillers, is montmorillonite (MMT) (Kim *et al.*, 2003). Recently, the preparation of nano-clay containing carbohydrate film has been reported (Mathew & Dufresne, 2002, Uyama *et al.*, 2003, Park *et al.*, 2003).

Chemically derived by deacetylation of chitin (an abundant polysaccharide found in shellfish) chitosan possesses a unique cationic nature relative to other neutral or negatively charged polysaccharides. In an acid environment, the amino group NH_2 in chitosan can be protonated to yield NH_3^+, which yields antifungal or antimicrobial activities since cations can bind to anionic sites on bacterial and fungal cell wall surfaces. Chitosan, a nontoxic natural polysaccharide is finding roads in many applications one of them is food preservation. Chitosan films containing exfoliated hydroxyapatite layers maintain functionality in humid environments, provide good mechanical and barrier properties while having comparatble antimicrobial efficacies to solution-cast chitosan films (Risbud *et al.*, 2000, Juang and Shao, 2000).

3- Nanofibers and nanotubes

Two applications of nanotechnology that are in the early stages of having an impact on the food industry are nanofibers and nanotubes (Tarver, 2003). Because nonafibers are usually not composed of food-grade substances, they have only a few potential applications in the food industry. The production of fibers with diameters of less than 100 nm is now feasible with the invention of electrospining process (Wikipedia, 2006).

The food industry can use electrospun microfibers in several ways: (a) as a building/reinforcement element of composite green (that is, environmentally friendly) food packing material, (b) as building elements of the food matrix for imitation/artificial foods, and (c) as nanostructured and microstructured scaffolding for bacterial culture (Wikipedia, 2006).

Carbon nanotubes are popularly used as low resistance conductors and catalytic reaction vessels. Under appropriate environmental conditions, however, certain globular milk proteins can self-assemble into similarly structured nanotubes (Graveland-Bikker *et al.*, 2006a, b).

4- Biopolymeric nanoparticles

Biodegradable polymers have found wide applications in the field of biomedicine (Riley *et al.*, 1999, Tobio *et al.*, 2000). More development efforts are needed to adapt these methods to strictly use only food-approved processing aids and components. Methods that may fulfill these requirements to produce nanoparticles include salting out, spontaneous emulsification/ diffusion, solvent evaporation, polymerization and nanoprecipitation (Ibrahim *et al.*, 1992). In addition, electrospraying has shown to be capable of producing uniform particles of less than 100 nm from polymer and biopolymers solutions. Biopolymeric nanoparticles include the following:

(a) Salting out: It involves dissolving a high concentration of a salt and a protective colloid in the aqueous phase, forming a viscous gel. The polymer, which forms the bulk of the particle, and the drug to be encapsulated are dissolved in an organic, water miscible solvent (typically acetone). The two solutions are combined with vigorous stirring to form an oil-in-water (o/w) emulsion. Water is added to this emulsion, causing the organic solvent to diffuse into the aqueous phase. The water insoluble polymer will simultaneously aggregate and encapsulate the other compound present in the organic phase. Thus, forming nanoparticles. Lastly, acetone and salting-out agents are eliminated by cross-flow filtration. While salting out is associated with very high encapsulation, efficiencies compared to the other methods; its use is typically limited to the encapsulatin of lipophilic compounds (Ibrahim *et al.*, 1992).

(b) Nanoprecipitation: In contrast to the solid nanoparticles that the salting-out method generates, the nanoprecipitation method produces nanocapsules that consist of central oily core surrounded by a thin polymer wall (Fessi *et al.*, 1989; Guterres *et al.*, 1995). A polymer and a mixture of phospholipids are dissolved in water-miscible organic solvents such as acetone or ethanol. The compound to be encapsulated or loaded is dissolved in a lipophilic solvent and added to the organic solvent. The organic solution is then added *via* stirring, to an aqueous solution containing a surfactant. Addition to the aqueous solution causes the water-miscible solvent to rapidly diffuse into the aqueous phase, which results in the formation of lipophilic nanodroplets that contain the compound to be encapsulated. The water-insoluble polymer then migrates to the o/w interface where it adsorbs to form an interfacial membrane around the lipophilic core. The resultant suspension is then concentrated by evaporating the organic solvent and water under pressure.

