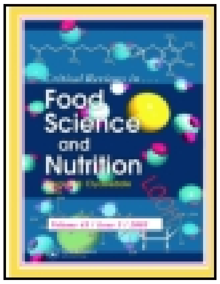

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Active Food Packaging Evolution: Transformation from Micro- to Nanotechnology

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Active Food Packaging Evolution: Transformation from Micro- to Nanotechnology

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Predicting which attributes consumers are willing to pay extra for has become straightforward in recent years. The demands for the prime necessity of food of natural quality, elevated safety, minimally processed, ready-to-eat, and longer shelf-life have turned out to be matters of paramount importance. The increased awareness of environmental conservation and the escalating rate of foodborne illnesses have driven the food industry to implement a more innovative solution, i.e. bioactive packaging. Owing to nanotechnology application in eco-favorable coatings and encapsulation systems, the probabilities of enhancing food quality, safety, stability, and efficiency have been augmented. In this review article, the collective results highlight the food nanotechnology potentials with special focus on its application in active packaging, novel nano- and microencapsulation techniques, regulatory issues, and socio-ethical scepticism between nano-technophiles and nano-technophobes. No one has yet indicated the comparison of data concerning food nano- versus micro-technology; therefore noteworthy results of recent investigations are interpreted in the context of bioactive packaging. The next technological revolution in the domain of food science and nutrition would be the 3-BIOS concept enabling a controlled release of active agents through bioactive, biodegradable, and bionanocomposite combined strategy.

Keywords nanoencapsulation, biodegradable, liposome, antimicrobial, regulatory issues, controlled release

INTRODUCTION

The word "necessity" has been transfigured into a more diabolical notion "Fear of death," and thus Fear of death is the mother of invention in the twenty-first century. This fear factor is assessed by the Centers for Disease Control and Prevention (CDC); Foodborne diseases cause approximately 76 million illnesses, 325,000 hospitalizations, and 5,000 deaths in the United States each year (Mead et al., 1999). More than 200 known diseases are transmitted through food. Acute gastroenteritis affects 250 to 350 million people in the United States annually and an estimated 25–30% of these cases are thought to be foodborne disease. Approximately one person out of four may experience some form of foodborne illnesses each year (McCabe-Sellers et al., 2004). Such incidences of foodborne illness are mounting in developing countries as well as in the developed world (Greig et al., 2007). The Foodborne Diseases Active Surveillance Network (Food Net) states that comparing 2007 with 2004–2006, the estimated incidence of infections caused by *Campylobacter, Listeria*, *Salmonella, Shigella, Vibrio,* and *Yersinia* did not decline significantly, and the incidence of *Cryptosporidium* infections increased by 44% (Vugia et al., 2008). At the same time these illness-outbreaks create an enormous social and economic burden due to food recalls. As a result of several food-related incidents and reported outbreaks worldwide, consumer confidence has begun to oscillate (Jevsnik et al., 2008; Sofos, 2008).

The post-process contamination caused by product mishandling and faulty packaging is responsible for about two-thirds of all microbiologically related class I recalls in the United States, with most of these recalls originating from contamination of ready-to-eat (RTE) food products (Cagri et al., 2004; Gounadaki et al., 2007). Post-processing protection using "active packaging and coatings" has been proposed as an

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innovative approach that can be applied to RTE products to minimize or prevent the growth of pathogenic microorganisms (Gandhi and Chikindas, 2007; Kristo et al., 2008; Min et al., 2008).

The future is indicated by the past, the present, and the consumer. During the last decade, consumer demand for foods which are natural, of high quality, have elevated safety, are minimally processed, have a longer shelf-life, and are easy-to-eat with a fresh taste and appearance has been regarded as a matter of cardinal importance (Sobrino-Lopez and Martin-Belloso, 2008). Meanwhile, increased awareness for environmental conservation and protection has promoted the development of edible coatings and films from biodegradable materials to maintain the quality of both fresh and processed food (Villalobos et al., 2006). Since the market for natural, minimally processed, and RTE foods is broadening, bio-active packaging is being implemented in strategies that actively contribute to food preservation and transformation concepts (Fernandez et al., 2008).

The invention of nanotechnology and its implementation in food products and active/smart packaging has been approved due to its enabling nature. This has the potential to revolutionize agriculture and food systems. Nanotechnology is a multidisciplinary approach that provides endless promising possibilities in supporting the lives of people (Baer et al., 2003; Khosravi-Darani et al., 2007; Un and Price, 2007). Nanoscience is currently enabling evolutionary changes in several technology areas but new paradigms will eventually have a much wider and revolutionary impact. Nanoscience is "the study of phenomena and manipulation of materials at atomic, molecular, and macromolecular scales (0.2–100 nm), where properties differ significantly from those at a larger scale," whereas nanotechnology is "the design, characterisation, production, and application of structures, devices, and systems by controlling the shape and size at the nanometre scale" (Royal Society and Royal Academy of Engineering, Nanoscience, and Nanotechnologies, 2004). The US definition is that "nanotechnology is 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, modelling, and manipulating matter at this length scale (NNI, 2001).

This review focuses on the potential of nanotechnology in active food packaging. It highlights, examines, and compares the known and predictive benefits of nano- versus microtechnology. The objective is to endow with a comprehensive introduction of novel trends in active food packaging. Furthermore, reports of some of the newest technologies have been described in the literature to functionalize nanostructured active material, with a special reference to potential applications in food systems. This review article aims to understand the recent status of regulatory issues and reveals the emerging concepts dealing with food nanotechnology that would improve the quality of human life.

ACTIVE PACKAGING

In view of the fact that food safety has become an ever more significant international concern, active packaging is considered to be a rapidly emerging concept (Weber et al., 2002). Active packaging is defined as an intelligent or smart system that involves interactions between package or package components and food or internal gas atmosphere and complies with consumer demands for high quality, fresh-like, and safe products (Labuza and Breene, 1989). In particular, active packaging changes the condition of packaged food to extend shelf life or improve food safety or sensory properties, while maintaining its quality (De Krujif et al., 2002). The improvement of sensory properties is argued to relate to active packaging. This emphasizes that as an indirect effect of improved food safety, the final sensory attributes of the product at its time of consumption, is better than the foods preserved in non-active packaging. Active food packaging is an inspiring advancement, which permits the food industry to unite the preservative functions of antimicrobials with the protective functions of a pre-existing packaging notion (Mauriello et al., 2004; Scanell et al., 2000).

Bioactive packaging is progressively more experimented upon because it is believed to have a significant potential in improving food safety and prolonging the shelf life of food products (Quintavalla and Vicini, 2002; Vermeiren et al., 1999). To date, various distinguished reviews have laid emphasis on the worth of active packaging for safer, healthier, and higher quality foods (Cagri et al., 2004; Coma, 2008; Joerger, 2007). Details about the O_2 scavenging system, the moisture absorption system, CO_2, and ethanol generation can be obtained from other reviews (Vermeiren et al., 1999; Ozdemir and Floros, 2004; Suppakul et al., 2003).

Active packaging realizes certain extraordinary but vital functions other than providing an inert barrier between the product and external conditions. The principal rewards that active food packaging brings are—the efficient control of surface contamination where the microbial growth predominantly originates; protecting food stuff with high water activity such as fish and sea food (Millete et al., 2007); comparatively prolonged retention of antimicrobial activity (Scanell et al., 2000); extension of shelf-life of foods by residual activity over time (Mauriello et al., 2004); reducing the risk of pathogen development, i.e., log reduction (Scanell et al., 2000); restrain partial inactivation of active substances by product constituents cross-reaction (Mauriello et al., 2005); controlled diffusion of bactericidal or bacteriostatic active agents; target specific microorganism population to provide higher safety (Quintavalla and Vicini, 2002); a comparatively low use of preservative agents; simplification of the production process by combining the addition of preservatives and the packaging step; improving sensorial properties (Vermeiren et al., 2002); the ability to inhibit the germination of spores; applicable to ready-to-eat food stuff (Janes et al., 2002); imperative control of post-process contamination (Kristo et al., 2008); and above all, prevent economic loss and possible deaths due to foodborne infections.

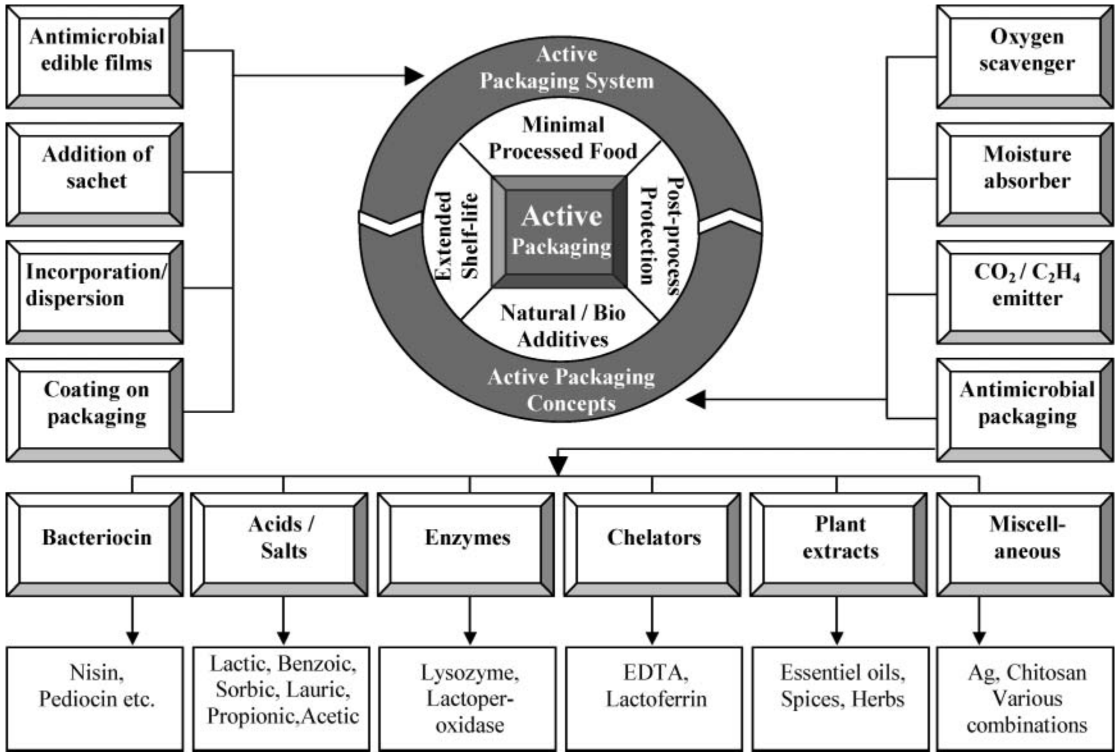

Figure 1 Active food packaging systems, concepts and application matrix.

As the main focus of this review is to analyze the worth of nanotechnology in active food packaging, therefore rather than discussing details of individual aspects of active packaging, just the specific key points of active food packaging are summarized (Fig. 1).

A whole range of active additives have been successfully incorporated in packaging material to confer antimicrobial activity including silver substituted zeolite (Del Nobile et al., 2004), organic acids and their salts, bacteriocin such as nisin and pediocin (Franklin et al., 2004), enzymes such as lysozyme (Min et al., 2008; Conte et al., 2006), chelators like EDTA and lactoferrin (Al-Nablusi and Holley, 2006; Hoffman et al., 2001); the organic compound triclosan (Vermeiren et al., 2002), plant extracts (Joerger, 2007), chitosan (Rhim et al., 2006), and a combination of a few of the above mentioned as hurdle technology (Kristo et al., 2008).

