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Review on - Nanotechnology Applications in Food Packaging and Safety

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Abstract:*Nanotechnology, the science of very small materials, is poised to have a big impact in food production and packaging.Public perception will be crucial to the realization of these technological advances. Today, nanotech R&D of food packaging and the monitoring of nanotech food packaging is a major focus in the food industry. Due to very large aspect ratios, a relatively low level of nanoparticle is sufficient to change the properties of packaging materials without significant changes in density, transparency and processing characteristics. New packaging solutions will focus more on food safety by controlling microbial growth, delaying oxidation, improving tamper visibility, and convenience. The rapid use of nano-based packaging in a wide range of consumer products has also raised a number of safety, environmental, ethical, policy and regulatory issues. Nanotechnologies are expected to play a major role, taking into account all additional safety considerations and filling present packaging needs. This review also provides the most complete accounting of nano-enabled packaging for food products in various markets around the globe.***

Keywords: Nanotechnology, Food Technology, Food Safety, Pathogens, Nanoparticles, Packaging, Convenience, Regulatory Issues.

Introduction:

In today's competitive market new frontier technology is essential to keep leadership in the food and food processing industry. Consumers demand fresh, authentic, convenient and flavorful food products. The future belongs to new products and new processes, with the goal of enhancing the performance of the product, prolonging the shelf life, freshness, improving the safety and quality of food product.At one billionth of a meter, a nanometer is miniscule - much too small for the human eye to see. And for most humans, anything measuring 100 nm or less may be impossible to comprehend as significant. For this reason, it would seem illogical that structures measuring 1 - 100 nm would not only exist but would also have implications and applications that could be essential to humankind (Ravichandran 2009).

Research in the nanotechnology field has skyrocketed over the last decade, and already there are numerous companies specializing in the fabrication of new forms of nanosized matter, with anticipated applications that include medical therapeutics and diagnostics, energy production, molecular computing and structural materials. In 2008, nanotechnology demanded over $15 billion in worldwide research and development money (public and private) and employed over 400,000 researchers across the globe (Roco*et al.*, 2010).

Nanotechnologies are projected to impact at least $3 trillion across the global economy by 2020, and nanotechnology industries worldwide may require at least 6 million workers tosupport them by the end of the decade (Roco*et al.*, 2010).The use of protective coatings and suitable packaging by the food industry has become a topic of great interest because of their potentiality for increasing the shelf life of many food products (Ahvenainen, 2003; Coles *et al.*, 2003; Hernandez *et al*., 2000). By means of the correct selection of materials and packaging technologies, it is possible to keep the product quality and freshness during the time required for its commercialization and consumption (Brown, 1992; Stewart *et al.*, 2002). A big effort to extend the shelf life and enhance food quality while reducing packaging waste has encouraged the exploration of new bio-based packaging materials, such as edible and biodegradable films from renewable resources (Tharanathan, 2003). Nowadays, the largest part of materials used in packaging industries is produced from fossil fuels and are practically un-degradable. For this, packaging materials for foodstuff, like any other short-term storage packaging material, represent a serious global environmental problem (Kirwan and Strawbridge, 2003). Unfortunately, so far the use of biodegradable films for food packaging has been strongly limited because of the poor barrier properties and weak mechanical properties shown by natural polymers. However, like conventional packaging, bio-based packaging must serve a number of important functions, including containment and protection of food, maintaining its sensory quality and safety, and communicating information to consumers (Robertson, 1993). The application of nanocomposites promises to expand the use of edible and biodegradable films (Lagaron*et al.*, 2005; Sinha Ray andBousmina, 2005). It will help to reduce the packaging waste associated with processed foods and will support the preservation of fresh foods, extending their shelf life (Labuza andBreene, 1988; Vermeiren*et al.*, 1999).

Nanotechnology has the potential to improve food quality and safety significantly. Currently a lot of work is being carried out on nanosensors targeting improved pathogen detection in food systems. Many electronic companies have been investigating electrically conducting polymers. These same materials can also be used to manufacture sensors that can detect very low levels of molecular signals of spoilage and foodborne pathogens within minutes of exposure. According to the researchers involved in the project, this device can detect parts per trillion and costs about 50 cents to produce. It is also expected that the tongue technology could potentially be incorporated into food packages, such as meat wrappings, and would change color when the meat starting to spoil. According to nutraingredients.com, scientists at the University of Bonn in Germany are working on nanoscale level dirt-repellent coatings. Nanotechnology enables designers to alter the structure of packaging materials at the molecular level. For example, plastics can be manufactured with different nanostructures to gain various gas and moisture permeabilities to fit the requirements of specific products such as fruits, vegetables, beverage and wine. As a result, shelf-life and flavor and color preservation of the products can be improved. Nanostructured films and packaging materials can prevent the invasion of pathogens and other microorganisms and ensure food safety. Nanosensors embedded in food packages will allow the determination of whether food has gone bad or show its nutrient content. By adding certain nanoparticles into packaging material and bottles, food packages can be made more light- and fire-resistant, with stronger mechanical and thermal performance and controlled gas absorption.However, achievements and discoveries in nanotechnology are beginning to impact the food industry and associated industries; this affects important aspects from food safety to the molecular synthesis of new food products and ingredients (Chen *et al.*, 2006).