(c) Solvent evaporation: The polymer and compound to be encapsulated are dissolved into a water-immiscible, volatile organic solvent. This solution is subsequently added to an aqueous solution containing a stabilizing compound and then homogenized to form an emulsion. The formation of microspheres is a phase separation process in which the organic solvent diffuses into the aqueous phase from the surface of the droplets in the emulsion. This increases the polymer concentration at the phase boundary and eventually causes the polymer to precipitate, forming the particle (Bodmeier & NcGinity, 1987a, b). The volatile solvent is evaporated under vacuum and produces encapsulated particles ranging in size from 10 to 250 nm (Beck *et al.*, 1979). Depending on the choice of the base biopolymer used to manufacture, the nanoparticles, particle surfaces may be hydrophobic or hydrophilic (Weiss *et al.*, 2006).

5- Oils and fats

The use of nanotechnology is described to provide cost savings, enhance product shelf life, and increase health benefits in the oils and fats sector. In the USA, nanotechnology has enabled a rapid response to new legislation on the production of healthier foods. Since January, 2006 products containing at least 0.5 g/serving of *Trans* fats have required appropriate labels. In March 2006, California-based oil fresh launched frying oil which contains nanoparticles to significantly extend the fry life of the oil. Oil breakdown is suppressed *via* fused nanoceramic catalyst particles which reduce oxidative degradation. Nanotechnology-based fats are likely to be useful as coatings for pharmaceuticals, enabling the drugs to be delivered to the correct site in the body (Case, 2006).

6- Unique milk proteins

Partial hydrolysis of milk protein α-lactalbumin by a protease from *Bacillus licheniformis* results in building blocks, which self assemble into nanometer-sized tubular structures at appropriate conditions. These nanostructures promise various applications in food nanomedicine and nanotechnology. Important aspects for application of α-lactalbumin nanotubes are the formation conditions and nanotube stability (Graveland- Bikker and de Kruif, 2006). The self assembly of partially hydrolysed α-lactalbumin into nanotubes is undertaken as follows:

$$\begin{tikzcd}
\alpha\text{-Lactalbumin} \arrow[r, "\text{enzyme}"] & \text{hydrolysed molecules} \arrow[d, "\mathrm{C}_a^{2+}"] \\
 & \text{nanotubes}
\end{tikzcd}$$

It is worth to mention that the α-lactalbumin nanotubes will be effective as viscosifying agent, because of the high aspect ratio and their stiffness. Using the α-lactalbumin nanotubes would provide an alternative thickener, with a high protein density. In addition, a-lactalbumin has some important functional properties. Furthermore, the gels made of α-lactalbumin nanotubes are strong gels as compared to other protein gels at equal concentrations. Therefore, the nanotubes could serve as a gelation agent. Besides the fact that the gel is strong, it has some additional properties. Firstly the gel formation is reversible, which can be a desirable characteristic for a particular application. Secondly, the gel is transparent, which can be a desired characteristic as well. Lastly, because the α-lactalbumin nanotubes can be disassembled in a controllable way, for example by changing the pH to acidic value, the gel structure can easily be broken down by the same means. All these properties of the gel, provide a novel gelation agent with novel functional properties (Graveland-Bikker & de Kruif, 2006).

7- Nutraceuticals and functional foods

Applications of nanotechnology in preparing nutraceuticals and functional foods can be reviewed under the following headings:

(a) Microemulsions

Compounds that ordinarily are not water soluble or are only sparingly soluble can, with the help of micelles be made water soluble. Micells are submicron spherical particles, typically 5-100 nm in diameter, that are formed spontaneously upon dissolution of surfactants in water at concentrations that exceed a critical level, known as the "critical micelle concentrations" (CMC). Micelles containing solubilized materials are referred to as microemulsions or swollen micelles. While micelles have been used as a delivery system for pharmaceutical compounds for quite a long time, their use as carrier systems for functional food components has only recently attracted increased attention (Chen *et al.*, 2006).

