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NANO TECHNOLOGY IN FOOD PROCESSING: AN OVERVIEW

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Over the past few decades, the evaluation of a number of science disciplines and technologies have revolutionized food and dairy processing sector. Most notable among these are biotechnology, information technology etc. Recently "Nanotechnology", an essentially modern scientific field that is constantly evolving as a broad area of research, with respect to dairy and food processing, preservation, packaging and development of functional foods. Food and dairy manufacturers, agricultural producers, and consumers could gain a more competitive position through nanotechnology. Furthermore, the delivery of bioactive compounds for nutritional as well as development of functional food are possible through this technology. Nanotechnology will replace many fields with tremendous application potential in the area of dairy and food sectors. Several critical challenges, including discovering of beneficial compounds, establishing optimal intake levels, developing adequate food delivering matrix and product formulation including the safety of the products need to be addressed. And, also the potential negative effects of nanotechnology- based delivery systems on human health need to be considered.

Key Words: Nanotechnology, Food processing, Challenges.

INTRODUCTION

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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. Nanotechnology has the potential to revolutionize the food and dairy processing sectors. Nanotechnology is based on the prefix "nano", a Greek word meaning "dwarf". According to Pehanich (2006), nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers. To be more specific, nanotechnology is defined as the design, production and application of structures, devices, and systems through control of the size and shape of the material at the nanometer (10-9 of a meter) scale where unique phenomenon enable novel applications (Ravichandran et al., 2006; National Nanotechnology Initiative, 2006). This technology has already revolutionized the health care, textile, information technology, and energy sectors etc. and has been well publicized (Kumar and Rai, 2009). Several products enabled by nanotechnology are already in the market, such as antibacterial dressings, transparent sunscreen lotions, light-diffracting cosmetics, penetration enhanced moisturizers, stain and odour repellent fabrics, scratch free paints for cars, and self cleaning windows, dirt repellent coatings, long lasting paints and furniture varnishes, and even some food products (Miller, 2008).Nanotechnology has been described as the new industrial revolution and both developed and developing countries are investing more in this technology. Recently the Helmuth Kaiser Consultancy predicted that the nano food market will surge from 2.6 billion USD to 20.4billion USD by 2010 and is extended to grow to $30.4billion in 2015. The government of India established the Nano-science and technology initiative in the later part of the 2001 through Department of Science and Technology (DST), New Delhi and invested about Rs. 350 Crores (2002-06) and granted approval for the nano mission worth Rs. 1000 crores for next five years (Patra *et al.,* 2009). Nanotechnology can be applied by two different approaches either "bottom up" or "top down". in food and dairy processing (Ravichandran, 2010). The top down approach involves a physical processing of the food materials, such as dry-milling of wheat into fine flour that has a high water-binding capacity. The antioxidant activity in green tea powder is improved by when the size of the powder is reduced to 1000 nm, the digestion and absorption resulted in an increase in the activity of an oxygen-eliminating enzyme (Shibata, 2002). By contrast, self-assembly and self-organization are concepts derived from biology that have inspired a bottom-up food nanotechnology. For example, self-assembly structures through organization of casein micelles or starch and the folding of globular proteins and protein aggregates which create stable entities to form nanometer scale via self organization (Dickinson and Van Vliet, 2003).

In food and dairy industries, the applications of nanotechnology include nano particulate Delivery Systems (nano dispersions and nano capsules), Packaging (nano laminates, nano composites bottles, bins with silver nano particles), Food Safety and Biosecurity (nano sensors) etc. (Chen *et al.* 2006). The nano technology will play an vital role in the food and dairy processing in near future and would involve two forms of nano food applications viz, food additives (nano inside) and food packaging (nano outside). The nano scale food additives may be used to influence texture, flavour, nutritious improvement, provide functionally and even detect pathogens and food packaging involves extend food shelf life, edible, nano wrapper which will envelope foods, preventing gas and moisture exchange, 'smart' packaging (containing nano-sensors and anti-microbial activators) for detecting food spoilage and releasing nano-anti-microbes to extend food shelf life (Richardson and Piehowski, 2008; Miller, 2008).

Nanotechnology in Food and Dairy Processing

Cell membranes, harmones, DNA etc. that exist in nature are example of nano structures and the food molecules, proteins, fats, carbohydrates etc. are not exceptional and the results of nano scale level murges between sugars, fatty acids and amino acids (Powell and Colin, 2008).'Nano foods' from the Helmut Kaiser Consultancy (2009) estimates an increasing growth in the development of food and dairy related nano products and patent applications. Nanotechnology can be applied to develop nano scale materials, controlled delivery systems, contaminant detection and to create nano devices for molecular and cellular biology from how food is grown to how it is packaged. The application of nano technology with respect to food and dairy industry will be covered under two major heads viz. food additives (nano inside)and food and dairy packaging (nano outside).

