Review Article

Recent Innovations in Nanotechnology in Food Processing and its Various Applications – A Review

GuhanNath S[1a], Sam Aaron I[1b], A. Allwyn Sundar Raj[2*], T.V.Ranganathan[3]
[1a & 1b]Bachelor of Food Processing and Engineering,
[2*]Research Scholar and [3]Professor & Head of the Department,
Department of Food Processing and Engineering, Karunya University, Coimbatore – 641114, Tamil Nadu, India.
***Corresponding author's E-mail:** asrthegreat@gmail.com

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ABSTRACT

Nano science and nanotechnology are new frontiers of this century and food nanotechnology is an emerging technology. Food nanotechnology is an area of emerging interest and opens up a whole universe of new possibilities for the food industry. In food engineering, two major applications related to nanotechnology (i.e) food Nano sensing and food nanostructured ingredients are being expected. In the former field, better food quality and safety evaluation can be achieved by using nanotechnology. Recently "Nanotechnology", is essentially a 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. Nano food packaging materials may extend food life, improve food safety, alert consumers that food is contaminated or spoiled, repair tears in packaging, and even release preservatives to extend the life of the food in the package. Nanotechnology applications in the food industry can be utilized to detect bacteria in packaging, or produce stronger flavors and color quality, and safety by increasing the barrier properties. Meanwhile, food nanotechnology as a new technology is requiring reviews of potentially adverse effects as well as many positive effects. In this review, we intended to cover some of the recent developments in nanotechnology and their applicability to food processing and packaging.

Keywords: Nanotechnology, Nano science, Nano sensors, Food Processing, Food Packaging, Nutraceuticals and Preservation.

INTRODUCTION

The term 'nano' is derived from the Greek word for dwarf[1].The term "Nanotechnology" was first used in 1974 by the late Norio Taniguchi and concepts were given by Richard Feynman in 1959[2]. A nanometer is a thousandth of a thousandth of a thousandth of a meter (10-9 m). One nanometer is about 60,000 times smaller than a human hair in diameter or the size of a virus, a typical sheet of paper is about 100,000 nm thick, a red blood cell is about 2,000 to 5,000 nm in size, and the diameter of DNA is in the range of 2.5 nm. Therefore, nanotechnology deals with matter that ranges from one-half the diameter of DNA up to 1/20 the size of a red blood cell[3]. Nanotechnology focuses on the characterization, fabrication, and manipulation of biological and nonbiological structures smaller than 100 nm. Structures on this scale have been shown to have unique and novel functional properties. Consequently, interest and activities in this research area have greatly increased over the past years. Nano science is defined as the study of phenomena and the manipulation of materials at the atomic, molecular and macromolecular scales, where the properties differ from those at a larger scale[4].

According to the National Nanotechnology Initiative (2006), "Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Nonetheless, scientists have embarked on a field of science that could literally fit on a person's fingernail: *nanotechnology*, a derivative of chemistry, engineering, physics, and micro fabrication techniques[5]. Nanotechnology based on highly reactive particles of sizes less than 100 nanometer is predicted to be central to developing and using new electronics and energy technologies during the present century[6]. Food undergoes a variety of postharvest and processing-induced modifications that affect its biological and biochemical makeup, so nanotechnology developments in the fields of biology and biochemistry could eventually also influence the food industry[7]. Ideally, systems with structural features in the nanometer length range could affect aspects from food safety to molecular synthesis[8]. Designing and producing food by shaping molecules and atoms is the future of the food industry worldwide[9].

Functional food will benefit firstly from the new technologies, followed by standard food, nutraceuticals, and others[10]. Food technology is regarded as one of the industry sectors where nanotechnology will play an important role in the future[11]. 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[12]. Nanomaterial's on which most of the research has been carried out are normally powders composed of nanoparticles which exhibit properties that are different from powders of the same chemical composition, but with much larger particles. Research is in progress into their potential in food nanotechnology sector including food packaging, foods and supplements due to their unique functions and applications of nanomaterials[13].

In 2006, Food and Drug Administration (FDA) defined nanomaterial's as "particles with dimensions less than micrometer scale that exhibit unique properties"[14]. Tens of millions of dollars are being spent in a global race to apply nanotechnologies in food production, processing and packaging[13]. This article provides an overview of some current development efforts in the area of nanotechnology as it applies to food systems. In particular, the article presentssomeof the morphologically different structures and associated manufacturing technologies that could be used to build functional food systems. Although nanotechnology potentially has numerous applications in the food industry, this article does not delve into the areas of food safety and security.