Reports of successful application of microemulsions include encapsulation of limonene, lycopene, lutein and omega-3 fatty acids using a variety of food-grade emulsifiers. Patent applications have been filed for the use of microemulsions to incorporate essential oil in flavoured carbonated beverages and to encapsulate α-tocopherol to reduce lipid oxidation in fish oil (Weiss & McClements, 2002).

(b) Liposomes

Liposomes, or lipid vesicles are formed from polar lipids that are available in abundance in nature, mainly phospholipids from soy and egg liposomes typically vary in size between 20 nm and a few hundred micrometers. Like micelles, liposomes can incorporate a wide variety of functional components in their interior. However, in contrast to micelles, they can be used to encapsulate both water- and lipid – soluble compounds. Because of the charge of the polar lipids used in the preparation of liposomes, charged but water soluble ionic species can be trapped inside the liposomes. The pH and ionic strength of the liposomal core can thus differ from those of the continuous phase in which the liposomes are later dispersed (Chen *et al.*, 2006).

Taylor *et al.* (2005) reviewed food applications of lipsomes. They cited studies on liposomes to increase shelf life of dairy products by encapsulating lactoferrin, a bacteriostatic glycoprotein as well as nisin Z, on antimicrobial polypeptide. Antimicrobial efficiency of other ingredients in the encapsulated form has also been reported (Were *et al.*, 2004; Gaysinksy *et al.*, 2005). Liposomal entrapped phosvitin was used to inhibit lipid oxidation in a variety of dairy products and ground pork-liposome-encapsulated vitamin C retained 50% activity after 50 days of refrigerated storage, whereas free ascorbic acid lost all activity after 19 days.

(c) Nanoemulsions

Nanoemulsions are simply very fine oil-in-water (o/w) emulsions with mean droplet diameter of 50-200 nm. Bioavailability of lipophilic active ingredients can be substantially improved by delivery in nanoemulsions (Nakajima, 2005). For example, nanoemulsions have been used in parenteral nutrition for quite some time.

Because of their small size, nanoemulsions may exhibit some interesting textural properties that differ from those of an emulsion containing large droplets. They may behave like a viscous cream even at loss oil-droplet concentrations, a fact that has attracted attention in the development of low-fat products (Nakajima, 2005).

(d) Cubosomes

Cubosomes are biocontinuous cubic phases which consist of two separate, continuous, but non-intersecting hydrophilic regions divided by a lipid layer that is controlled into a periodic minimal surface with zero average curvature (Spicer, 2004).

According to Chen *et al.* (2006), cubosomes may be used in controlled release of solubilized bioactives in food matrices as a result of their nanoporous structure (approximately 5-10 nm), their ability to solubilize hydrophobic, hydrophilic and amphiphilic molecules, and their biodegradability and digestibility by simple enzyme action. The cubic phase is strongly bioadhesive, so it may find applications in flavour release *via* its mucosal deposition and delivery of effective compounds. Yet, its tortuous structure may lead to applications where masking unpleasant taste or flavour is desireable, because of the slow effective diffusivity.

8- Food packaging

Some of the food packaging applications are being postulated, such as intelligence, sensing and signaling microbiological and/or biochemical change, or active dispensing antimicrobials. Nanotechnology can play a key role in this respect *via* securing permeability of plastics for food protection (high and gas permeability). Beside improvements in mechanical and heat resistance properties, nanocomposite compounds can exhibit dramatically enhanced barrier properties as represented by lower oxygen transmission rates (OTRs). Nylon-6 nanocomposites can achieve an OTR almost four times lower than unfilled nylon-6 nanocomposites. The reduction is typically attributed to the increase in effective diffusion distance, as solutes must travel a tortuous path around well dispersed platelets of high aspect ratio. As a result of the nanometer-length scale, excellent transparency is retained in sheets and films formed from nylon-6 nanocomposites (Brody, 2003).

Focus on the elementary components of food packaging and the perceived links with nanotechnology offers some intriguing possibilities: silicate nanoparticles (the current major target opportunity); metallic/ ceramic nanoparticles (carbon nanofibers) to combine light weight and strength for both equipment and structures, self-assembled monolayers to offer functionality in single layers, thus obviating multilayers and their vagories; nano bar codes; gas-barrier structures; encoding or decorating individual surfaces, counterfeit protection, especially for high-value consumer products, using nanotaggants; nanocrystalline indicators to sense and signal modified – atmosphere environments within packages; light-activated oxygen sensing inks; food deterioration sensors; and power for intelligent packaging, such as radio frequency identification (RFID). Although this list represents only a summary of some packaging potentials, it appears to be formidable in terms of magnitude and possible future significance (Brody, 2006).

