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Nanotechnology: An emerging technology in packaging of food products

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Food packaging is a critical technology addressing the ever-increasing demands for convenience, freshness, ease, shelf-life, safety and security of food products. The main purpose of food packaging is to protect the food from microbial and chemical contamination, oxygen, water vapour and light. The type of packaging used therefore has an important role in determining the shelf-life of the food. Nanotechnology can be intervened to achieve the purpose of food packaging and it will become one of the most powerful forces for innovation in the food packaging industry. Nanoscience and nanotechnology have already been applied in various fields, such as computer electronics, communication, energy production, medicine and the food industry. The nanoscale devices are often manufactured with the view to imitate the nanodevices found in nature and include proteins, DNA, membranes and other natural biomolecules. Nanoscience and nanotechnology are new approaches to research and development that concern the study of phenomena and manipulation of materials at atomic scales, where material properties differ significantly from those at a larger scale. In the food packaging arena, nano materials are being developed with enhanced mechanical and thermal properties to ensure better protection of food from exterior mechanical, thermal, chemical or microbial effects.

Key Words : Nanotechnology, Packaging, Nanoscale

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INTRODUCTION

Nanoscience and nanotechnology have already been applied in various fields, such as computer electronics, communication, energy production, medicine and the food industry. The nanoscale devices are often manufactured with the view to imitate the nanodevices found in nature and include proteins, DNA, membranes and other natural Biomolecules (Sanguansri and Augustin, 2006; German *et al*., 2006). The word "nano" comes from the Greek for "dwarf". Nanotechnology has the potential to generate new food packaging. The food products must be of good quality, safe, good sensory attributes, inexpensive and with a good shelf life. This can be achieved with a good quality food packaging material. Biodegradable packaging materials originating from renewable sources have been the attraction for current food scientists. The research focuses on understanding, observing and controlling the properties of matter with length between 1 and 100 nanometers (1 nanometer= 10^{-9} meter). Nanotechnology already formed the basis for a number of commercially available

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products. The technology has been widely used by the electronics industry for many years. Even agricultural production and food industries have witnessed the use of nanotechnology that it can be integrated in to number of food systems and food packaging products (Manikantan and Varadharaju, 2009). In the food packaging arena, nano materials are being developed with enhanced mechanical and thermal properties to ensure better protection of food from exterior mechanical, thermal, chemical or microbiological effects. This would endow packaged food with an additional level of safety and functionality. Also it would offer advantages along the supply chain and potentially increase the self-life of food. Some of the potential uses of nanotechnology in food packaging include modify the permeation behaviour of films, increasing barrier properties, improving mechanical and heat resistance properties, developing active anti-microbial and antifungal surfaces, sensing and signalling microbiological and biochemical changes. Material exhibiting anti microbial properties by nano particles of silver have already entered the market.

Nanotechnology enables the designers to alter the structure of the packaging materials on the molecular scale, to give the materials desired properties. With different nanostructure, the plastics can obtain various gas/water vapour permeability to fit the requirements of preserving fruit, vegetable, beverage, wine and other food. By adding nanoparticles, people can also produce bottles and packages with more light- and fire-resistance, stronger mechanical and thermal performance and less gas absorption. These properties can significantly increase the shelf-life, efficiently preserve flavour and colour, and facilities transportation and usage. Further, nanostructured film can effectively prevent the food from the invasion of bacteria and micro-organism and ensure the food safety.

About 400-500 nano-packaging products are estimated to be in commercial use at the moment, while nanotechnology is predicted to be used in the manufacture of 25 per cent of all food packaging within the next decade. The contributing factor of these developments include significant benefits in terms of lightweight but strong packaging materials and prolonged shelf life of packaged foodstuffs, and the likely low risk to the consumer attributable to the fixed or embedded nature of engineered nano materials (ENMs) in plastic polymers. A number of nanotechnology-derived food contact materials (FCMs) are currently available worldwide, the main areas of application of which fall into the following broad categories: (FMCs incorporated nanomaterilas for improved packaging properties (flexibility, gas barrier properties, temperature/moisture stability); Biodegradable polymer-nanomaterial composites, with enhanced mechanical and functional properties; 'Active' FCMs incorporating nanoparticles withantimicrobial or oxygen scavenging properties;'Intelligent' and 'Smart' food packaging, which incorporates nanosensors to monitor and report the condition of the food.