The regulatory systems for active packaging employed in the United States and Europe is apparently similar, but each has its own special set of exemptions. In brief, the US approach considers that "the dose makes the poison" so that toxicological justification is not needed, while the European approach starts from the principle that there must be toxicological data on all substances regardless of the level of anticipated exposure (Heckman, 2005). Most of the active agents are judged as food contact material instead of food additive (EU Regulation, 2004) A European study named EU FAIR R&D programme (1999), initiated amendments to European legislation for food-contact materials to establish and implement active and intelligent systems regulations for packaged food. The legal consequences of a new EU framework regulation on food contact materials, which include controls on active/intelligent packaging and its eventual benefits for the consumer and industry have been thoroughly reviewed (Weber et al., 2002; De Jong et al., 2005; Rasmussen and MacLellan, 2001).

Safe uses of active and intelligent packaging have been recently integrated by Regulation 450/2009/EC. The new Regulation establishes specific requirements also for the marketing of active and intelligent materials and articles intended to come into contact with food. It is mentioned that the substances responsible for the active and intelligent functions can either be contained in separate containers (e.g. oxygen absorbers is small sachets) or be directly incorporated in the packaging material (e.g. oxygen absorbing films). Moreover, the materials may be composed of one or more layers or parts of different types of materials, such as plastics, paper, and board as well as coatings and varnishes. Only the active and intelligent "components" should be subjected to authorization. The term "active component" means a system based on individual substance or a combination of substances which cause the active function of an active material or article. It may release substances or absorb substances into or from the packaged food or the environment surrounding the food. The community list of authorized substances that can be used to manufacture an active or intelligent component of materials shall therefore be established, once the European Food Safety Authority (EFSA) has performed a risk assessment and has issued an opinion on each substance (http://ec.europa.eu/food/food/chemicalsafety/foodcontact/). EFSA guidelines explain which factors the authorities will take into account when making safety assessments. This includes for example the toxicological properties of the product and the

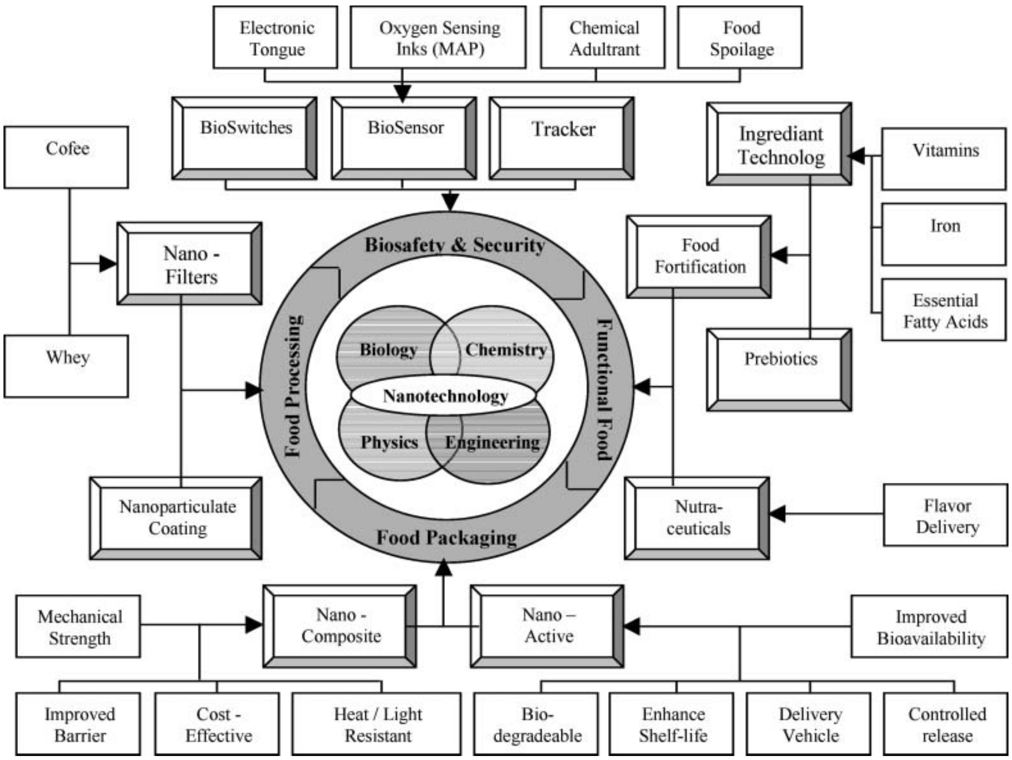

Figure 2 Vital nanotechnology application scopes in food.

extent to which they, or their breakdown products, could transfer into foods.

Further research on active food packaging materials is necessary not only to reveal the mechanisms of action of existing systems, but also to develop novel efficient active agents. Sufficient knowledge is required not only on the independent properties of the coating films and the antimicrobial compounds but also on their interactions. An upcoming center of attention will be the use of bio-derived active antimicrobial compounds with a wide spectrum of activity and low toxicity. Current trends suggest that active packaging will generally incorporate micro- or nanotechnology to accomplish more effective and efficient improvement. Parallel tests with diverse foods will be indispensable before we reach the ideal combination, working equally well for a majority of foods.

VITAL NANOTECHNOLOGY BENEFITS: APPLICATION SCOPES IN FOOD

The prefix “micro” was first used during the 1980s, and the prefix “nano” has been nominated to portray the current generation of dimension-reducing technologies. Nanotechnology generally refers to objects that are one-billionth of a meter in diameter. For the moment, an internationally standardized conception that defines nanotechnology does not exist yet. Nonetheless, we present the following depictions as more accepted ones.

Nanotechnology is important because it is cheap, relatively safe, clean, and the financial rewards are very high. Nanotechnology touches or will touch every aspect of our life (El Naschie, 2006). Nature has been performing “nanotechnological feats” for millions of years (Scott and Chen, 2008). The vital nanotechnological benefits in the food regime have been presented in Fig. 2.

In the food industry significant advancement by nanotechnology are: new functional materials; micro- and nanoscale processing; product development; and the design of methods and instrumentation for food safety and biosecurity (Moraru et al., 2003). At the Second International Food Nanoscience Conference (Chicago, USA, August 1, 2007), IFT’s president Dennis Heldman asserted that the immense opportunities of nanoscience are possible in the areas of (i) food safety and biosecurity (ii) food processing (iii) food packaging (iv) ingredient technologies (Bugusu and Lubran, 2007). One can speculate that understanding the unique possessions of edible stuff of nanometer size will result in innovative, safer, healthier, and tastier foods. At the “*Nano4Food*” conference proceeding,Professor Stroeve emphasized that “Food-related nanotechnology research is already underway and could significantly affect our food supply within the next decade” (Nachay, 2007). Chau et al. (2007) have concluded that the global development of nanofoods is in fact in its initial stage, and yet a nanotechnology food market of US $20.4 billion in 2010, is expected.

Food nanotechnology has the potential to alter nutrient intake by broadening the number of enriched and fortified food products (Nickols-Richardson, 2007). Perspectives of nanoscale materials in the food industry have been reviewed well by Sanguansri and Augustin (2006) and Darnton-Hill and Nalubola (2002). The solubility of functional lipids (carotenoids, phytosterols, essential fatty acids, natural antioxidants) in food formulations is a matter of foremost concern. Moreover, functional lipids with low water solubility may be prone to reduced bioavailability. Nanotechnology provides a good opportunity to improve the solubility of such active ingredients and to increase their bioavailability (Moraru et al., 2003). Omega-3 (highly unsaturated fatty acids) present in marine oils is responsible for their numerous beneficial effects on the retina, the cardiovascular system, the nervous system, etc. The problem with their direct incorporation into food products is their ease of oxidation and, therefore, the corresponding losses. For this reason they must be microencapsulated in most food applications (Kolanowski et al., 2007; 2006; Luff, 2007; Shahidi, 2000; Yep et al., 2002). With the advancement in technology, nano-encapsulation may enhance the stability and optimum release of these essential micro/macro-nutrients and thus play a vital role in increasing the survival rate from coronary heart diseases as a consequence of these nano-functional foods.

Malnutrition contributes to more than half of the deaths of children under five in developing nations. Several inexpensive agricultural and food applications of nanotechnology have the potential to decrease malnutrition, and thus infant mortality (Court et al., 2005). Flavored waters and milk fortified with vitamin, mineral, and other functional ingredients via nanoemulsion technology has gained a lot of importance. Carotenoids, in addition to their provitamin-A activity, have recently been implicated in the prevention of, or protection against serious human health disorders such as cancer, heart disease, macular degeneration, and cataracts. Physical stability of beta-carotene nanodispersions was superior during storage (Tan and Nakajima, 2005). Particle size is a determinant of iron (major malnutrition element) assimilation from feebly soluble Fe compounds. Decreasing the particle size of metallic Fe and ferric pyrophosphate added to foods increases Fe absorption (Rohner et al., 2007). Reducing poorly soluble Fe compounds to nanoscale may increase relative bioavailability and stability and thus their nutritional value. Thus, nano-ingredient food technology has the potential to get rid of major malnutrition dilemmas.

Several filtration technologies do not provide good quality, while with others the quality of the product is good but the cost is too high and needs to be cheap. With using nano-filters the investment (lower applied pressure, higher flux) and operation costs (lower pressure) of the equipment can be relatively low (Rektor and Vatai, 2004; Vincze and Vatai, 2004). More than one-third of the population of rural areas in Africa, Asia, and Latin America have no clean water. More than 2 million children die each year from water-related diseases. Inexpensive, easily transportable, and easily cleanable systems like nanomembranes and nano-clays purify, detoxify, and desalinate water more efficiently than conventional systems (Court et al., 2005).

Food NanoBioProcessing will achieve the goal of bioprocessing (utilize natural biological processes to generate a required compound from a specific waste/feedstock) with greater efficiency. The developments of devices that allow rapid identification of microbes present in feedstock are examples of research at the nanoscale that will increase the efficiency of bioprocessing (Scott and Chen, 2008). Nanosensors for the detection of pathogens and contaminants possibly will make manufacturing, processing, and consignment of food products more secure. Particular nanodevices may perhaps enable precise tracking and recording of the environmental conditions and shipment history of a specific product (Fonseca et al., 2007; Holland, 2007).Fellman (2008) has developed a method to produce nanoparticles with a triangular prismatic shape that can be used in detecting biological threats. In contrast, the use of nanotechnology for intelligence inks in modified atmosphere packaging (MAP) is gaining popularity.

The novel concept of BioSwitch nano-system contained by package works under the principle that if and when the microbial level reaches a certain level amylase is secreted, which partially degrades the encapsulated antimicrobials (Nachay, 2007). Researchers are optimistic that they can manufacture materials enabled to change properties depending on external or internal conditions. These sensors, often carbon nanotubes, are advantageous (rapid, cost-effective, recycled) over conventional chromatographic, enzymatic, or spectroscopic methods which are expensive and time consuming.