9- Identification pathogens in food

Current technology can provide all of the data necessary to ensure the safety of food. Standard microbiological assays can provide the ultimate sensitivity and identify the presence of a single cell in given food sample. However, these assays suffer from long incubation steps and therefore, provide results only after 24- 48 hr or even longer. They also suffer from relatively complex procedures that require handling by trained technicians in a laboratory setting. More recently, lateral flow assays- the technology used in pregnancy test kits have been used to substitute for some of the complex sample handling. These tests are based on antibodies that can determine the presence of pathogens with a 10-20 min. assay. The more- cutting- edge molecular biological assays employing polymerase chain reaction (PCR) that identify pathogens *via* their nucleic acid sequences can also reach detection limits of a few cells per food sample sometimes within 6 hr. However, they are still very complex and expensive techniques that need to be performed in a highly specialized laboratory (Baeumner, 2004).

According to Baeumner (2004), many challenges have to be overcome to develop sensors that could be used by the consumer and first responder to quickly determine the identity and quantity of pathogens in a food sample in a simple, inexpensive, and sensitive manner. In this respect, biosensors similar to pregnancy test kits are being developed for the rapid, reliable, yet inexpensive identification and quantification of pathogenic organisms. Nanotechnology plays a major role in such a subject.

Baeumner *et al.* (2004) developed a universal biosensor that can be made specific for any pathogenic organism of interest within a few minutes with no special equipment and skills. It detects pathogens on the basis of their nucleic acid sequences. A universal membrane was generated and universal liposomes that are made specific within a simple 10 min incubation step.

It is worth to mention that the lateral flow assay is a technology ready for commercialization today. Nanotechnology is critical in the development of new bioanalytical tools that will help achieving the goal of building the ultimate pathogen sensor for the consumer and first responder. Nanotechnology will also be important for the development of novel materials that will make sample preparation from complex food materials less challenging. Research is needed to develop nanomaterials that help integrate the nano- and micro- world with the required macro-world of food analysis. This is especially important considering that typical nano- and microsensors can analyze only tiny volumes, often less than 1 μl, which cannot provide information representative of an entire food sample that might be several hundred milliliters in size. Thus "smart" novel materials can be developed that can extract pathogens directly on the biochip or that can be added to the sample prior to bioanalysis to enable the analysis of sample sizes greater than 1 g and 1 ml (Baeumner *et al.*, 2004).

Thus, it is critical to apply nanotechnology to the development of new techniques that can be utilized for the development of suitable sample preparation steps, such as extraction, concentration, and isolation. Combining this with rapid, portable, highly sensitive, specific, yet inexpensive detection technology will allow overcoming challenges encountered today in pathogen detection (Baeumner, 2004).

10- Food product innovation

An important area of food nanotechnology is in the design of functional food ingredients such as food flavours and antioxidants. Ultimately, the goal is to improve the functionality of these ingredients in food systems, which may minimize the concentrations needed. These new functional ingredients are increasingly integrated into the food matrix development process. Functional ingredients are rarely utilized directly in their pure form. Instead, they are often incorporated into some form of delivery system. A delivery system must perform a number of different roles: (1) It serves as a vehicle for carrying the functional ingredient to the desired site of action, (2) It may have to protect the functional ingredient from chemical or biological degradation to maintain the functional ingredient in its active state, (3) It may have to be capable of controlling the release rate or the specific environmental conditions that trigger release, (4) the delivery system has to be compatible with other components in the system, as well as being compatible with the physicochemical and qualitative attributes (e.g. appearance, texture, taste and shelf-life) of the final product (Imafidon & Sponier, 1994; Lawrence & Rees, 2000; Haruyama, 2003). Food ingredients such as nanoparticulate lycopene and coarotenoids are becoming commercially available. Bioavailability and the ability to disperse these compounds are typically higher than that of their traditionally manufactured counterparts (Weiss *et al.*, 2006).