Food Additives (Nano Inside): Nano-dispersions and Nano-capsules

Functional ingredients (for example, drugs, vitamins, antimicrobials, antioxidants, flavorings, colorants, and preservatives etc.) comes in different molecular and physical forms such as polarities (polar, non polar, amphiphilic), molecular weights (low to high), and physical states (solid, liquid, gas). These ingredients are rarely utilized directly in their pure form; instead, they are often incorporated into some form of delivery system. Weiss *et al.* (2006) examined that a delivery system must perform a number of different roles. First, it serves as a vehicle for carrying the functional ingredient to the desired site of action. Second, it may have to protect the functional ingredient from chemical or biological degradation (for example, oxidation) during processing, storage, and utilization; this maintains the functional ingredient in its active state. Third, it may have to be capable of controlling the release of the functional ingredient, such as the release rate or the specific environmental conditions that trigger release (for example, pH, ionic strength, or temperature). Fourth, the delivery system has to be compatible with the other components in the system, as well as being compatible with the physicochemical and qualitative attributes (appearance, texture, taste, and shelf-life) of the final product. In order to achieve above said objectives, a number of potential delivery systems based on nanotechnology could be used as association colloids, bio-polymeric nano-particles and nano-emulsion.

Association colloids

A colloid is a stable system of a substance containing small particles dispersed throughout. An association colloid is a colloid whose particles are made up of even smaller molecules. Surfactant micelles, vesicles, bilayers, reverse micelles, and liquid crystals are some examples of association colloids which have been used to encapsulate and deliver polar, non polar, and amphiphilic functional ingredients (Flanagan and Singh, 2006; Golding and Sein, 2004). The dimensions of many association colloids are in the range of 5 to 100 nm, and these structures are therefore considered to be nano particles.

Nano fibers

Nano fibers with diameters from 10 to 1000 nm, makes them ideal for serving as a platform for bacterial cultures as well as structural matrix for artificial foods. Since nano fibers are usually not composed of food grade substances, they have only a few potentialapplications in the food industry (Weiss *et al.*, 2006).Electro-spinning is a manufacturing technology capable of producing thin, solid polymer strands (nanofiberes) from solution by applying a strong electric field to a spinneret with a small capillary orifice. The food industry can use electro spun microfibers in several ways such as a building/reinforcement element of composite green (that is, environmentally friendly) food packaging material, as building elements of the food matrix for imitation/artificial foods, and as nano structured and micro structured scaffolding for bacterial cultures. Though the electro spun fibers application is increasing, its use in food and dairy processing are relatively few and are made primarily from synthetic polymers. As progress in the production of nano fibers from food biopolymers is made, the use of biopolymeric nano fibers in the food industry will increase(Ravichandran, 2010).

Nano-tubes

Carbon nano-tubes have been used nonfood application. The structures have been used as low resistance conductors or catalytic reaction vessels among other uses. Graveland-Bikker and Kruif (2006), have reported that certain globular proteins from milk (such ashydrolyzed α-lactalbumin) can be made to self assemble to form nano-tubes under appropriate conditions. This technique is applicable to other proteins as well and has been explored to assist in the immobilization of enzymes or to build analogues to muscle-fiber structures. Nano-tubes made of the milk protein α -lactalbumin are formed by self-assembly of the partially hydrolysed molecule (Graveland-Bikker *et al.* 2006). Otte *et al.*(2005) examined that at neutral pH and in presence of an appropriate cation, these building blocks self-assemble to form micro meter long tubes with a diameter of only 20nm. The minimum concentration to form nanotubes of α-lactalbumin is 20 g/l. The α-lactalbumin nano-tubes could withstand conditions similar to a pasteurization step(72ºC/40s). According to Gouin (2004), the features of the α-lactalbumin nano-tube makes it an interesting potential encapsulating agent. Because α-lactalbumin is a milk protein it will be fairly easy to apply the nano-tubes in foods or pharmaceutics. These nanostructures promise various applications in food, nano medicine etc.(Rajagopal and Schneider, 2004). In general protein hydrolysis increases the digestibility of protein. Furthermore α -lactalbumin has important nutritional value. A nanotube made by food /dairy proteins or their derivatives have so far only been reported for α lactalbumin.