Packaging that incorporates nanomaterials can be "smart/intelligent" which means that it can respond to environmental conditions or repair itself or alert a consumer to contamination and/or the presence of pathogens. Self-healing packaging materials use nano/micro-encapsulated repairing agents. Small amounts of an encapsulated "healing agent" will be released by crack propagation or other triggering mechanism, which have been incorporated into polymeric coatings. The substitution of flexible polyolefin layers with novel, thin, functional polymer coatings in the production of paperboard packaging entails the risk of deteriorated barrier and mechanical properties. However, tiny capsules with a hydrophobic core surrounded by a hydrophobically modified polysaccharide membrane reasonably enhanced the packaging functionality. The results showed a reduced tendency for deteriorated barrier properties and local blockage of cracks formed upon creasing. The self-healing mechanism engages the break of tiny capsules local to the applied stress, with subsequent release of the core material. Fracture propagation is hampered by plasticization of the underlying coating layer, while the augmented hydrophobicity assists in sustaining the barrier characteristics (Andersson et al., 2009). Security of the food supply may possibly be enhanced by making "pathogen-repulsive" surfaces or packaging materials that change color in the incidence of injurious microorganisms or toxins (Moraru et al., 2003). Nanotechnology for food packaging had grown from a \$66 million business in 2003 to a \$360 million business in 2008, with an average annual increase of 40% (Brody, 2006). There is an increase in the number of nanotechnology developments in either type of packaging, active and intelligent (Nachay, 2007).

It is believed that the first area of nanotechnology will impact upon in the food industry is food packaging. "*GoodFood*" is a multidisciplinary European project designed to raise awareness of the benefits that micro- or nanotechnologies could bring to the food industry. The objective of the project is to help bring the lab to the foodstuff, from the land to the market, extending the control of the total food chain (Fonseca et al., 2007). This project has developed the new generation of analytical methods based on micro- and nanotechnology solutions for the safety and quality assurance along the food chain in the agro-food industry (http://www.goodfood-project.org/www/results/). Key projects in the long list of solutions include the development of a sensor prototype to detect foodborne pathogens in dairy products, Electrochemical Magneto Immunosensing which is a novel strategy for the detection of pesticides residues, DNA sensing of *Aspergillus carbonarius* and other black *Aspergilli* on grapes with a direct multi-detection DNA chip, rapid PCR screening method for identification of *Aspergillus* species, an innovative e-nose approach for food quality assessment, highly sensitive IR-optical sensor for ethylene-monitoring, miniaturized gas-chromatographic like system for fish quality assessment, and the FID reader method with onboard sensing capability for monitoring fruit quality.

Nanotechnology is likely to be engaged for effective and efficient amendments of food products by bioactive and smart nano-packaging technology. As active nano-packaging is the main theme of our review, a key approach for superior delivery of active ingredients is "micro- and nanoencapsulation." In the following sections, we have attempted to review novel micro- and nanotechnology trends in active food packaging, their selective formulation techniques and overarching concerns over nano-food regulations.

MICRO- AND NANOTECHNOLOGY TRENDS

Currently the customized mode of application of antimicrobial agents is the direct introduction to the food system in free form. However, the problem lies in the fact that the interaction of these compounds with different food components reduces their efficacy against the pathogens and thus high antimicrobial quantities are required to reduce the microbial number within limit. Therefore, to cope with these drastic problems along with an increase in the potential of antimicrobial activity and stability in complex food systems, researchers have devised "encapsulation of antimicrobials." Though encapsulation methods indicated a significant improvement, but real satisfactory results have been achieved by innovative micro- and nanotechnology applications in active packaging.

Different Inhibitors/Active Agents Incorporated at Micro/Nano-Scale

Bacteriocin

The only bacteriocin that has been approved by the World Health Organization as a preservative in food is nisin (FDA, 2008). Nisin exists in two related forms, nisin A and nisin Z. The two forms differ at amino acid position 27; that is, nisin A includes histidine, whereas nisin Z contains asparagine at this position (Mulders et al., 1999). Nisin has an inhibitory effect against a wide variety of Gram positive foodborne pathogens and spoilage microorganisms (Rodriguez, 1996) and can also act on several Gram negative bacteria as a synergistic effect in the presence of some chelating agent (Alvarez et al., 2007; Aymerich et al., 2005). The FDA critically evaluated available information on nisin, confirmed the GRAS status of nisin, and reported that nisin is safe for human consumption at an Acceptable Daily Intake (ADI) of 2.94 mg/per/day. Nisin is proposed for use as an antimicrobial agent on cooked meat and poultry products sold ready-to-eat at 2.5 mg nisin/lb of cooked meat or poultry product, approximately 5.5 mg nisin/kg of food (FDA: GRAS Notice No. GRN 000065).

Excessive nisin amounts are required for guaranteeing effective pathogen growth inhibition because nisin is structurally unstable in food due to its deprivation by interaction with food and cell matrices, and the development of tolerant and resistant *Listeria* strains (Chi-Zhnag et al., 2004). On the other hand, proteolytic enzymes in the food systems, especially in fresh meat products, are responsible for the inactivation of bacteriocin and thus decreasing antimicrobial efficacy (Degnan et al., 1993). In order to improve the bio-availability, the practical way reported is encapsulation of bacteriocin which limits the degree of its degradation in a food model system. The higher stability of encapsulated nisin may be attributed to its maintenance at a high concentration and purity inside nano-vesicles or immobilized on vesicle membranes (Laridi et al., 2003).

Up till now, literature study reveals that relatively low attention has been paid to microencapsulate bacteriocin in foods. In various pharmaceutical and cosmetic applications liposomes have been employed to protect and control the release of active compounds (Benech et al., 2002a; 2002b; Trie et al., 2001). However, the use of liposomes to encapsulate antimicrobials to improve the microbiological stability and safety of foods has received the attention of investigators just a few years ago (Benech et al., 2002a; 2002b).

In terms of encapsulation of food antimicrobials, existing data relating to the bacteriostatic and bacteriolytic capability of liposomes with entrapped antimicrobials is still limited. In this regard a novel work has been done by gathering data relating to liposomes in a fine review (Taylor et al., 2005). The ability of liposomes to withstand exposure to environmental and chemical stresses typically encountered in foods and food processing operations was analysed by the encapsulation efficiency (EE), ζ-potential, and particle size distribution. Liposomes consisting of distearoylphosphatidylcholine and distearoylphosphatidylglycerol, with nisin entrapped, retained 70–90% EE despite exposure to elevated temperatures (25–75°C) and a range of pH (5.5–11.0). Results suggest that liposomes may be an appropriate candidate for nisin entrapment in low- or high-pH foods with light heat treatment tolerance (Taylor et al., 2007).

Benech et al. (2002b) investigated that the encapsulation of nisin Z in liposomes can provide a powerful tool to improve nisin stability and inhibitory action. The inhibition of *Listeria innocua* in cheddar cheese was evaluated during six months of ripening by adding purified nisin Z in liposomes to cheese milk and compared by in situ production of nisin Z by *Lactococcus lactis* subsp. *lactis biovar diacetylactis* UL719. Immediately after cheese production, 3- and 1.5-log-unit reductions in viable counts of *L. innocua* were obtained in cheeses with encapsulated nisin and the nisinogenic starter, respectively. After 6 months, cheeses made with encapsulated nisin contained less than 10^1 CFU of *L. innocua* per g and 90% of the initial nisin activity, compared with 10^4 CFU/g and only 12% of initial activity in cheeses made with the nisinogenic starter (Benech et al., 2002b). The encapsulation of nisin in phospholipid helps the starter culture against the inhibitory effects of nisin (Benech et al., 2002a).

Different proliposomes (Pro-lipo H, Pro-lipo S, Pro-lipo C, and Pro-lipo DUO) were tested for their capacity to encapsulate nisin Z ranging from 9.5% to 47%. The increase in the cholesterol content in lipid membranes up to 20%, w/w, resulted in a slight reduction in EE. The pH of nisin Z aqueous solution and nisin Z concentration had a significant effect on the amount of the encapsulated nisin (Laridi et al., 2003). Nisin insertion and subsequent perturbations of permeability in lipid membrane are increased with increasing negatively charged lipids and unsaturated phospholipids (El Jastimi et al., 1999). Liposome H may thus be less susceptible to the nisin-membrane destabilizing action compared with the other tested liposomes as 85% of the total phospholipid content is phosphatidylcholine (zwitterionic lipids).

In a meat model system, the entrapment of pediocin AcH in liposomes (18% entrapment efficiency) made from phosphatidylcholine improved the antilisterial activity of pediocin compared with free pediocin. In case of direct incorporation, a decrease in pediocin activity (12–54% recovery of original activity) occurred. Higher pediocin activity (29–62% increase; average over all concentrations) was recovered from the model food system containing encapsulated bacteriocia as compared to free pediocin AcH. The additional recovery of pediocin activity provided by liposomes declined the potential for the direct application of biopreservatives (Degnan and Luchansky, 1992). It has been suggested by the author that encapsulation with higher melting point lipids or different polarity of the capsule might enhance the efficiency for delivering bioactive agents in the food system.

From the dairy industry point of view, the use of nisin in free form is costly and has drawbacks of lower stability, lower activity, and reduced bioavalability (Roberts and Zottola, 1993). The other disadvantages of using free nisin include possible interference with the cheese-making process, inhibition of cheese starter culture, and loss of lactic acid bacteria needed for ripening and flavor development (Buyong et al., 1998). The distinct advantage is that if the encapsulation material is made of natural ingredients it proves beneficial for our health (Huwiler et al., 2000; Lahiri and Futerman, 2007; Thompson and Singh, 2006). This is how researchers has been forced to think and opt for micro- and nano-encapsulation of antimicrobials to avoid the possible defects of using them in free form and on the other hand having the advantage of their effective, stable, and longer bioavailability.

The addition of nisin, free or incorporated in micro-particles, did not influence cheese proteolysis and volatile compound profile. Nisin, free or incorporated in calcium alginate microparticles, was added to pasteurized milk (80% cows' and 20% ewes' milk) used for the manufacture of Hispanico cheese. The efficiency of nisin incorporation in calcium alginate microparticles was calculated to be 94% (Garde et al., 2003). Incorporation of calcium alginate is preferred because of its food-grade additive status, low cost, and simple incorporation process. Another study has revealed that Liposome-encapsulated nisin did not appear to affect cheese proteolysis, rheology, and sensory characteristics. Cheeses with added *Lb. casei* and liposome-encapsulated nisin Z exhibited the highest flavor intensity and were preferred as the best for sensory parameters (Benech et al., 2003).

The mode of application of the antimicrobial agent in the food system is crucial for success. Free nisin has lower accessibility to bacterial cells in cheese milk because a majority of the nisin adheres to fat and protein surfaces. On the other hand, this method is expensive, non-homogeneous, and may result in cheese starter inhibition (Roberts and Zottola, 1993). Similarly the growth, acid, and aroma production of starter cultures might be affected by the addition of nisinogenic strains, which results in an inferior quality product. To avoid such phenomenon, nisin-producing strains should be combined with nisin, a resistant or tolerant starter culture, to ensure a proper balance between lysed and intact cells. The optimum composition of the *Lactococcus lactis* UL 719/commercial flora Danica (FD) mixed culture, 0.6 /1.4%, may offer Gouda cheese with a greater control over undesirable microflora in cheese, both from the perspective of cheese quality as well as safety (Bouksaim et al., 2000). Micro-encapsulation has a great deal of stability, protection and controlled release in pharmaceuticals, agricultural chemicals, and food ingredients. In this regard three excellent reviews have been published (Champagne and Fustier, 2007; Gouin, 2004; Madene et al., 2006).