Nanoparticles reinforced materials for improved packaging properties:

The most prominent products in the food industry's research and development pipeline include new polymer nanocomposites for packaging and wrapping. Nanocomposite technology has been described as the next great frontier of material science in packaging. This technology is developed to improve barrier performance pertaining to gases such as oxygen and carbon dioxide. It also enhances the barrier performance to ultraviolet rays, as well as adding strength, stiffness, dimensional stability, and heat resistance (Manikantan *et al*., 2009). Bioactive packaging materials need to be able to keep bioactive compounds, such as prebiotics, probiotics, encapsulated vitamins or bioavailable flavonoids, in optimum condition until they are released in a controllable manner into the food product (Lopez-Rubio *et al.*, 2006; Guerra *et al*., 2005; Brody, 2005). Bioactive-packaging materials can help to control oxidation of food stuffs and to prevent the formation of off-flavors and undesirable textures of food. Bioactive compounds that are encapsulated into the packaging itself are a promising approach because this would allow the release of the active compounds in a controllable manner. Several already approved food additives could be used for such nanoencapsulation, including carrageenan, chitosan, gelatin, polylactic acid, polyglycolic acid and alginate (Lopez-Rubio *et al*., 2006; Kumar, 2000; Agullo´ *et al*., 2003).

Polymer composites with nanoclay packaging :

These are among the first nanocomposites to emerge on the market as improved materials for packaging (including food packaging). Nanoclay has a natural nanoscaled layer structure, which when incorporated into polymer composites restricts the permeation of gases. Nanoclay–polymer composites have been made from a thermoset or thermoplastic polymer reinforced with nanoparticles of clay. These include polyamides (PA), nylons, polyolefins, polystyrene (PS), ethylene-vinylacetate (EVA) copolymer, epoxy resins, polyurethane, polyimides and polyethyleneterephthalate (PET).

Polymer nanocomposites consist of resins (either thermoset or thermoplastics) that have fillers added with at least one dimension measured in nanometres. Because the nanoparticles are so small and their aspect rations (largest dimension/ smallest dimension) are very high, even at such low loadings, certain polymer properties can be greatly improved without the detrimental impact on density, transparency, and processability associated with conventional reinforcements like talc or glass. New plastics created with this technology demonstrate an increased shelf life and are less likely to shatter. Once perfected, these plastics will offer the improved characteristics at competitive price and more attractive for use in food and beverage packaging and pharmaceutical applications.

Nano biodegradable packaging:

The use of nanomaterials to strengthen bio plastics (plant-based plastics) may enable bio based nanocomposites plastics to be used instead of fossil-fuel based plastics for food packaging and carry bags. Bio based nanocomposites are a new class of materials in food packaging industry with improved barrier and mechanical properties as compared to those of neat biopolymers. They are biodegradable and they are also produced from renewable resources. So, these make them environment friendly. It should be noted that barrier properties and especially mechanical properties of biobased nanocomposite films are stronger than edible films and synthetic polymeric films. Unlike edible films, they could not have been consumed as a part of food.

Bio based nanocomposites are produced from incorporation of nanoclay into biopolymers (or Edible films). Advantage of bio based nanocomposites are numerous and possibilties for application in the packaging industry are endless. Bio based nanocomposites can be used to extend the shelf-life of the fresh products such as fruits and vegetables by controlling respiratory exchange. Also it can improve the quality of fresh frozen, and processed meat, poultry and seafood products by retarding moisture loss, reducing lipid oxidation and discoloration, enhancing product appearance, and reducing oil uptake by battered and breaded products during frying.

Bio based nanocomposites are composed of biopolymer, nanoclay and usually compatibilizing agents. Major component of bio based nanocomposites is biopolymers. Biopolymers have great commercial potential for bio plastic and edible films, but some of the properties such as brittleness, low heat distortion temperature; high gas permeability and low melt viscosity for further processing restrict their use in a wide range of applications (Ray and Bousmina, 2005). As mentioned earlier, modification of biopolymers with nanotechnology is an effective way to improve their properties. Biopolymer derived from renewable resources are broadly classified according to method of production. This gives the following three main categories (Petersen *et al.,* 1999):

– Biopolymer directly extracted/ removed from natural materials (mainly plants) such as hydrocolloids (polysaccharides and proteins). The most frequently utilized polysaccharides were cellulose and starch (and their derivatives), chitosn, seaweed extracts (caragreenans and alginates), exudates (Arabic gum), seed (gaur gum), xanthan and gellan gum and pectin. Proteins include collagen, gelatine, casein, whey proteins, corn zein, wheat gluten and soy proteins.