Nano-capsules

A number of new processes and materials derived from nanotechnology have the potential to provide new solutions to dairy and food processing fronts. In recent years, there has been considerableinterest in exploring the potential of nanotechnology in encapsulation and delivery of biologically active substances into targeted tissues, enhance the flavour andother sensory characteristics of food and dairy products. Casein micelle (CM) plays a role as natural nano-capsular vehicle for nutraceuticals. The CM is important due to their biological activity, good digestibility. The micelles are very stable to processing and retain their basic structural identity through most of these processes(Gouin, 2004).Uricanu *et al.* (2004) reported that casein micelles (CM) are in effect nano-capsules created by nature to deliver nutrients such as calcium phosphate and protein to the neonate. A novel approach is to harness CM for nano-encapsulation and stabilization of hydrophobic nutraceutical substances for enrichment of non-fat or low-fat food products. Such nano-capsules may be incorporated in dairy products without modifying their sensory properties. The general approach is to develop nano sized carriers or nano sized materials, in order to improve the absorption and, hence, potentially the bioavailability of added materials such as vitamins, phytochemicals, nutrients, or minerals. The materials can be incorporated into solid foods, delivered as liquids in drinks, or even sprayed directly on to mucosal surfaces.

Food ‘fortification’ through Nanotechnology

Nanotech companies are trying to fortify processed dairy and food products with nano encapsulated nutrients, their appearance and taste boosted by nano-developed colours, their fat and sugar content removed or disabled by nano-modification, and ‘mouthfeel’ improved. Food ‘fortification’ will be used to increase the nutritional claims for example the inclusion of ‘medically beneficial’ nano-capsules will soon enable chocolate chip cookies or hot chips to be marketed as health promoting or artery cleansing. Nano technology will also enable junk foods like ice cream and chocolate to be modified to reduce the amount of fats and sugars that the body can absorb. This is possible by using nano particles to prevent the body from digesting or absorbing these components of the food. In this way, the nano industry could market vitamin and fibre-fortified, fat and sugar-blocked junk food as health promoting and weight reducing (Miller, 2008).

Nanostructures and Nanoparticals in Food

Most polysaccharides and lipids are linear polymers with thicknesses less than nanometers, while food proteins are often globular structures (1-10 nm) in size. The functionality of many raw materials and the processing of foods arise from the presence, modification, and generation of forms of self-assembled nano structures (Chen *et al.* 2006). The crystalline structures in starch, and processed starch-based foods that determine gelatinization and influence the nutritional benefits during digestion, the fibrous structures that control the melting, setting, and texture of gels, and the two dimensional(2D) nanostructure formed at oil-water and air-water interfaces that control the stability of food/dairy foams and emulsions (Rudolph, 2004).For example, the creation of foams (e.g., the head on a glass of beer) or emulsions (e.g., sauces, creams, yoghurts, butter, and margarine) involves generating gas bubbles, or droplets of fat or oil, in a liquid medium. This requires the production of air water or oil-water interface and the molecules present at this interface determine its stability. These structures are one molecule thick and are examples of two dimensional nanostructures. A source of instability in most foods is the presence of mixtures of proteins and other small molecules such as surfactants (soap-like molecules or lipids) at the interface (Morris, 2005). Atomic Force Microscopy has allowed to visualized and understand these interactions and to improve the stability of the protein networks that can be simultaneously applied widely in the dairy, baking and brewing industries. The knowledge gained in the nanotechnology in the field of medicine , electronics etc. could be adapted in the field of food and dairy processing, more specifically in food safety (e.g., detecting pesticides and microorganisms), in environmental protection (e.g., water purification), and in delivery of nutrients (Roco, 2003;Chau, 2007) The area that has led to most debate on nanotechnology and food is the incidental or deliberate introduction of manufactured nano particles into food materials.

Food Packaging (Nano Outside)