Wan claimed that calcium alginate micro-particles containing nisin provide substantial stability against enzymes. The incorporation efficiency of micro-particles smaller than 150 μm was 87–93% and the nisin in the alginate-incorporated form was 100% active against an indicator culture of *Lactobacillus curvatus*. A formulation of 1:9 provides the best barrier against proteolytic inactivation of nisin (Wan et al., 1997). The data reveal that micro-particles of food grade polymers provide a more effective system than liposome encapsulation but to realize the actual potential of this technology requires further research.

A long-lasting antibacterial activity was displayed by Nisin-loaded poly-L-lactide nano-particles produced by gas precipitation which was maintained through 1000 h with the in vitro release results. Due to controlled release these nisin-loaded nano-particles showed a weaker antibacterial activity within the first 3 h incubation as compared to free nisin samples. Interestingly, degraded or cell taken up nisin is replaced by active nisin freshly released by the particles throughout the experiment (Salmaso et al., 2004). It is quite apparent that protein stabilization and slow release is necessary to yield a long-lasting efficient antibacterial activity.

To give a targeted controlled release is a key functionality for which several techniques have been investigated. Nisin embedded packaging materials or nisin adsorbed solid surfaces such as polyvinilic or polysaccharide films allowed for prolongation of the biological activity (Suppakul et al., 2003; Conte et al., 2006; Cha et al., 2003; Coma et al., 2001; Natrajan and Sheldon, 2000; Siragusa et al., 1999; Ugurlu et al., 2007). Nisin-loaded polymeric micro-/nano-particles seem to be promising formulations to achieve long-lasting antimicrobial activity. These polymeric micro- /nano-colloids are physically stable and can be easily formulated with a variety of materials obtaining the controlled release rate of the active agent (Salmaso et al., 2004).

Mode of Application

In terms of encapsulation of various active agents, a comparison of micro- and nanotechnology data of encapsulation have been gathered with important parameters from the origin till the end use (Table 1).

Lactoferrin

To avoid foodborne illness outbreaks, one of the effective natural antimicrobial for food systems is lactoferrin (LF) which is the main iron-binding glycoprotein present in the milk of mammals that controls bacterial, fungal, or parasitic growth (Franklin et al., 2004; Al-Nabulsi and Holley, 2007; Kim et al., 2004; Pan et al., 2007a; 2007b; Lao et al., 2001; Al-Nabulsi and Holley, 2005). LF enhances the growth of probiotic bacteria like bifidobacterium and meanwhile it also shows antioxidant, antiviral, anti-inflammatory, and anti-cancer qualities (Kim et al., 2004; Lao and Brock, 2001). Lactoferrin occurs naturally in milk and milk-derived ingredients and products. Thus, people who consume milk or milk-derived ingredients already consume lactoferrin. The animal toxicity studies demonstrate that there are no adverse effects related to the consumption of milk-derived lactoferrin at levels up to 2000 milligrams/kilogram/day (FDA: GRAS Notice No. GRN 000042).

Lactoferrin has been used as a potential antimicrobial in coatings but the cations including Na^{+}, Ca^{2}, and Mg^{2} interfere with its activity (Franklin et al., 2004; Al-Nabulsi and Holley, 2005). To avoid this microencapsulation and controlled release technology has found broad applications. Paste-like microcapsules were incorporated in edible whey protein isolates (WPI) packaging film to test the antimicrobial activity of LF against a meat spoilage organism *Carnobacterium viridans*. The film was applied to the surface of bologna after its inoculation with the organism and stored under vacuum at 4 or 10°C for 28 d. The growth of *C. viridans* was delayed at both temperatures and microencapsulated LF had greater antimicrobial activity than when unencapsulated (Al-Nabulsi et al., 2006).

Lysozyme

Lysozyme is of interest for use in food systems since it is a naturally occurring enzyme with antimicrobial activity. Lysozyme can be derived from eggs, plants, bacteria, and animal secretions; it is commercially used to inhibit the growth of *Clostridium tyrobutyricum* in cheese (Min et al., 2008). Eggwhite lysozyme is proposed for use as an antimicrobial agent on cooked meat and poultry products sold ready-to-eat at 2.0 mg eggwhite lysozyme/lb of cooked meat or poultry product, approximately 4.4 mg eggwhite lysozyme/kg of food (FDA: GRAS Notice No. GRN 000064). Acceptable Daily Intake "not specified" means that, on the basis of the available data (chemical, biochemical, toxicological, and other), the total daily intake of the substance arising from its use at the levels necessary to achieve the desired effect and from its acceptable background in food does not, in the opinion of the Committee, represent a hazard to health.

Entrapment efficiency, the mean average size, and the stability of the commercially available form that contains 2.5% nisin and lysozyme, are influenced by lipid composition. Encapsulation of commercial nisin extract and lysozyme in PC-, PG-, and cholesterol containing liposomes was achieved and the highest concentration of antimicrobials was encapsulated in 100% PC liposomes but also resulted in higher leakage. The antimicrobial loading was decreased by the addition of cholesterol and PG but cholesterol decreased leakage of PC liposomes (Gregoriadis and Davis, 1979; Hsieh et al., 2002). Application of nisin and lysozyme affected liposome stability; nevertheless, the intact encapsulated liposomes were physically stable for 2 weeks (Were et al., 2003). We can assume that for microbiological stabilization of food products, stable nanoparticulate of polypeptide antimicrobials can be achieved by selecting suitable lipid-antimicrobial combinations.

Silver

Silver compounds have been widely used as broad-spectrum antimicrobials in a variety of applications including dental work, catheters, and burn wounds (Dibrov et al., 2002). Silver ions inactivate vital bacterial enzymes and recent works have shown that silver ions, trapped with zeolites (inorganic ceramic) have the potential for inactivation of vegetative bacterial cells (Cowan et al., 2003; Galeano et al., 2003; Jiang et al., 2004). Silver nitrate is used as an antimicrobial agent, in an aqueous solution with hydrogen peroxide, in bottled water. Silver nitrate is recommended as values NTE (not to exceed) 17 μg/kg in the treated bottled water, and hydrogen peroxide NTE 23 mg/kg (FDA Food Additives Reg. 172.167). FDA is currently evaluating the potential toxic/carcinogenic effects resulting from exposure to dietary supplements and nanoscale-sized particles associated with food containers, food preparation surfaces, and food wraps (www.fda.gov/AboutFDA/WhatWeDo/track/ucm203296.htm). This research will help the

Table 1 Between and within comparison of micro- and nanotechnology systems of encapsulation

Antimicrobial	Encapsulation Method	Carrier/Polymer Carrier/Polymer	Size	Encapsula-tion efficiency EE (%)	Residual activity(%)	Target Organism	Log unit reduction	Medium/Product	Duration of study	Reference
Micro-scale										
Lactoferrin	Paste like microcapsules	WPI	1–4 μm	–	36–40	*Carnobacterium viridans*	2–3	Bologna	28 days	(Al-Nabulsi et al., 2006)
Nisin	Micro-particles	Calcium alginate	< 150 μm	87–93	25–75	*Lactobacillus curvatus*	Below detection limit	MRS, Skim-milk	4 weeks	(Wan et al., 1997)
Lactoseperoxidase system	Acacia gum core and spray drying	Caseinate, paper	microbeads			Several	5–30 cm^2 inhibition zone	Soy agar	48 hours	(Jacquot et al., 2004)
Micro- to Nano-scale										
Nisin Z	Liposome	Pro-liposomes (H,S,C & DUO)	140–2400 nm	9.5–47	20–39	*Pediococcus acidilactici UL5*	4–7	Milk, whey, PBS	27 days	(Laridi et al., 2003)
Chitosan Nano-silver Ag-zeolite Montmorillonite	Solvent casting	Chitosan	79 nm-<5 μm	–	–	*Staphylococcus aureus* *Listeria monocytogenes* *Salmonella* Typhimurium *Escherichia coli*		Soy agar	8 hours	(Rhim et al., 2006)
Nano-scale										
Nisin Z	Liposome	ProliposomeH	80–120 nm	47	90	*L. innocua*	3	Cheese	6 months	(Benech et al., 2002)
Nisin A	CO_2 anti-solvent ppt	Poly-L-lactide	200–400 nm	78–81	81–84	*Lactobacillus delbrueckeii*	4–5	MRS medium	40 days	(Salmaso et al., 2004)
Nisin	Liposome	PC PC/cholesterol (70/30) PC/PG/cholesterol (50/20/30)	144 nm 223 nm 167 nm	63 54 59		—	—	—	2 weeks	(Were et al., 2003)
Nisin Z	Liposome	ProliposomeH	80–120 nm	-	92	*Listeria* *Lactococcus* and *Lactobacillus*	0–3	Cheese	2–6 months	(Benech et al., 2002)
Nisin Z	Liposome	Prolipo H	app 740 nm	34.6	93	*Lactobacillus casei*	0.5	Cheese	6 months	(Benech et al., 2003)
Nisin	Liposome	PC PC-cholesterol (7:3) PC- PG-cholesterol (5:2:3)	100–200 nm	29–38	—	*L. monocytogenes*	2	Soy agar	30 hours	(Were et al., 2004)
Nisin	Liposome	Disteroylphosphadyl-choline Disteroylphosphadyl-Glycerol	100–240 nm	72–91	70–90	—	—	—	—	(Taylor et al., 2007)
Lysozyme	Liposome	PC PC-cholesterol (7:3) PC- PG-cholesterol (5:2:3)PC	100–200 nm	19–43	—	*L. monocytogenes*	strain dependent -	Soy agar	30 hours	(Were et al., 2004)
Lysozyme	Liposome	PC/cholesterol (70/30) PC/PG/cholesterol (50/20/30)	161 nm 162 nm 174 nm	61 60 61	—	—	—	—	2 weeks	(Were et al., 2003)
Silver	Plasma depositing	Polyethyleneoxide	90 nm	—	—	*Alicyclobacillus acidoterrestris*	2	Apple juice, malt	100 hours	(Del Nobile et al., 2004)
Silver	Plasma	Rubber, steel, paper	nano-particles	—	—	*L. monocytogenes*	4–5	Polmer surface	24 hours	(Jiang et al., 2004)

FDA determine the health effects from exposure to dietary supplements and from nano-particles associated with food preparation materials. A complete analysis of pharmacokinetic studies of nanosilver particles administered by intravenous injection is ongoing.

The use of nanoparticle metallic silver particles as an antimicrobial agent in polyurethane coatings has been achieved which are applied on particular parts of food packaging machines and also on food handling robots in order to reduce the risk of bacterial contamination (Wagener et al., 2006). In the United States, the Food and Drug Administration has added to its list of food contact substances an Ag^+ based system-AgION®. *Alicyclobacillus acidoterrestris* is Gram positive, spore-forming bacteria which is a spoilage agent in acidic beverages. The effectiveness of Ag^+-based antimicrobial film in inhibiting the growth of an *A. acidoterrestris* strain in acidified malt extract broth and apple juice was investigated. The results indicate a 2 log comparative reduction in viable microbial count of thermal resistance microorganism in acidic beverages (Vermeiren et al., 2002). Concerns relating to the amount of silver used in edible films should not be neglected during the production of such active films.

Silver nanoparticle thin layers were deposited onto medical- and food-grade silicone rubber, stainless steel, and paper surfaces. The antimicrobial properties of the silver-coated surfaces were demonstrated by exposing them to *Listeria monocytogenes.* No viable bacteria were detected after 12 to 18 h on silver-coated silicone rubber surfaces thus 4–5 log reduction was achieved (Jiang et al., 2004) These results depict that silver is one of the strongest bactericide and it becomes more effective as nanoparticles.