Nevertheless, scientists and industry stakeholders have already identified potential uses of nanotechnology in virtually every segment of the food industry (Fig. 1), from agriculture (e.g., pesticide, fertilizer or vaccine delivery; animal and plant pathogen detection; and targeted genetic engineering) to food processing (e.g., encapsulation of flavor or odor enhancers; food textural or quality improvement; new gelation or viscosifying agents) to food packaging (e.g., pathogen, gas or abuse sensors; anticounterfeiting devices, UV-protection, and stronger, more impermeable polymer films) to nutrient supplements (e.g., nutraceuticals with higher stability and bioavailability). Undeniably, the most active area of food nanoscience research and development is packaging: the global nano-enabled food and beverage packaging market was 4.13 billion US dollars in 2008 and has been projected to grow to 7.3 billion by 2014, representing an annual growth rate of 11.65% (Innovative Research and studies 2009). This is likely connected to the fact that the public has been shown in some studies to be more willing to embrace nanotechnology in ‘‘out of food’’ applications than those where nanoparticles are directly added to foods (Market attitude Research 2009; Siegrist 2007 and Siegrist 2008).

Nanotechnology is quickly moving fromthe laboratory onto supermarket shelves and our kitchen tables and has the potential to revolutionize food systems (Scirinis and Lyons 2007).Further, worldwide commercial foods and food supplementscontaining added nanoparticles are becoming available. Nanotechnology promises big benefits for food safety, quality, and shelf life, provided the challenges it brings can be overcome (Stones 2009). This review critically discusses use of nanotechnology in various for packaging systems and Safety.

Nanotechnology in the food industry

The term "nanofood" describes the food which has been cultivated, produced, processed or packaged using nanotechnology techniques or tools, or to which manufactured nanomaterials have been added (Morris, 2007). Food security, disease treatment delivery methods, new tools for molecular and cellular biology, new materials for pathogen detection, and protection of the environment are examples of the important links of nanotechnology to the science and engineering of agriculture and food systems. Examples of nanotechnology as a tool for achieving further advancements in the food industry are as follows:

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

Food technology is regarded as one of the industry sectors where nanotechnology will play an important role in the future (ASEAN Conference 2009). It is commonly distinguished between two forms of nanofood applications: food additives (nano inside) and food packaging (nano outside). Nanoscale food additives may for example be used to influence product shelf life, texture, flavor, nutrient composition, or even detect food pathogens and provide functions as food quality indicators. In the context of food packaging, nanotechnologies are mainly considered to be of use to increase product shelf life, indicate spoilt ingredients, or generally increase product quality, e.g., by preventing gas flow across product packaging (Nickols and Piehowski 2008).

Packaging

One aim of innovative packaging solutions is the reduction of spoilage. Production, processing, and shipment of food products could be made more secure through the use of nanosensors for pathogen and contaminant detection. Silver, a well-known anti-microbial agent, is being infused into storage containers to retard bacterial growth and allow for longer storage of foods. In a case study, the 24-hour growth of bacteria was reduced by over 98 percent because of the silver nanoparticles (Woodrow Wilson International Center for Scholars, 2006d). Nanomaterials are being developed with enhanced mechanical and thermal properties to ensure better protection of foods from exterior mechanical, thermal, chemical, or microbiological effects. Nanocomposites, for instance, are nanoparticles bonded in polymers so that the materials have enhanced properties such a lighter weight and better recyclability, as well as spoilage and flavor issues. Nanocomposite materials are currently being used in beer bottles; allowing for a 6-month shelf life (A to Z of Nanotechnology, 2006).

Biobased Packaging

Biodegradable plastics are polymeric materials in which at least one step in the degradation process is through metabolism in the presence of naturally occurring organisms. Under appropriate conditions of moisture, temperature and oxygen availability, biodegradation leads to fragmentation or disintegration of the plastics with no toxic or environmentally harmful residue (Chandra andRustgi, 1998).