NANO - FOOD MARKET

The worldwide sales of nanotechnology products in the food and beverage packaging sector increased from US$ 150 million in 2002 to US$ 860 million in 2004 and are expected to reach to US$ 20.4 billion by 2010[15]. The consulting firm Cientifica, has estimated the then (2006) food applications of nanotechnologies at around $410 million (food processing US$100 million, food ingredients US$100 million and food packaging US$210 million). There is a large potential for growth of the food sector in developing countries. Today, many of the world's leading food companies including H.J. Heinz, Nestle, Hershey, Unilever, and Kraft are investing heavily in nanotechnology research and development [(16, 17,18, and 14)]. As of March 2006, over 200 ''nano'' consumer products are currently available, and about 59% and 9% of the products are categorized as ''Health and Fitness'' and ''Food and Beverage'' products, respectively[19].

NANOTECHNOLOGY – SCIENCE AND TECHNOLOGY

Nanotechnology has the potential to impact many aspects of food and agricultural systems. Food security, disease treatment delivery methods, new tools for molecular and cellular biology, new materials for pathogen detection, and protection of the environment are 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
- 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.

Application matrix of nanotechnology in food science and technology is schematically shown below (Fig. 1).

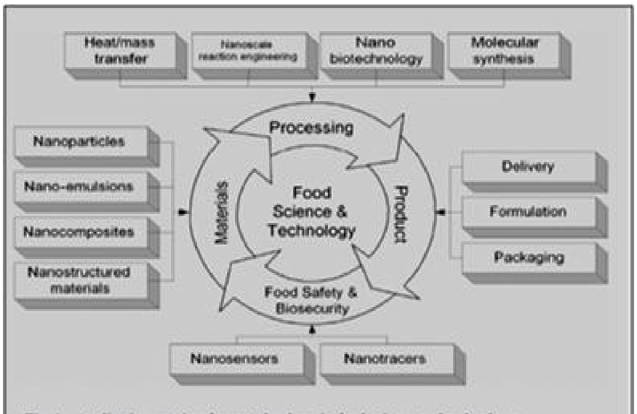

Fig. 1. Application matrix of nanotechnology in food science and technology

It may be stated that there are a large number of potential applications of nanotechnology within the food industry. Applications in food packaging are considered highly promising because they can improve the safety and quality of food products. This includes intelligent packaging, which is reactive to the environment and active packaging, which is able to interact with the food product.

In addition, the relationship between the morphology of food materials and their bulk physicochemical properties has been investigated[20] for example, biopolymers in solutions, gels, and films[21, 22]. Functional nanostructures can incorporate individual biological molecules, which is useful in the development of biosensors that can use natural sugars or proteins as target-recognition groups[23]. Scientists have provided insights into the potential benefits of nanotechnology in food safety[24].

The main achievements, such as harnessing the casein micelle, a natural Nano -vehicle of nutrients, for delivering hydrophobic bioactives; discovering unique nanotubes based on enzymatic hydrolysis of α-lactalbumin; introduction of novel encapsulation techniques based on cold-set gelation for delivering heat-sensitive bioactives including probiotics; developments and use of Maillard reaction based conjugates of milk proteins and polysaccharides for encapsulating bioactives; introduction of β-lactoglobulin–pectin nanocomplexes for delivery of hydrophobic nutraceuticals in clear acid beverages; development of core-shell nanoparticles made of heat- aggregated -lactoglobulin, nanocoated by beet-pectin, for bioactive delivery; synergizing the surface properties of whey proteins with stabilization properties of polysaccharides in advanced W/O/W and O/W/O double emulsions; application of milk proteins for drug targeting, including lactoferrin or bovine serum albumin conjugated nanoparticles for effective *in vivo* drug delivery across the blood–brain barrier; beta casein nanoparticles for targeting gastric cancer; fatty acid-coated bovine serum albumin nanoparticles for intestinal delivery, and Maillard conjugates of casein and resistant starch for colon targeting were reported[25]. Nanocharcoal adsorbent finds applications such as decoloration of food products[26].

NANOTECHNOLOGY IN AGRICULTURAL PRODUCTION

During primary production, nano-formulated agro-chemicals are employed to increase the efficacy of the agro-chemicals compared to conventional formulations. Only some pesticides containing nano-sized or nano-formulated agro-chemicals were identified as available on the market. Residues of these products might be present in products as consumed. Furthermore, NPs are used for water and soil cleaning purposes. Carry-over of the used NPs to crops cannot be excluded, resulting in potential consumer exposure[27]. Examples of used NPs are aluminium oxide, lanthanum particles and nanoscale iron powder in the process of water purification and/or soil cleaning in figure 2. Nanostructured materials exhibit unique properties that open windows of opportunity for the creation of new, high performance materials, which will have a critical impact on food manufacturing, packaging, and storage.