Chitosan

The uses of renewable resources to produce edible or biodegradable packaging materials that can improve product quality and reduce waste disposal problems are being explored. The literature available for natural biopolymer-based nanocomposite materials is limited, especially concerning antimicrobial films; (See excellent reviews in this regard by Pandey et al., 2005 and Ray and Bousmina, 2005). Chitosan, the second most abundant biopolymer, safe, and non-toxic, holds antibacterial and antifungal properties (Agnihotri et al., 2004; Kim and Kang, 2007). The recommended dose of chitosan as a dietary supplement is 1.5 to 3.0 grams per day. This dosage has been recommended based on the results of clinical trials with human volunteers. It is possible that the consumption of chitosan may provide health benefits from additional dietary fiber intake. Further, no untoward effects have been reported in multiple studies involving chitosan consumption by human volunteers consuming similar amounts of chitosan (FDA: GRAS Notice No. GRN 000073).

A recent study has been done to develop biodegradable antimicrobial bionanocomposite films with acceptable properties for applications in food packaging using biopolymer such as chitosan, as well as Nano-silver, silver zeolite, and nanoscale layered silicates. Tensile strength increased by 7–16%, whereas water vapor permeability decreased by 25–30% depending on the nanoparticle material tested. While the silver containing ones chitosan-based nanocomposite films depicted a potential of antimicrobial activity (Al-Nabulsi and Holley, 2006). The chitosan films containing silver nanocomposites depicted an excellent potential of antimicrobial activity.

Lactoperoxidase System (LP-s)

In developing countries the use of LP-s system as temporary preservation of raw milk is increasing (Kussendrager and Van Hooijdonk, 2000). The major inconvenience is mixing of the components, i.e., lactose peroxidase, hydrogen peroxide oxidoreductase, thiocyanate, and H_2O_2, for which encapsulation as microbeads has been tested. LP-s microbeads are easily incorporated inside protein films and remain active after drying (Jacquot et al., 2004). There are some limitations to the application of this system at nano-scale because it is just not an antimicrobial peptide, enzyme, or metal but a whole system consisting of 4 distinct components. Already it is an excellent effort to design such micro-particles, but on the contrary real success of this system has not been realized as LP-s is approved just for raw milk application by FDA. The EU support the proposal by New Zealand to amend footnote 9 in Appendix A: "Any trade in milk treated by the lactoperoxidase system should only be on the basis of mutual agreement between countries concerned, and without prejudice to trade with other countries." (Codex Alimentarius Commission, 32nd Session, 2009, ALINORM 09/32/9C).

Potential Advantages of Nanotechnology Concerning Active Agent Incorporation in Food

Owing to micro- and nanotechnology numerous advantages can be availed of as these potentials have been the driving force to carry out investigations in the promising field of active food packaging, as shown in Table 2. The research work found in literature proves that the evolution from micro- to nano-scale has amplified the listed benefits.

Eventually micro- and nano-encapsulation has brought a revolution because of the fact that by utilizing these techniques not only the control against foodborne pathogens is more effective but also long-lasting, thus enabling the researchers and industrialists to provide a healthier, safer, and an enhanced shelf-life food to the consumer. It is true that micro- or nano-entrapment in liposomes enhances nisin stability, availability, and distribution which may improve the control of undesirable bacteria in foods stored for long periods. It can be proposed that allergenicity and product labelling concerns are expected to be minimal as liposomes used in micro- and nano-technology are generally formed from lipids that are naturally occurring in various food staples. Therefore it is very crucial to induce further work in the nano-active-packaging, where natural antimicrobials would

Table 2 Potential advantages of micro- or nanotechnology for novel trends

Potential advantages	References
Protection	
To reduce or prohibit bacteriocins affinity to food components	(Laridi et al., 2003)
Safeguard antimicrobial peptide from inhibitors or unfavorable conditions in food matrix	(Laridi et al., 2003)
Stability	
Act as long term preservative in foods for long periods of time	(Laridi et al., 2003)
Avoid interference with lactic starter growth during fermentation	(Laridi et al., 2003)
Relatively stable to pasteurization protocols	(Taylor et al., 2007)
Improved viability of probiotics for future use	(Picot and Lacroix, 2004)
Cost-effective	
Economical as relatively lower dose of antimicrobial is required as compared to free form	(Roberts and Zottola, 1993)
Functionality	
Comparatively enhanced activity and bioavailability	(Roberts and Zottola, 1993)
Isolation/Immobilization	
No or lesser harmful effects on organoleptically important bacteria e.g. LAB for flavor	(Buyong et al., 1998)
Use of active ingredients in low- or hi-pH-foods e.g. nisin is pH-sensitive compound	(Taylor et al., 2007)
Controlled release	
Release of active agents can triggere by physical or chemical stress	(Lee and Rosenberg, 2000)
Effective and easier lactoseperoxidase system provision	(Jacquot et al., 2004)
Controlled release of active ingredients	(Sorrentino et al., 2007)
Nutrition	
Biopolymers for nano-encapsulation are usually edible hence nutritive	(Thompson and Singh, 2006)
Structurization	
High mechanical and barrier properties with nanocomposite	(Rhim et al., 2006)
Nano-particles disperse and act as reservoirs of active ingredients	(Rhim and Ng, 2007)
Senso-textural	
Certain masking effect without destroying texture is possible	(Nachay, 2007)
Optimization	
Integration of nanosensors for detection of pathogen	(Nachay, 2007)
Application of nanotechnology promise to expand the use of edible and biodegradable packaging	(Chen et al., 2006; Rhim and Ng, 2007)

be used with or instead of conventional preservatives utilizing micro- or more preferably nanotechnology to improve the shelf life and safety of perishable foods.

MICRO- AND NANO- ENCAPSULATION TECHNIQUES IN FOOD PACKAGING

Nanoencapsulation is the expertise of wrapping solids, liquids, or gaseous materials in minuscule, conserved capsules that may liberate their contents at controlled rates under particular conditions of the food matrix (Taylor et al., 2005; Champagne and Fustier, 2007; Sukhorukov et al., 2005). With the emergence of nanotechnology, ongoing research has been focused towards nanoencapsulation to attain even more stability, versatility, and effectiveness.

The review of literature reveals a number of excellent review papers on nano- and microencapsulation technologies, which are the applications of nano- and microencapsulated ingredients in the food industry (Gandhi and Chikindas, 2007; Taylor et al., 2005; Gouin, 2004; Madene et al., 2006; Anal and Singh, 2007; Mozafari et al., 2006; Peniche et al., 2003; Yih et al., 2006). The scientific data with respect to active ingredients have been excellently summarized (Champagne and Fustier, 2007; Desai and Park, 2005; Graveland-Bikker and de Kruif, 2006; Lopez-Rubio et al., 2006; Ubbink and Kruger, 2006). The development of innovation lies in the concept of micro- and nanoencapsulation and controlled release of bioactive components or nanocomponents from biodegradable/edible and/or sustainable packaging systems. We attempt to illustrate the principles of different approaches in micro- or nanoencapsulation of active ingredients.

The aim of this review is to give critical perspectives of nano- and microencapsulation with reference to active packaging in the food industry, their strengths/weaknesses, and the mode of release.

Spray drying is the most extensively used microencapsulation technique in the food industry (flavor, vitamins, lipids, etc.); however, the customary aqueous state demand, low solubility, and high water evaporation makes it tiresome. Spray drying makes use of several coating materials such as protein: sodium caseinate, soy protein, whey protein, gelatin; cellulose: hydroxyl propyl methyl cellulose (HPMC), carboxy methyl cellulose (CMC); lipids: fatty acids, cholesterol, wax; carbohydrate: chitosan, etc. (Heurtault et al., 2003; Kolanowski et al., 2004; Loksuwan, 2007).

Nanoparticle suspension might be stabilized by water elimination into re-dispersible dried solid particles in the presence of different water-soluble excipients as drying auxiliaries (Tewa-Tagne et al., 2007). Thus spray drying is a striking technique for improving the nanoparticle conservation. But in the field of antimicrobial packaging, the use of spray drying for nanoencapsulation has not been introduced yet.

In contrast spray drying, spraychilling/cooling does not employ the evaporation of water. A molten medium with low melting point containing the bioactive compound is atomized through a nozzle into a vessel. The cold air in the vessel enables the solidification of the gel particle into a fine powder particle. The liquid droplet thus solidifies and entraps the bioactive product. Nevertheless, due to little choice of covering material (high melting point), the spray-chilling application is near the ground in food packaging nanoencapsulation. This technology is utilized for lipids such as potassium iodate, retinyl palmitate, and ferric pyrophosphate which were microencapsulated in hydrogenated palm fat by spray cooling for food fortification purposes(Wegmuller et al., 2006).

Extrusion Coating is a relatively new technique of encapsulation but due to a number of limiting draw backs (Table 3), no research work had been carried out using this process for controlled release of antimicrobial agents as core material.

Several controlled release options are feasible with Fluidized Bed Coating because this technology is capable of applying a uniform layer on solid particles with almost every type of coating materials. The cost is also low because of the fact that no energy for evaporation is engaged. Conversely, Desai and Park (2005) have suggested that the food industry should implement a somewhat different approach to this rather costly technology (Desai and Park, 2005). The fluidized coating methods, top-, bottom-, and tangential-spray, are capable of encapsulating very tiny particles as minute as 100 μm. A more ample fluidized bed coating process and application in the food industry had been reviewed (Dewettinck and Huyghebaert, 1999). Up till now, this technique of encapsulation has been used for vitamin, iron, and certain salts for preservation but none of the work refers to micro- or nanoencapsulation of antimicrobial peptides/bacteriocin.

Calcium alginate beads have food-grade additive status, they are low cost, and have a simple incorporation process with high encapsulation efficiency. Successful incorporation (around 90% encapsulation efficiency) of nisin has been done at a micro-scale (150 μm) and further size reduction can be done by grinding and sieving for nano-scale (Garde et al., 2003; Wan et al., 1997). The arresting problem in this system is faster diffusion which may arise due to chelating of calcium with phosphate, citrate, and acetate in the food system. One striking approach may utilize the alginate beads in combination with successful encapsulation material like liposome.

The coacervation nano- or microencapsulation principle is the phase separation of one or more hydrocolloids from the initial solution and the subsequent deposition of the newly formed coacervate phase around the active ingredient suspended or emulsified in the same reaction media (Wu et al., 2005). In simple coacervation, the hydrophilic colloid is deprived of the solvent by “salting out” (addition of a competing hydrophilic substance, such as a salt or alcohol). Complex coacervation is generated by mixing two oppositely charged polyelectrolytes. The polyelectrolyte complex/coacervate complex separates into a polymer rich phase that coexists with a very dilute phase (Peniche et al., 2003).