Biodegradable polymers can be classified according to their source:

- Polymers directly extracted or removed from biomass (i.e. polysaccharides, proteins, polypeptides, polynucleotides).
- Polymers produced by classical chemical synthesis using renewable bio-based monomers or mixed sources of biomass and petroleum (i.e. polylactic acid or bio-polyester)
- Polymers produced by micro-organism or genetically modified bacteria (polyhydroxybutyrate, bacterial cellulose, xanthan, curdian, pullan).

Recently, several research groups started the preparation and characterization of various kinds of biodegradable polymer nanocomposites showing properties suitable for a wide range of applications (SinhaRay andBousmina, 2005). So far, the most studied biodegradable nanocomposites suitable for packaging applications are starch and derivates, polylactic acid (PLA), poly(butylene succinate) (PBS), polyhydroxybutyrate (PHB), and aliphatic polyester as PCL.

- ***Starch and their derivates:***

Starch is a promising raw material because of its cyclic availability from many plants and excessive production with regard to current needs and its low cost (Gonera and Cornillon, 2002; Smits *et al*., 1998). As a packaging material, starch alone does not form films with appropriate mechanical properties unless it is first plasticized, or chemically modified. When starch is treated in an extruder by application of both thermal and mechanical energy, it is converted to a thermoplastic material. In the production of thermoplastic starches, plasticizers are expected to efficiently reduce intra-molecular hydrogen bonds and to provide stability to product properties. There are many opportunities for using starch as packaging material (Kim and Pometto, 1994).

- ***Polylactic acid (PLA):***

The use of conventional chemical synthesis for the production of polymers gives a wide spectrum of possible biopolyesters. To date, PLA is the polymer with the highest potential for a commercial major scale production of renewable packaging materials. Lactic acid, the monomer of PLA, may easily be produced by fermentation of carbohydrate feedstock. The carbohydrate feedstock may be agricultural products such as maize, wheat, molasses, and whey.

- ***Polyhydroxybutyrate (PHB):***

PHB is accumulated by a large number of bacteria as energy and carbon reserves. Due to its biodegradability and biocompatibility this biopolyester may easily find industrial applications (Van der Walle*et al.*, 2000). Potentially, PLA and PHB offer numerous opportunities in packaging applications. In addition, they are compatible with many foods, such as dairy products, beverage, fresh meat products and ready meals.

- ***Polycaprolactone (PLC):***

PCL is also interesting for applications in the medical and agricultural areas (Nakayama *et al.,* 1997). PCL exhibits high elongation at break and low modulus. Its physical properties and commercial availability make it very attractive as a material for commodity applications.

Food Packaging

Food packaging is considered to be one of the earliest commercial applications of nanotechnology in the food sector. Reynolds (2007) reported that about 400-500 nano-packaging products are estimated to be in commercial use, while nanotechnology is predicted to be used in the manufacture of 25% of all food packaging within the next decade.Nano-packaging can also be designed to release antimicrobials, antioxidants, enzymes, flavours and nutraceuticals to extend shelf life (Cha and Chinnan, 2004). El Amin (2005) reported that exciting new nanotechnology products for food packaging are in the pipeline and some anti-microbial films, have already entered the market to improve the shelf life of food and dairy products.

Novel food packaging technology is by far the most promising benefit of nanotechnology in the food industry in the near future. Companies are already producing packaging materials based on nanotechnology that are extending the life of food and drinks and improving food safety. Food packaging and monitoring are amajor focus of food industry–related nanotechologyresearch and development (R&D) (Broody 2003).Leading the way is active or 'smart' packaging that promises to improve food safety and quality and optimizes product shelf life. Numerous companies and universities are developing packaging that would be able to alert if the packaged food becomes contaminated, respond to a change in environmental conditions, and self-repair holes and tears.

Worldwide sales of nanotechnology products to the food and beverage packaging sector increased fromUS$150 million in 2002 to US$860 million in 2004 and are expected to reach to US$20.4 billion by 2010 (Fletcher 2006). The main reasons for the late incorporation of food into the nanotechnology sector are issues associated with the possible labeling of the food products and consumer-health aspects.

A scientific group at the Norwegian Institute of Technology is using nanotechnology to create tiny particles in the film, to improve the transportation of some gases through the plastic films to pump out unwanted carbon dioxide that would shorten the shelf life of the foods. They are also looking at whether the film could also provide barrier protection and prevent gases such as oxygen and ethylene from deteriorating foods (Sintef,2004).