Customers today demand a lot more from packaging in terms of protecting the quality, freshness and safety of foods and the nanotechnology, which uses microscopic particles, is effective and affordable and will bring out suitable food and dairy packaging in the near future (El Amin, 2006).Food packaging is considered to be one of the earliest commercial applications of nanotechnology in the food sector. Reynolds (2007) reported that about 400-500nano-packaging products are estimated to be in commercial use, while nanotechnology is predicted to be used in the manufacture of 25% of all food packaging within the next decade. The significant purpose of nano-packaging is to set longer shelf life by improving the barrier properties of food packaging to reduce gas and moisture exchange and UV light exposure (Sorrentino *et al.* 2007). For example, Du Pont has announced the release of a nano-titanium dioxide plastic additive namely "DuPont lightstabilizer210", which could reduce UV damage of foods in transparent packaging (El Amin, 2007).By 2003, over 90% of nano-packaging was based on nano composites, in which nano materials were used to improve the barrier properties of plastic wrapping for foods and dairy products. Nano-packaging can also bedesigned to release antimicrobials, antioxidants, enzymes, flavours and nutra cuticles 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. Furthermore, nano materials are being developed with enhanced mechanical and thermal properties to ensure better protection of foods from external mechanical, thermal, chemical or micro biological effects with an addition level of safety and functionality. 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 nano scale 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. Alternatively, they could improve the textural properties of foods or serve as carriers of functional agents such as colors, flavors, antioxidants, nutrients, and antimicrobials and could also increase the shelf life of manufactured foods, even after the packaging is opened. The U.S. Company Sono-Tec Corporation announced in early 2007 that it has developed an edible antibacterial 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 nano laminate consists of 2 or more layers of materials with nano meter dimensions that are physically or chemically bonded to each other. According to Decher and Schlenoff (2003), one of the most powerful methods is based on the LbL deposition technique, in which the charged surfaces are coated with interfacial films consisting of multiple nanolayers of different materials. Weiss *et al.* (2006) reported that nanolaminates offer some advantages for the preparation of edible coatings and films over conventional technologies and may thus have a number of important applications within the food and dairy industry. A variety of different adsorbing substances could be used to create the different layers, including natural polyelectrolytes (proteins, polysaccharides), charged lipids (phospholipids, surfactants), and colloidal particles (micelles, vesicles, droplets). It would be possible to incorporate active functional agents such as antimicrobials, antibrowning agents, antioxidants, enzymes, flavors, and colors into the films. These functional agents would increase the shelf life and quality of coated foods. These nano laminated coatings could be created entirely from food-grade ingredients (proteins, polysaccharides, lipids) by using simple processing operations such as dipping and washing.

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. Although consumers are thrilled at the exciting food and dairy products emerging through the application of nanotechnology, there is a serious question about safety and will requiring attention by the industry as well as the policy makers. It is important to note that nanomaterials (increased contact surface area), might have toxic effects in the body that are not apparent in the bulk materials (Dowling, 2004). Despite the lack of regulation and risk knowledge, a wide variety of food and nutrition products containing nano scale additives arealready in the market (e.g. iron in nutritional drink mixes, micelles that carry vitamins, minerals, and phytochemicals in oil, and zinc oxide in breakfast cereals etc.) and nanoclays incorporated in plastic beer bottles. The additives universally accepted as GRAS will have to be reexamined when used at nanoscale level. The nanoparticles are more reactive, more mobile, and likely to be more toxic. This toxicity is one of the important issues must be addressed. There is strong possibility that nanoparticles in the body can result in increased oxidative stress that, in turn, can generate free radicals, leading to DNA mutation, cancer, and possible fatality. It is also not fully understood whether enhancing the bioavailability of certain nutrients or food additives might negatively affect human health (Moraru *etal.*,2003). 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).

Regulation of nanotechnologies to ensure food safety

The health implications of food processing techniques that produce nanoparticles and nano scale emulsions also warrant the attention of food regulations. The potential for such foods to pose new health risks must be investigated in order to determine whether or not related new food safety standards are required (Bowmanand Hodge, 2007). 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 the United States, nanofoods and most of the food packaging are regulated by the United States Food and Drug Administration (US FDA) (Badgley *et al.*2007), while in Australia, nanofood additives and ingredients are regulated by Food Standards Australia and New Zealand (FSANZ), under the Food Standards Code(Bowman and Hodge, 2006).There is an urgent need for a common regulatory system capable of managing any risks associated with nano foods and the use of nanotechnologies in dairy and food industry. Governments must also respond to nanotechnology's broader social, economic, civil liberties and ethical challenges. To ensure democratic control of these new technologies in the important area of food and dairy, public involvement in nanotechnology decision making is essential (U.K.RS/RAE, 2004).

CONCLUSION

The prediction is that nanotechnology will transform the entire food and dairy industry near future. Nanotechnology has already entered into food and dairy industries, research facilities are established, potential applications are under study. Although only a handful of nano food products are now available in the market, the tremendous potential will attract more and more competitors in this field. However, there are few issues, particularly regarding the accidental or deliberate use of nano particles in food, or food-contact materials, that consumers are concerned about the potential negative effects of nanotechnology-based delivery systems on human health and also regulatory stands. Several critical challenges, including discovering of beneficial compounds, establishing optimal intake levels, developing adequate food delivering matrix, product formulations and safety of the products need to bead dressed. Irradiation technology took more than 5decades of research and safety assessment for its acceptance in food and dairy processing. Nanotechnology also will have to wait till all safety issues are resolved. There is an urgent need for regulation of nanomaterials before their incorporation into food and dairy processing including packaging. Nanomaterials must not cause any health risks for consumers or to the environment. More research studies are required to investigate the hazards of nanomaterials, taking the size as a main factor even though some of the chemical materials in the form of large particles are safer than when they are in the nano state.

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