Capsaicin microcapsules were prepared by the complex coacervation of gelatin, acacia, and tannins and indicated that the capsaicin microcapsules displayed potential antimicrobial applications in food storage (Xing et al., 2006). The problem of the controversial cross-linker formaldehyde/glutaraldehyde was altered by glycerol, a good potential non-toxic cross-linking material for the applications of encapsulation (Huang et al., 2007). In the coming years, coacervation might be widely used because

Table 3 Comparison of different micro- or nanoencapsulation techniques

Encapsulation method	Strengths	Weaknesses
Spray drying	Continuous basis operation Economical, comparative lower cost Flexible, adjustable to processing equipment	High temperatures use Only water-soluble wrap material can be used otherwise expensive.
Spray chilling	Least expensive	High melting point shell material (mostly fat) microcapsules are insoluble in water
Extrusion	True encapsulation (complete wrap) Long shelf life	Payload is low Salute leakage during extrusion large particle formation 500–1000 μm. High temperature and pressure may cause degradation of active agents.
Fluidized bed	Broad options of coating material Variety of control release possibilities Increased shelf life	For effective coating, atomized coating droplets should be smaller than encapsulated particle. Coating imperfections
Alginate beads	Easy preparation on small scale Encapsulate all materials	Fast diffusion Very expensive process and a complex system
Coacervation	Very high payloads achievable Sustained release	Cross-linker has to deal with food regulatory laws
Liposome	Simple production methods Stability in high water activity environment High encapsulation efficiency of large unilammelar vesicles Targeted delivery in food stuff (content, T°) Non-toxic and acceptable for foods Range of size; few nm to several micron Liposome can withstand dairy fermentation cycle Food sensory and rheological properties appear intact Cholesterol addition may improve stability/integrity Phospholipids of natural source is easy on the pocket	Delivery cost of liposome-encapsulated ingredients (aqueous form) Nisin may disrupt liposomal membrane

of a very high payload achievable while the only constraint for the moment is the price tag.

Self-assembly of the hydrolyzed milk protein α-lactalbumin leads to long, straight, and stabilized nanotubes containing a special feature "cavity." The characteristics of the alpha-lactalbumin nanotube make it an interesting potential encapsulating agent, like the 8-nm cavity and the controlled disassembly (Raviv et al., 2005). They withstand conditions similar to a pasteurization step in the food industry. As α-lactalbumin is milk protein, it will be fairly easy to apply the nanotubes in food or pharmaceutical applications in the future.

Whether it is nano- or micro-scale, liposome encapsulation has become equally effective and admirable. Recent studies suggest that liposomes are even naturally present in the very first food we take, namely breast milk (Keller et al., 2000; Keller, 2001).

To date, however, in comparison with pharmaceutics and cosmetics, little use of micro- or nanoliposome has been made in the food industry. Regarding encapsulation of antimicrobial compounds (nisin, pediocin, lysozyme), different formulations of lipids has given significant results for inhibiting *Listerial spp.* in dairy and meat food matrix. Thus nanoliposomes are commanding the means to inhibit the growth of pathogenic organism in food matrix, while preventing the harmful effect of antimicrobials on the food's actual senso-textural properties (Laridi et al., 2003; Benech et al., 2002a; 2002b; 2003; Taylor et al., 2005; Degnan and Luchansky, 1992; Were et al., 2003; 2004). For bacterial targeting a new "Mozafari method" for nanoliposome preparation has been devised. This method is based on heating treatment, and the liposomal ingredients were added to a preheated (60°C, 5 min) mixture of nisin and glycerol. The mixture was further heated (60°C) while stirring (approx. 1000 rpm) on a hotplate stirrer for a period of 45–60 min under nitrogen atmosphere. The reaction was performed in a home-made glass vessel specially designed by Mozafari, typically in a total volume of 10 ml ultra pure water (Colas et al., 2007).

One critical aspect is the release of active compounds (Fig. 3) like antimicrobial peptides, from the liposome. The different postulates are (1) liposomes are "kinetically stable" for defined period of time, so extrinsic parameters (pH, T°, ionic strength) and intrinsic parameters (phospholipids concentration, composition, entrapped compound nature, and concentration) influence the functionality of liposome (2) "fusion" between the liposome and the pathogen outer membrane (3) core (antimicrobial) material induced leakage (4) liposome membrane permeability which for instance had been reduced by cholesterol (5) diffusion due to low molecular weight of the antimicrobials (6) opening of liposomal membrane releasing antimicrobial in aqueous phase which results in rapid reduction while membrane-immobilized bacteriocin would be delivered over a longer term (7) certain antimicrobial like nisin-induced leakage by changing the membrane structure (8) anonymous interaction between the liposome and the fat globule membrane may result

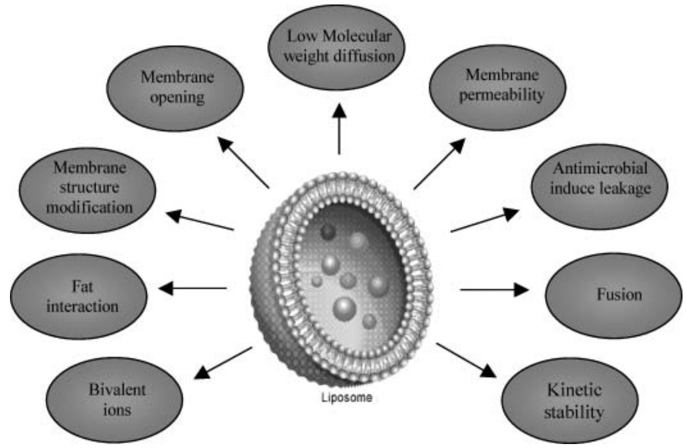

Figure 3 Illustration of active agent release from liposome.

in destabilization of the liposomal membrane and subsequent release of active compounds (9) bivalent ions Ca^{++}/ Mg^{++} induce destability of the liposome especially in the products containing higher bivalent ions concentrations like whey (Laridi et al., 2003; Benech et al., 2002a; Taylor et al., 2005; Were et al., 2003).

Concerning the food industry, the "microencapsulation cost" and the "delivery form of liposome encapsulated components" are key setbacks. The cost issue is most likely resolved by the performance of microfluidization as being cost-effective, having a high encapsulation efficiency, is solvent free, and is a continuous fabrication technique which produces few hundred liters of aqueous liposomes per hour (Maa and Hsu, 1999; Zheng et al., 1999). In our opinion the other issue of delivery, storage, and shipping are quiet non-vital from the food packaging point of view as nano-capsules are incorporated in active coatings of food and delivery conditions and the cost is not supplementary.

The field of nanoencapsulation and release is very promising in terms of potential applications and presents a platform for many applications in food technology, medicine, pharmacy, biotechnology, cosmetics, or detergency (Sukhorukov et al., 2005). Cost considerations in the food industry are much more inflexible than they are for instance in the pharmaceutical or cosmetic industries. The selection of the nanoencapsulation method and coating materials are interdependent. Coating materials can be selected from a wide variety of natural or synthetic polymers, conditional on the material to be coated and features desired in the final nanocapsules. Gouin has roughly estimated a maximum cost for a microencapsulation process in the food industry at 0.1 €/kg considering that the functional ingredients are of minor utilization in foodstuffs (1–5%). Generally the customer will accept a price increase of 0.1 € per portion for a new food product (Gouin, 2004).

In our opinion, for antimicrobial encapsulation, multilamellar vesicles (MLV) liposomes are suitable due to their low cost (little energy input required), good entrapment efficiency, and maximum storage stability, while for large-scale production high pressure homogenization-microfluidization is considered best because it is fast, efficient, cost-effective, and without organic solvent compulsion. Higher stability, efficient activity of the encapsulated antimicrobial (higher log reduction), controlled release under different physicochemical conditions (% moisture, pH, fat, protein), optimum encapsulation efficiency, long-lasting post-processing protection, natural source and nutritious characteristics, and no regulatory issues are some of the key points which have grabbed the attention of food scientists around the globe and hence there is an emphasis on utilizing liposomes for nano-scale active food packaging.

The amount of material (expensive bioactive agents) required to put forth a specific effect when encapsulated is much less due to improved stability and targeting than the amount required when unencapsulated. A well-timed and targeted release improves the effectiveness of active agents, broadens the application range of food ingredients, and ensures optimal dosage, thereby improving the cost-effectiveness of the product.

SOCIAL, ETHICAL, REGULATORY AND TOXICOLOGICAL ISSUES DEALING WITH NANOTECHNOLOGY

Successful introduction of a new technology requires careful attention to the interactions between the technology and society. These interactions are bi-directional. On the one hand, technology changes and challenges social patterns and, on the other hand, the governance structures and values of the society affect progress in developing the technology (Keller, 2007). Certain scepticism exists in our society between technophiles and technophobes.

Nanotechnology application may raise new challenges in the safety, regulatory, or ethical domains that will require societal debate thus resulting in a sustainable technology which has public acceptance (Helland et al., 2008). General or overview references are provided that will serve as a guide to the literature and indications of the contributions in the field.

Social Issues

All potential applications of nanotechnology significantly affect our lives, our health, our convenience, and our environment; therefore, they tend to trigger major concerns from the public. Unless the concerns related to ethics and social impacts are thoroughly addressed, the progress of nanotechnology could be severely hampered (Sheetz et al., 2005).

Nanotechnology is seen as a transformative technology, which has the potential to stimulate scientific innovation while greatly benefiting society. However, the enthusiasm with which the scientific and technical communities are embracing the technology is being tempered by concerns over possible downsides, including risks to human health (Maynard, 2006). Assuming nanotechnology is a “giga-ideology,” a fine review collects the clear standpoints of different members of society (Munshi et al., 2007).

Results of Survey

Even more than scientists and governments, the general public will have the power to shape the direction of nanotechnology development. To avoid a backlash similar to the one created by publicity about genetically modified crops, the nanotechnology community must address and inform the general public; their trust and acceptance must be earned (Sheetz et al., 2005).

A survey conducted at the University of Texas (Fig. 4), including 978 students and staff from non-scientific fields reports that only 17% know what nanotechnology is, while 45% had only heard about nanotechnology, which is larger than the 29% identified by the Royal Society in 2004 (Sheetz et al., 2005).

The results from the study of 1,800 persons in an online survey experiment were released in March 2007 by the Cultural Cognition Project in America. The survey found that over 80% of U.S. respondents had heard “little” or “nothing at all” about

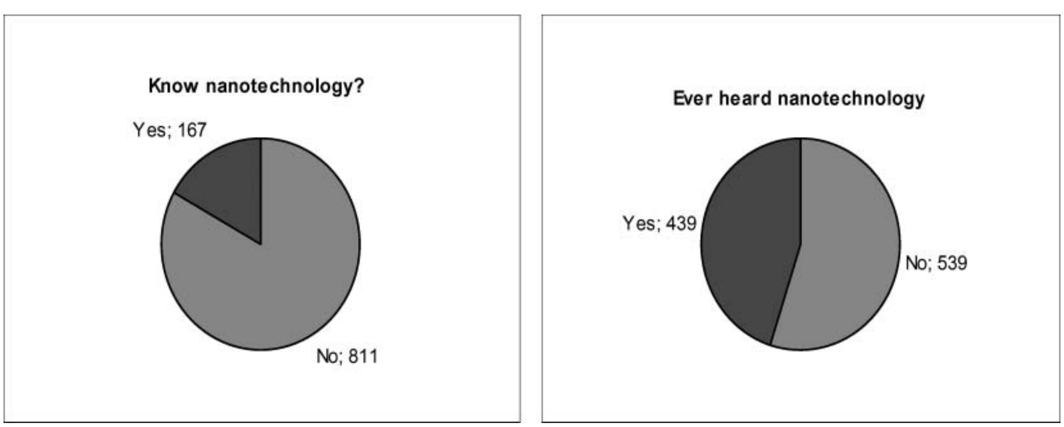

Figure 4 Survey results of nanotechnology knowledge in public (Data from Sheetz et al., 2005).