- **Nano-Coatings**

Waxy coating is used widely for some foods such as apples and cheeses. Recently, nanotechnology has enabled the development of nanoscale edible coatings as thin as 5 nm wide, which are invisible to the human eye. Edible coatings and films are currently used on a wide variety of foods, including fruits, vegetables, meats, chocolate, cheese, candies, bakery products, and French fries (Morillon*et al.* 2002; Cagri*et al.* 2004; Rhim 2004). These coatings or films could serve as moisture, lipid, and gas barriers. The U.S. Company Sono-Tec

Corporationannounced in early 2007 that it has developed an edibleantibacterial nano-coating, which can be applied directly to bakery goods (El Amin, 2007).

- **Nanolaminates**

Nanotechnology provides food scientists with a number of ways to create novel laminate films suitable for use in the food and dairy industry. A nanolaminateconsists of 2 or more layers of materials with nanometer dimensions that are physically or chemically bonded to each other. A variety of different adsorbing substances could be used to create the different layers, including natural polyelectrolytes (proteins, polysaccharides), charged lipids (phospholipids, surfactants), and colloidal particles (micelles, vesicles, droplets). It would be possible to incorporate active functional agents such as antimicrobials, antibrowningagents, antioxidants, enzymes, flavors, and colors into the films. These functional agents would increase the shelf life and quality of coated foods.

- **Clay nanoparticles and nano crystals**

The barrier properties of dairy and food packaging materials are improved by incorporating as well as embedding nanoclays and nanocrystals. The advantage of clay nanocomposite in the packaging material offers improved shelf life, shutter proof, light in weight and heat resistant (Ravichandran, 2010).

- **Nanosensors**

Packaging equipped with nano-sensors is also designed to track either the internal or external conditions of food products, pellets and containers, throughout the supply chain. For example, such packaging can monitor temperature or humidity over time and then provide relevant information of these conditions, for example by changing colour. Nanosensorsin plastic packaging can detect gases given off by food when it spoils and the packaging itself changes color to alert you. These films are packed with "silicate nanoparticles" to reduce the flow of oxygen into the package and the leaking of moisture out of the package to stay food fresh. The present technologies, to detect microbes especially pathogens in food products take 2 to 7 days.

Application in food packaging

Nano packaging applications as Food Contact Materials (FCMs) are anticipated to grow from a $66 million business in 2003, to over $360 million by 2008 (Scrinis and Lyons, 2007). Applications for food contact materials (FCMs) using nanotechnology is as follow:

- FCMs incorporating nanomaterials to improvepackaging properties (flexibility, gas barrierproperties, temperature/moisture stability, lightand flame resistant, transparency, mechanicalstability).
- ''Active'' FCMs that incorporate nanoparticleswith antimicrobial or oxygen scavengingproperties.
- ''Intelligent''or "smart" food packagingincorporating nanosensors for sensing andsignaling of microbial and biochemicalchanges, release of antimicrobials,antioxidants, enzymes, flavours andnutraceuticals to extend shelf-life.
- Biodegradable polymer–nanomaterialcomposites by introduction of inorganicparticles, such as clay, into the biopolymericmatrix and can also be controlled withsurfactants that are used for the modification oflayered silicate (Sozer and Kokini, 2009;Chaudhry*et al.*, 2008; Miller and Sejnon, 2008;Joseph and Morrison, 2006; Doyle, 2006;Lopez- Rubio *et al.*, 2006; Brody, 2007).

1. **Improved packaging**

A variety of nanoparticle reinforced polymers, also termed as ''nanocomposites'' have been developed, which typically contain up to 5% w/w nanoparticles with clay nanoparticle composites with improved barrier properties (80-90% reduction) for the manufacture of bottles for beer, edible oils and carbonated drinks and films (Chaudhry*et al.*, 2008; Meech, 2007; Brody, 2007). United States Food and Drug Administration (USFDA) have approved the use of nanocomposite in contact with foods (Sozer and Kokini, 2009).

2. **Active packaging**

Nano silver, Nano magnesium oxide, nanocopper oxide, nano titanium dioxide and carbon nanotubes are also predicted for future use in antimicrobial food packaging (Doyle *et al.*, 2006, Miller and Sejnon, 2008; Chaudhry*et al.*, 2008). Kodak company is developing antimicrobial packaging for food products that will be commercially available in 2005 and 'active packaging,' which absorbs oxygen (Asadi and Mousavi, 2006). Oxygen scavenging packaging using enzymes between poly ethylene films have also been developed (Lopez *et al.*, 2006). An active packaging application could also be designed to stop microbial growth once the package is opened by the consumer and rewrapped with an active-film portion of the package (Brody, 2007).