– Biopolymers produced by classical chemical synthesis from renewable bio derived monomers like polylactate.

– Biopolymers produced by micro-organisms or genetically transformed bacteria like polyhydroxyalkanoates.

Biopolymers like starch present some drawback, such as the strong hydrophilic behaviour (poor moisture barrier) and poorer mechanical properties than the conventional non-biodegradable plastic films used in food packaging industries (Huang *et al.,*2006; McGlashan and Hally, 2003; Park *et al.*, 2003; Park *et al.,* 2002). So, incorporation of nanoclay in biopolymers like starch can improve its properties such as barrier and mechanical properties (Vaia *et al.*, 2007). The most commonly used nanoclays include montmorillonite, a 2:1 phyllosilicate (Chiou *et al.,* 2005).

Antimicrobial nanopackaging materials:

The incorporation of antimicrobial compounds into food packaging materials has received considerable attention. Film with antimicrobial activity could help control the growth of pathogenic and spoilage microorganisms. An antimicrobial nanocomposite film is particularly desirable due to its acceptable structural integrity and barrier properties imparted by the nanocomposite matrix, and the antimicrobial properties contributed by the natural antimicrobial agents impregnated within. Materials in the nanoscale range have a higher surface-to-volume ratio when compared with their microscale counterparts. This allows nanomaterials to be able to attach more copies of biological molecules, which confers greater efficiency. Nanoscale materials have been investigated for antimicrobial activity so that they can be used as growth inhibitors, killing agents or antibiotic carriers.

Polymer composites with nano-metals or metal oxide packaging:

Polymer nanocomposites incorporating metal or metal oxide nanoparticles are utilized for their antimicrobial action, abrasion resistance, UV absorption, and strength. Some nano materials have been used to develop active packaging that can absorb oxygen and therefore keep food fresh. Other nano materials have been incorporated as UV absorbers to prevent UV degradation in plastics such as PS, PE and PVC. The commercially important nanomaterials in this respect include nanosilver and nanozinc oxide for antimicrobial action, nanotitanium dioxide for UV protection in transparent plastics, nanotitanium nitride for mechanical strength and as a processing aid, and nano silica for surface coating. The most common nanocomposites used as antimicrobial films for food packaging are based on silver, which is well known for its strong toxicity to a wide range of micro-organisms, with high temperature stability and low volatility.

Coating containing nanoparticles:

Coatings that contains nanoparticles are used to create antimicrobial, starch resistance, anti-reflective, or corrosion- resistant surfaces. This involves the coating of nanoparticulate from a metal, metal oxide or a film resin substance with nanoparticles. The coating have been reported to be very efficient at keeping out oxygen and retaining carbondioxide and can rival traditional active packaging technologies such as oxygen scavengers (Garland, 2004).

Waxy coating is used widely for some foods such as apples and cheeses. Recently, nanotechnology has enabled the development of nanoscale edible coating as thin as 5 nm thick, which are invisible to the human eye. These edible nano-coating could be used on meats, cheese, fruits, vegetables, confectionary, bakery goods and fast foods. They could provide a barrier to moisture and gas exchange, act as a vehicle to deliver colours, flavours, antioxidants, enzymes and anti-browning agents could also increase the shelf-life of manufactured foods, even after the packaging is opened.

Another trend in this respect is the chemical release nano-packaging. The technique enables food packaging to interact with the food. The exchange can be processed in both directions. Packaging can release nanoscale antimicrobials, antioxidants, flavours, fragrances or nutraceuticals into the food or beverages to extend its shelf-life or to improve its taste or smell. Conversely, nano- packaging using carbon nanotubes are being developed with the ability to pump out carbon dioxide that would otherwise result in food or beverages deterioration. Nano-packaging that absorbs undesirable flavours is also in development stage.

Chemical release packaging is also designed to release biocides in response to growth of a microbial population, humidity or other changing conditions. Other packaging and food contact materials incorporate antimicrobial nanomaterials, that are designed not to be released, so that the packaging it shelf acts as an antimicrobial agent. These products commonly use nanoparticles of silver, although some use nanosize zinc oxide or chlorine dioxide and other materials. Nano magnesium oxide, nano copper oxide, nano titanium dioxide and carbon nanotubes are also predicted for future use in antimicrobial food packaging.