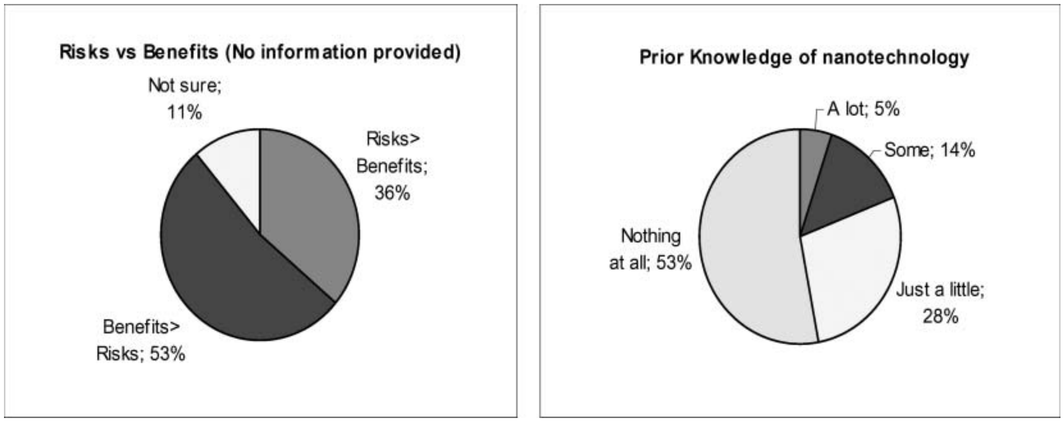

Figure 5 Public opinion of risk vs. benefits of nanotechnology (Data from Kahan et al., 2007).

nanotechnology. Nevertheless, the vast majority of subjects—more than 90%—held an opinion about whether nanotechnology's benefits would outweigh its risks, even when supplied with no additional information (Kahan et al., 2007). A full 81% of the subjects reported having heard either "nothing at all" (53%) or "just a little" (28%) about nanotechnology prior to being surveyed. Only 5% reported having heard "a lot" (Fig. 5).

The perceptions of lay people ($N = 375$) and experts ($N = 46$) in 20 different nanotechnology applications were examined in Germany. The probable dreadfulness of applications and trust in governmental agencies are important factors in determining perceived risks. Lay people perceived greater risks than experts which would diminish if measures were taken to enhance their trust in governmental agencies (Siegrest et al., 2007). One can foresee that the public perception of nanotechnology will be crucial for the realization of technological advances (Roco, 2003).

A survey of American nanotechnology researchers (N = 177) suggests that a wide range of nanotechnologies will likely prove important in the years ahead in a range of areas. Health and technological benefits were identified as more important than environmental benefits and seem to have priority for the need for regulation (Besley et al., 2007).

Perception of Nanotechnology

As always with pioneering science, the pace of social understanding lags behind technological progress (Table 4). The ambiguity of the term nanotechnology is one major problem for policy makers. In recent years the prefix "nano" has come to be associated with almost anything new, small, molecular, atomic, trendy, ominous, or eye-catching. This overhype in order to sell food and entertainment has elicited unreasoned fear in the general public. Food nanotechnology implications are massive and the scientific community should not adopt the policy of wait-and-see. The greater the awareness and understanding of food nanotechnology, the more informed and productive will the decisions be forthcoming from social discussions.

Americans are more optimistic about nanotechnology than Europeans, with almost half of them saying that such technologies will improve the quality of life. Just a quarter of Europeans reported such optimism. Whereas only a quarter of Americans said they did not know anything about the likely impact of nanotechnology, half of the Europeans gave this response (Gaskell et al., 2005). Americans are positive regarding potential health benefits topping the list of key benefits, with invasion of privacy and military uses emerging as key concerns. Many respondents, unsurprisingly, have low trust in business leaders to appropriately manage the technology (MacOubrie, 2006).

The attitude towards actual products has not been studied; instead surveys have been conducted to realize perceptions towards nanotechnology (Sheetz et al., 2005; Besley et al., 2007; Gaskell et al., 2005; MacOubrie, 2006). In the years to come the type of food product/application will influence public perception towards food nanotechnology.

Scientists, futurists, and ethicists agree that nanotechnology has the potential to profoundly shape the human body and the physical and social environments in which humans live because of the extraordinary number of devices, processes, and applications that can be created with this transformative technology (Nickols-Richardson, 2007).

Consumer Education

As with any emerging technology, the full consequences of invasive incorporation into society are currently unknown (Nickols-Richardson, 2007). Policies that acknowledge new risks that may arise from the exploitation of nanotechnology should be designed in order to enjoy benefits. Otherwise, the danger remains that we might stay locked in a "blind spot" where we do not see that we do not see.

Portraying nanotechnology positively by using mass media will be a promising idea as first impression lasts forever. One cannot leave public education in the grip of science fiction movie writers, whose presentation of nanotechnology is misleading. Effective education measures can be taken to spread information. The National Science Foundation has created the "Nano-kid" project for this purpose (Royal Society and Royal Academy of Engineering, 2004). The production of scientists

Table 4 Social and ethical nanoscience and nanotechnology concerns

Nanotech Concern	Strengths	Weaknesses
Nano-divide	If the public in poor countries is well-informed, NT will narrow this divide	NT as every technology is likely to add to this divide between rich and poor
Privacy, safety and security	NT is an economic engine that can redefine the well being nations	If near-invisible devices become available, How one's privacy is protected?
Multi / inter-discipline	NT is capable of enhancing personal safety and security	Who will control access?
	Ubiquitous computing	
Regulation	Combined research from sociologists, scientists, and engineers required	Complex applications realization of NT need coordination & open exchange
Medical concerns	Issues of NT regulation are just beginning to receive attention	Who will regulate it? The question remains open. (Scientists, industry etc.)
		The (existing) gap in healthcare will grow rapidly between rich & poor
Environment issue	Precisely controlled or programmable medical nano-machines and –robots	At what point do we become more machine than human?
Self replication	Drug delivery, cancer treatment, medical imaging, tissue reconstruction. . .	
Media hype	Nanoparticle shell chemotherapy is literally "magic bullet"	Nanoshells for drug delivery may accumulate and cause damage
Economy	Possibility of technological products without dangerous by-products	Nanomaterials (smaller more toxic) may cause tissue and organ damage
Trial-and-error	Mimicking nature	"Grey goo theory," "evil villain"
Work force issues	Movies and television shows are useful to inform public about NT	Mostly the portrayal is inaccurate and is associated with villain not hero e.g. Prey, Xmen, Spiderman, Matrix, Nanobreaker game
Political issues	Enhance production and storage of energy and agricultural products	Destruction of old methods of production and human resource
Intellectual property	Efficient materials and devices with higher strength-to-weight ratios	Difficult to predict the outcomes of experiment for new nanostructures
Human enhancement	Best results in today's practical nanoscience come from this approach	Educated workforce provision from deprived regions
	Training programmes for technicians, undergraduate and master level	Can local politics, ideology and local industries best shape these decisions
	All students study social and ethical issues	Maintain technological leadership
	Share technological development obligation	Rules vary across nations; can they function in nano-oriented economy?
	Laws, regulation and treaties offer protection by patents	Only God should perform such modifications (controversial positive?)
	Enhance the physical and mental capabilities	

Data source: (Lewenstein, 2005; Romig Jr et al., 2007; Sheetz et al., 2005; Uskokovic, 2007).

and engineers who specialize in nanotechnology must increase to meet the demands of the growing industry. Teaching children about nanotechnology is also a great tool to indirectly inform the general public as well (Sheetz et al., 2005).

One of the major concerns in this new field is the development of the necessary manpower. The number of training centers is very low, and greater commitment from the government is needed. Whatever the future, we must ensure that the benefits of nanotechnology research reach all of mankind.

Government Policy and Role

The United States of America has invested billions of dollars in nanotechnology (nearly $3.7 billion for 2005–2008 in the US). Europe has in the meantime an enormously large nanotechnology program (one billion euros, while for the UK alone $45 million per year had been allocated until 2009), billions of Euros worth nanotechnology centers are mushrooming everywhere (Royal Society and Royal Academy of Engineering, 2004). India and The People's Republic of China are investing generously in nanotechnology. The history of technology in general is a history of competition even between friendly neighbors (El Naschie, 2006). These are small investments compared with the $1 trillion return in market shares expected from applications of nanotechnology in the next 6–7 years. On the other hand, it has been extrapolated that nanotechnologies have the potential to create seven million jobs in the global market by 2015 (Roco, 2003). The nanotech areas of greatest scientific uncertainty, such as the toxicology of nanoparticles, should not be exempted from funding (Royal Society and Royal Academy of Engineering, 2004).

Ethical Issues

As a rule, the more prosperous a technology appears to be the more unpredictable the consequences and potential dangers it may entail. Therefore, both sides of a new technology, that is, its beneficial development and the possible negative consequences, should be investigated in parallel (Table 4). Therefore, the tendency of mainstream science to quickly sell nanotech to the financial community, and to collect money from proposed ideas should be undertaken with extreme care and deliberation (Royal Society and Royal Academy of Engineering, 2004).

Uskokovic has excellently narrated the benefits and risks of nano-biomedicine treatments helping in a variety of useful ways—hyperthermia treatment; drug delivery and targeting; magnetic separation, protein detection, and purification; magnetic field-assisted radionuclide therapy; magneto-relaxometrical diagnostics and eye surgery; the detection of intracellular molecular interactions, with the possibility of developing gene and/or cellular metabolic therapy. Concerns about the possible adverse health effects of nanoparticles include the relative persistence (several months) of nanoparticles in lung tissue; their potential to pass the blood–brain barrier to reach brain tissues and induce damage; and their absorption through the skin into the bloodstream via uptake into lymphatic channels (Uskokovic, 2007). But nanoparticles are ubiquitous in ambient and indoor air; in fact they have been present in the environment since the earliest stages of evolution.

Ethics needs to keep pace with science in order to avoid negative coordination because certain issues are conflicting with religion like trans-humanism (Mnyusiwalla et al., 2003). The ethical debate began with fundamental worries about the place of human beings in the world (playing God, etc.). Indeed, the motto or the hidden agenda of nanotechnology is, "nature does it, why can't we do it"? How can the body be distinguished from a technique which obtains its potential effectiveness exactly from the ability to imitate natural mechanisms and natural functions (Lenk and Biller-Andorno, 2007).

Despite the potential impact of nanotechnology, there is a paucity of published research on its ethical, legal, and social implications. As the science leaps ahead, the ethics lags behind. There is danger of derailing nanotechnology if the study of ethical, legal, and social implications does not catch up with the speed of scientific development (Mnyusiwalla et al., 2003).

Regulatory Issues

One of the ways of gaining the public's confidence is a rigorous regulatory system that assures the safety and efficacy of a new technology. Given the limitations of existing regulatory tools and policies, three distinct initiatives are needed—first, a major increase in nanomaterial risk research; second, rapid development and implementation of voluntary standards of care; and third, development of adequate regulatory policies on risk management (Walsh et al., 2008).

Up to now, there is no international regulation on food nanotechnology or nano-products. Only a few government agencies or organizations from different countries have established standards and regulations to define and regulate the use of nanotechnology. The reader needs to consult the first review published in this field of food nanotechnology regulation (Chau et al., 2007).