3. **Smart/ Intelligent packaging**

BioMerieux have developed a multi-detection test – Food Expert ID for nano surveillance response to food scares. The nanotech company pSiNutria are also developing nano-based tracking technologies, including an ingestible BioSiliconwhich could be placed in foods for monitoring purposes and pathogen detection, but could also be eaten by consumers (Scrinis and Lyons, 2007; Miller and Sejnon, 2008). Engineered nanosensors are being developed by Kraft along with Rutgers University (U.S.) with in packages to change colour to warn the consumer if a food is beginning to spoil, or has been contaminated by pathogens using electronic 'noses' and 'tongues' to 'taste' or 'smell' scents and flavours (Joseph and Morrison, 2006, Asadiand Mousavi, 2006; Scrinis and Lyons, 2007; Sozerand Kokini, 2009). Nestlé, British Airways, MonoPrixSupermarkets are using chemical nanosensors that can detect colour change (Pehanich, 2006).

Nanotechnology and food safety

Food safety means that all food products must be protected from chemical, biological, physical and radiation contamination through processing, handling and distribution. So far the present review has focused on the application of nanotechnology in the dairy and food processing including packaging. The nanotechnology has brought revolution in the non-food sectors; however, it is slowly gaining popularity in the dairy and food processing. The additives universally accepted as GRAS will have to be reexamined when used at nanoscale level.The nanoparticles are more reactive, more mobile, andlikely to be more toxic. The ingredients in these nanoparticles must undergo a full safety assessment by the relevant scientific advisory association before these are permitted to be used in the dairy and food products including packaging (U.K.RS/RAE, 2004).

Regulations

The European Union regulations for food and food packaging have recommended that for the introduction of new nanotechnology, specific safety standards and testing procedures are required (Halliday, 2007). In India food safety regulations are introduced but not adequate for the monitoring safety of nanoparticles. Existing laws are inadequate to assess risks posed by nano based foods and packaging because:

Toxicity risks remain very poorly understood(because of their unique properties); Are notassessed as new chemicals according to many regulations;Current exposure and safetymethods are not suitable for nanomaterials and Many safety assessments use confidential industrystudies (Chaudhry*et al.,* 2008; Miller and Senjen, 2008).

Several organizations are already involved in nanotechnology research, regulations, and guidelines; I discuss their activities below. The Food and Drug Administration (FDA) has provided its perspective on nanotechnology on its Web site (http://www.fda.gov/nanotechnology/). One important fact to remember is that the FDA regulates products, not technologies. The Web site makes the following observations about issues FDA anticipates in the regulation of nanotechnology products:

- "The likelihood that many of the nanotechnology products that the Agency regulates will be combination products (i.e., drugdevice, drug-biologic, or device-biologic products).
- Because FDA regulates products based on their statutory classification rather than the technology they employ, FDA's regulatory consideration of an application involving a nanotechnology product may not occur until well after the initial development of that nanotechnology.
- Because FDA has limited regulatory authority over certain categories of products, the Agency may have limited authority over the use of nanotechnology related to those products. For example, there is no premarket approval of cosmetic products or their ingredients, with the exception of color additives" (FDA, 2006).

Conclusion:

The use of nanotechnology to manufacture of processed foods with enhanced processing, health and packaging functionalities - flavour, texture, shelf-life, transportability, reduced costs and nutritional traits will facilitate the expansion of the range, quality and quantity of processed foods, and to thereby meet the contemporary demands for both 'health' and 'convenience'.

Nanotechnology has the potential to improve foods, making them tastier, healthier, and more nutritious, to generate new food products, new food packaging, and storage. However, many of the applications are currently at an elementary stage, and most are aimed at high-value products, at least in the shortterm. In addition to this, nanomaterialscan be used to make packaging that keeps the product inside fresher for longer. Intelligent food packaging, incorporating nanosensors, could even provide consumers with information on the state of the food inside. Food packages are embedded with nanoparticles that alert consumers when a product is no longer safe to eat. Sensors can warn before the food goes rotten or can inform us the exact nutritional status contained in the contents. In fact, nanotechnology is going to change the fabrication of the entire packaging industry.

Regulatory bodies, such as FDA, should author guidance with respect to the criteria to be followed in evaluating the safety of food, food packaging, and supplement uses of nanomaterials with novel properties. New approaches and standardized test procedures to study the impact of nanoparticles on living cells are urgently needed for the evaluation of potential hazards relating to human exposure to nanoparticles. It is widely expected that nanotechnology- derived food products will be available increasingly to consumers worldwide in the coming years.

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Fig. 1. Nanotechnology has applications in all areas of food science, from agriculture to food processing to security to packaging to nutrition and neutraceuticals. Some potential applications are shown here. The applications which will be reviewed in this article are those in the orange quadrant, which are the most likely to be marketed in the near term.