11- Atomic force microscopy (AFM) as a nanotechnology tool in food science

Atomic force microscopy (AFM) provides a method for detecting nanoscale structural information. It collects data for images by "feeling" rather than looking. In comparison with common forms of microscopes used in food science, AFM offers a number of unique features (Braga and Ricci, 2004): (1) High magnification with high resolution and detect atomic-scale defects. (2) Minimal sample preparation, no dyes, no vacuum or gold sputtering as in SEM/TEM, no fluorescence as in CLSM, the sample can keep their native status or near native status. (3) The ability to obtain different views of the sample from a single data collection, 2D and 3D images can be acquired at the same time. (4) The samples can be imaged in air or in an aqueous environment, thus it is possible to observe ongoing processes directly. (5) The possibility of manipulating macromolecules and investigating the interaction between macromolecules. There are three kinds of operation modes (contact, noncontact, and tapping mode) that can be applied to different materials. The AFM has been applied extensively in biological science, material science, chemistry and recently food science (Braga & Ricci, 2004, Yang *et al.*, 2007). Generally, the AFM application in food science can be divided into 6 main categories: (1) Qualitative and (2) Quantitative analysis of macromolecule structure (Yang *et al.*, 2005, 2006b, c, Li and Xie, 2006), (3) Molecular interaction (Woodward *et al.*, 2004), (4) Molecular manipulation (Yang *et al.*, 2006a), (5) Surface topography (Thiré *et al.*, 2003), (6) Nanofood characterization (Rousseau, 2006).

The AFM has brought in much original knowledge on food properties and could be used to direct food processing and storage. By means of AFM, researchers have succeeded in modifying pectin molecular structures (Round *et al.*, 1997), propose the degradation mode of pectin in fruit through the statistical results of pectin chain width (Yang *et al.*, 2005, 2006b, c) and obtain direct process images of the molecular interactions between protein and surfactants (Morris, 2004); this information cannot be obtained by other techniques.

For some health-related phytochemicals, AFM will offer an alternative way to understanding their interactions and thus lead to a sophisticated, holistic approach to disease prevention and treatment (Lila & Raskin, 2005). The AFM is a promising technology and would provide a great opportunity to combine other techniques and measure the overall quality of food (Yang *et al.*, 2007).

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تطبيقات تقنية النانو (النانوتكنولوجي) في التصنيع الغذائي: نظرة شاملة

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تُعني تقنية النانو (النانوتكنولوجي) بتصور وقياس والتحكم وتطويع المادة عند أبعاد تتراوح منن ١ إلى ١٠٠ نانومتر حيث تعطي ظواهر التداخلات البيئية الحديثة عند هذه الأبعاد صفات وظيفية فريدة لا تتسم بها المادة عند أبعادها التقليدية. ولقد أدت هذه القابلية الاستثنائية للحصول على مثل هذه الوظائف الفريدة إلى استحداث العديد من التقنيات الجديدة والتي لها مردودات جوهرية على كل مناحي العلوم والتقنية والصناعة والاقتصاد والبيئة وكل ما يتصل بحياة الإنسان. وعلى الرغم من أن تقنية النانو مازالت في بداياتها بالنسبة للتصنيع الغذائي إلا أن هناك عدداً كبيراً من تقنيات النانوتكنولوجي قد أخذت مكانها في مجال تصنيع الأغذية، وتعد بحق من التطبيقات الواعدة.

تتلخص أهم تطبيقات النانوتكنولوجي في مجال التصنيع الغذائي فيمايلي: الغرويات المرتبطة، مستحلبات النانو، جزيئات النانو، طبقات النانو، مركبات النانو، ألياف النانو، ترسيب النانو، الانتشار النانو، الكبسلة النانو. كذلك فإنه يمكن استخدام النانوتكنولوجي في إنتاج أغذية وظيفية وعلاجية وبروتينات جديدة من اللبن. وتعد عملية التعرف على الميكروبات المرضة في الغذاء وتطوير صناعة الزيوت والدهون وتعبئة الأغذية من المجالات البكر والواعدة لتكنولوجيا النانو في مجال التصنيع الغذائي.