FDA states that it regulates "products, not technologies." FDA experts believe that food nanotechnology products present challenges similar to those FDA faces for products of other emerging technologies. FDA experts recognize, however, that product safety and effectiveness can change as the size goes up or down within the nanoscale, adding additional complexity to the product review. The agency expects that many of the nanotechnology products it will regulate will span the regulatory boundaries between drugs, medical devices, and biologics. These, then, would be regulated under the rules established for "combination products" (FDA, 2008). FDA states that particle size is not the issue. If new toxicological risks that are derived from new materials or manufacturing techniques are identified, new safety tests will then be required.

The British Government commissioned the Royal Society and the Royal Academy of Engineers to undertake an independent study about nanotechnologies which was a requirement for public confidence in their safety. The report focused only on the potential health risks from exposure to free engineered nanomaterials (Royal Society and Royal Academy of Engineering, 2004). There are almost no eco-toxicological (including marine) studies with engineered nanomaterials. One of the only studies conducted with aquatic species (fish) suggests that oxidative stress may be a potential mechanism of toxicity associated with free engineered nanoparticles (Oberdorster, 2004). There is a clear need to optimize or develop a range of generic standard test procedures that can be applied to a range of nanomaterials to assess their relative toxicities. Each type of the nanoparticles may need to be assessed one by one because toxicological effects may possess similarities, the exact nature and magnitude of that toxicity may be substance specific, and indeed may vary with size (Owen and Depledge, 2005).

Another excellent review by Nel et al. (2006) concludes that although it is possible that nanoparticles may create toxic effects, there are currently no conclusive data or scenarios that indicate that these effects will become a major problem or that they cannot be addressed by a rational scientific approach. But one should evaluate the safety of nanomaterials and follow a proactive approach to address regulatory issues.

Particle size alone is not a good criterion for differentiating between more or less hazardous materials and technologies but the thing that matters is material structure (Maynard, 2006). As the famous proverb "all things are poison and not without poison; only the dose makes a thing not a poison." The present day regulatory programmes are ineffective because (i) nanomaterials will be far more potent at envisioned low concentrations due to high surface area-to-mass ratio (ii) too little is known to predict nanoproduct toxicity (iii) the nanoproducts are already in the market so the regulatory process lags far behind (Walsh et al., 2008). Voluntary standards are only a temporary expedient; regulatory programs are essential to secure public confidence and support for nanotechnology.

Toxicological Issues

Nanotechnologies cover many aspects, such as disease treatment, food security, new materials for pathogen detection, packaging materials, and delivery systems. As with most new and evolving technologies, potential benefits are emphasized, while little is known about the safety of the application of nanotechnologies in the agro-food sector (Bouwmeester et al., 2009). The concern over the probable adverse effects of nanomaterials on living systems has given rise to “nanotoxicology.” However, nanotoxicology has lagged far behind nanotechnology due to a number of experimental challenges and issues faced in designing studies involving toxicological assessment of nanomaterials. The high speed of introduction of nanoparticles-based consumer products observed nowadays urges the need to generate a better understanding about the potential negative impacts that nanoparticles may have on biological systems (Dhawan et al., 2009).

The technology of nanoparticles in the near future involves the incorporation of nano–active agents into packaging materials to increase the barrier properties of packaging materials (e.g., silicate nanoparticles, nanocomposites, and nano-silver, magnesium- and zinc-oxide). When the nanoparticles are applied into the food packaging materials, direct contact with food is only possible following the migration of the nanoparticles. The migration of metals from biodegradable starch/clay nanocomposite films used in packaging materials for its gas barrier properties to vegetable samples, was shown to be minimal (Avella et al., 2005), but more studies are needed to reach a conclusive statement.

It is likely to assume that the use of active packaging releasing nanoparticles with antimicrobial functions into the food (e.g., nano-silver and in rarer cases zinc-oxide nanoparticles), will lead to direct consumer exposure to metals. Hence, this necessitates the need for information on the effects of these nanoparticles to human health. Furthermore, attention should be paid to life-cycle analysis and effects on the environment (Bouwmeester et al., 2009). The EU’s approach to nanotechnology is “safe, integrated, and responsible.” To that end the EU had demanded its scientific committees and commission services to perform a scientific and legislative review on the suitability of the existing regulation for nanotechnologies. From a number of regulatory reports it became clear that there is currently no nano-specific regulation in the EU. The FDA has no nanotechnology specific regulations, as mentioned before; it regulates “products, not technologies” (Chaudhry et al., 2007).

Human beings are already exposed to a range of natural and man-made nanoparticles in the air, and exposure via the food chain, water supply, and medical applications is likely. Toxicology studies on animals, and cells in vitro, raise the possibility of adverse effects on the immune system, oxidative stress related disorders, lung disease, and inflammation. However, the doses needed to produce these effects are generally high and it remains to be seen if such exposure is possible via the environment or the work place. Data on exposure is also needed for risk calculations (Handy et al., 2007).

Due to lack of methods for the detection of natural/engineered nanoparticles in food matrices, special attention is required for the assessment of nanoscale delivery systems loaded with bioactive compounds. For nanoscale delivery systems, both the amount of bioactive compounds within the capsules as well as the free form in the food matrix has to be determined, because these factors determine the bioavailability and risk associated with it (Bouwmeester et al., 2009).

Optimistic Approach

While the science of nanomaterials and human health impact is maturing, it is still at a stage of raising many more questions than answers. The realization of benefits of nanotechnology should not be hindered by misplaced perceptions of risk to the environment and human health based on poor or no information. Works should not be directed towards erasing the unknown by premature generalizations, but instead towards carefully walking the endless line where the coasts of the known and the sea of the unknown meet. At present, much of nanotechnology constitutes no foreseeable risk to human beings or to the ecosystem (Seaton et al., 2005).

The obvious benefits not only balanced risk against need, but also probably shift public perception of risk. In France and Japan where 80% and 30% electricity is generated respectively from nuclear power, consequently has wider public acceptance than that in the U.S. in spite of the release of activity and waste disposal problems (Keller, 2007).

“How safe is food nanotechnology?” Such a general and unbound question is unlikely to yield useful information on the safety of specific nanotechnologies without further contextual information. Rather, appropriate contexts need to be defined and boundary conditions set if information on the safety of specific nanotechnologies is to be developed (Maynard, 2006). Waiting to address controversial issues until the development is complete may be too late to pacify public concerns.

Food nanotechnology may not be any different than any other area of emerging science and technology. Furthermore, it appears that according to the established methods of quantifying risk in the insurance and risk assessment communities, the fabrication of nanomaterials may present lower risks than those of current activities such as petroleum refining, polyethylene production, and synthetic pharmaceutical production (Robichaud et al., 2005). Studies support the hypothesis that nano-inside (e.g., foods) is perceived as less acceptable than nano-outside (e.g., packaging). Both opponents and proponents of food nanotechnology agree that further research is warranted.

EMERGING CONCEPT OF NANOTECHNOLOGY BLEND WITH 3-BIOS

The next technological revolution in the pasture of food science and nutrition would be 3-BIOS blend with nanotechnology; which refers to Bioactive, Biodegradable, and Bionanocomposite. It is likely to be the smartest development yet to be seen in modern food packaging innovations.

The innovative strength of bioactive packaging lies in the fact that it has a direct impact on the health of the consumer by creating healthier packaged foods. One may conclude, as discussed by Lopez-Rubio et al. (2006) that micro- and nano-encapsulation of the active substances either in packaging and/or within food will make available alternative, more efficient and, in some cases, unique merits to offer food with an improved impact on human health. As the interaction of active compounds with food ingredients influence their efficiency (Devlieghere et al., 2004) nano-encapsulation protection seems one far-reaching solution in food bio-preservation (Teixeira et al., 2008).

Within the scope of natural food preservation for post-production contamination, the application of antimicrobial peptides from lactic acid bacteria (LAB) in bioactive packaging films has received great attention (Cleveland et al., 2001). Despite the broader spectrum of nisin and maintaining its minimum inhibitory concentration (MIC) regarding the probable contaminating pathogens, there is a rising concern about the survival of microorganisms through resistance/immunity resistant against nisin (Naghmouchi et al., 2007). To summarize, there is an immense need for the research of innovative bacteriocins (Rodriguez et al., 2005) and their approval as generally recognized as safe (GRAS) by food regulatory authorities. Thus an ideal and more effective system can be developed for a wide-ranging solution of foodborne illness.

Currently, there is an escalating tendency to employ environmentally-friendly materials with the intention of substituting non-degradable materials, thus reducing the environmental pollution resulting from waste accumulation. To address environmental issues, and concurrently extend the shelf life and food quality, reducing packaging waste has catalyzed the exploration of new bio-based packaging materials such as edible and biodegradable films (Burke, 2006; Tharanathan, 2003). One of the approaches is to use renewable biopolymers such as proteins, polysaccharides, and lipids and their complexes, derived from animals and plants (Ray and Bousmina, 2005). Previous studies show that greater emphasis has been given on safety features associated with biopolymer based antimicrobial packaging (Cha and Chinnan, 2004). Cellulose-based materials are being widely used while animal origin proteins are also increasingly employed. Such biodegradable/edible packaging not only ensures food safety but at the same time is also a good source of nutrition (Khwaldia et al., 2004) but when otherwise used as a food ingredient, neither affects the organoleptic properties of food nor has any regulatory issues (Burdock, 2007).

Unfortunately, as affirmed by Sorrentino et al. (2007) until now the use of biodegradable films for food packaging has been strongly limited on account of the poor barrier and weak mechanical characteristics. To sort out these drawbacks, the application of bio-nanocomposites has emerged as recent technological advancement to reduce the packaging waste and improve the preservation time (Darder et al., 2007; Rhim and Ng, 2007). Nanotechnology carries potential applications in the development of natural biopolymer-based biodegradable packaging material with additional bioactive functions.

Current trends suggest that the next generation of biodegradable/edible and/or bioactive packaging is expected to exploit the substantial possibilities existing for bio-nanocomposite to produce novel packages with superior mechanical, barrier, and thermal performance. The potential benefits of edible films or coatings as carriers of active agents justify continued research in the field of active packaging. Technical challenges exist in incorporating appropriate antimicrobial agents into packaging systems.

CONCLUDING REMARKS AND 21ST CENTURY SHOW

To believe that every technology is dangerous is one thing but to not believe in technology can be very hazardous. The scientific breakthroughs of information technology, the discovery of DNA, nuclear technology, and molecular biology have changed the world we live in. Here in the first decade of the 21st century we now stand on the brink of another scientific innovation—nanotechnology.

In our opinion, owing to nanotechnology application in the food system and especially to active packaging, the probabilities of enhancing food quality, safety, stability, and efficiency as an innovative active packaging are just touching pores of our fingers and in the near future it might be under our grip. As a consequence of nano-active-packaging, a far less amount of material would be required to exert a specific effect which is particularly useful when dealing with expensive bioactive agents. A timely and targeted release may improve the effectiveness of micronutrients, broaden the application range of food ingredients, and ensure optimal dosage, thereby improving the cost-effectiveness of the product.

Nanoencapsulation processes that have been developed for pharmaceutical and chemical applications could easily be adopted in the food industry by substituting food grade coating material for the encapsulation of food ingredients. Future research is expected to focus on aspects of delivery and the prospective use of co-encapsulation concept at nano-scale, where two or more bioactive ingredients can be combined to give a synergistic effect. Migration or diffusion kinetics of the active agents towards the food system will be the prime challenge in the future for food science researchers. The authoritarian permission of novel active compounds and integration of 3-BIOS concept blended with nanotechnology may open the doors to the world of germ-free healthy foods.

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