Antimicrobial nano-emulsions packaging:

Nano-emulsions have been developed for use in the decontamination of food packaging equipment and in the packaging of food. A typical example is a nanomicelle-based product which is claimed to contain natural glycerine and removes pesticide residues from fruits and vegetables, as well as the oil/ dirt from cutlery.

Intelligent packaging concept based on nanosensors:

Nanotechnology has also enabled the development of nanosensors that can be applied as labels or coating to add an intellignnt function to food packaging in terms of ensuring the integrity of the packaging through detection of leaks (for food stiffs packed under vaccum or inert atmostphere), indications of time-temperature variations (e.g. freeze-thaw-refreezing), or microbial safety (deterioration of food stuffs). Examples include an indicator that turns from transparent to blue, informing the consumer that it has entered the modified atmosphere of the packaged materials. For this type of application, nanotechnology- derived printable inks have been developed. One example is an oxygen detecting ink containing light sensitive titanium oxide (TiO_2) nanoparticles, which only detect oxygen when they are ‘‘ switched on” with UV light. Other conductive inks jet printing based on copper nanoparticles have also been developed (Park *et al*., 2007). Other materials developed for potential food packaging applications are based on nanostructured silicon with nanopores. The potential applications include detection of pathogens in food and variations of temperature during food storage. Another relevant development is aimed at providing a basis for intelligent preservative packaging technology that will release a preservative only when a packaged food begins to spoil (ETC Group, 2004).

Smart nano food packaging:

Smart nano packaging responds to environmental conditions or repairs it or alert a consumer to contamination and/or the presence of pathogens. Chemical giant Bayer (Leverkusen, Germany) produces a transparent plastic film (called Durethan) containing nanoparticles of clay. The nanoparticles are dispersed throughout the plastic and are able to block oxygen, carbon dioxide and moisture from reaching fresh meats or other foods. The nanoclay also makes the plastic lighter, stronger and more heat resistant. ‘Smart’ food packaging warns when oxygen has got inside, or if food is going off. Such packaging is already in use in brewing and dairy production and consists of nanofilters that can filter out micro-organisms and even viruses. In lab experiments, the colour has been removed from beetroot juice, leaving the flavour; and red wine turned into white. Lactose can now be filtered from milk, and replaced with another sugar – making all milk suitable for the lactose-intolerant. Nanoceramic particles enable clustering of dirt molecules, thereby; keeping cooking oil fresh and soluble forever bread – Tip-Top – contains undetectable nanocapsules of omega-3 fatty acids. Vitamin B12 spray can simply be sprayed inside a child’s mouth to absorb the nanosized vitamins directly through the mucal cells, thereby, relieving the need to bribe children to eat fruits and vegetables. Nano-capsules delivered chemicals in rapeseed cooking oil, will stop cholesterol entering the bloodstream. Nano packaging with self cleaning abilities or nanoscale filters allow the removal of all bacteria from milk or water without boiling. In the area of nanolaminated coatings on the bioavailability of encapsulated lipids, bioactive lipophilic or fat-liking compounds could be incorporated into foods or beverages, which may increase the ingredient’s stability, palatability, desirability, and bioactivity (McClements, 2009). Functionalized nanostructured materials are finding applications in many sectors of the food industry, including novel nanosensors, new packaging materials with improved mechanical and barrier properties, and efficient and targeted nutrient delivery systems. Advances in processes for producing nanostructured materials coupled with appropriate formulation strategies have enabled the production and stabilization of nanoparticles that have potential applications in the food and related industries (Sanguansri and Augustin, 2006). The food processing industry should ensure consumer confidence and acceptance of nano foods.

Conclusion:

Packaging has developed into an essential technology in the handling and commercialization of food stuffs to provide, by maintaining or even increasing, the required levels of quality and safety, there are high expectations in food and packaging: longer shelf life, safer packaging, better traceability of products and healthier food is only a few of the expected improvements. Nanotechnology may be effective applied in the various areas of food packaging such as designing the packaging material according to the barrier requirements of the food materials to be stored, anti microbial coating to ensure the safety of the packaged food, sensing the reactions inside the packaging environment and utilizing the bio materials as packaging materials to reduce the pollution and intelligent packaging by using nanosensors and smart nano food packaging.

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