Chain phase	Application	Nanotechnology	Function
Agricultural production	Nanosensors	Nanospray on food commodities	Binds and colors micro-organisms
		Hand-held devices	Detection of contaminants, mycotoxins and microorganism
	Pesticides	Nano-emulsions, encapsulates	Increased efficacy and water solubility
		Triggered release nano-encapsulates	Triggered (local) release
	Water purification/soil cleaning	Filters with nano-pores	Pathogen/contaminant removal
		NPs	Removal/catalysation/oxidation of contaminants
Production and processing of food	Food production	Nano-ceramic devices	Large reactive surface area
	Refrigerators, storage containers, food preparation equipment	Incorporated nano-sized particles, mostly silver, occasionally zinc-oxide	Anti-bacterial coating
Conservation	Food products	Nano-sized silver sprays	Anti-bacterial action
	Packaging materials	Incorporated sensors	Detection of food deterioration
			Monitoring storage conditions
		Incorporated NPs	Increasing barrier properties, strength of materials
		Incorporated active NPs	Oxygen scavenging, prevention of growth of pathogens
Functional food, consumption	Supplements/ additive	Colloidal metal NPs	Claimed enhanced desirable uptake of metal
		Delivery systems "Nano-clusters"	Protecting and (targeted) delivery of content
		Nano-sized/-clustered food/drinks (nutrients)	Claimed enhanced uptake

Figure 2: Applications of nanotechnology in the agro-food sector[27].

NANOTECHNOLOGY IN FOOD PROCESSING

Nanotechnologies are applied in food production machinery. Examples of this type of nanotechnology are coatings of machines or the use of nano-sieves (e.g., to filter out bacteria). The type of material (and wear-off as a result of the use) of filters or coatings might require some attention, but this is not exclusively related to safety of nanotechnologies[27]. Current nanotechnology applications in the agro-food production chain are focused on the development of nano-sized food ingredients and additives, delivery systems for bioactive compounds, and innovative food packaging[13].

FOOD ADDITIVES (NANO INSIDE)

➢ Nanodispersions and Nanocapsules

Functional ingredients (for example, drugs, vitamins, antimicrobials, antioxidants, flavorings, colorants, and preservatives etc.) and comes in different molecular and physical forms such as polarities (polar, nonpolar, 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.[28] 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 under:

- Association colloids,

- Bio polymeric nanoparticles,
- Nano emulsion and so on.

A number of potential delivery systems based on nanotechnology follow.

❖ 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, nonpolar, and amphiphilic functional ingredients [24 and 29].Association colloids are thermodynamically favorable systems whose formation is normally driven by the hydrophobic effect - that is, the reduction of the contact area between the nonpolar groups of the surfactant that comprise the association colloid and water. The type of association colloid formed and the nature of the resultant structures depend on the concentrations and molecular characteristics of the surfactant and cosurfactant used as well as the prevailing environmental conditions (for example, temperature, ionic strength, and pH). The dimensions of many association colloids are in the range of 5 to 100 nm, and these structures are therefore considered to be nanoparticles. The major advantages of association colloid systems are that they form spontaneously, are thermodynamically favorable, and are typically transparent solutions. Thus, the choice of surfactants and cosurfactants to form colloids is critical in ensuring their functionality over a wide range of environmental conditions.

❖ Bio polymeric nanoparticles

[29]Nanometer range particles can be produced using foodgrade biopolymers such as proteins or polysaccharides through self-association or aggregation or by inducing phase separation in mixed biopolymer systems. Polylactic acid (PLA) a common biodegradable nanoparticle is often used to encapsulate and deliver drugs and micronutrients like iron, vitamin, protein etc. It has shown that the PLA need an associative compound such as polyethylene glycol for successful results and the functional ingredients can be encapsulated in nanoparticles and released in response to specific environmental triggers[30].

❖ Nano-emulsions

An *emulsion* is a mixture of two or more liquids(such as oil and water) that do not easily combine. Therefore, a nanoemulsion is an emulsion in which the diameters of the dispersed dropletsmeasure 500nmor less. Emulsions are often referred to as "nanoemulsions.", when the use of high-pressure valve homogenizers or microfluidizers often causes emulsions with droplet diameters of less than 100 to 500 nm and functional food components can be incorporated within the droplets, the interfacial region, or the continuous phase[31]. According to[32], the different types of nanoemulsionswith more complex properties - such as nanostructured multiple emulsions or nanostructured multilayer emulsions - offer multiple encapsulating abilities from a single delivery system that can carry several functional components and these components could be released in response to a specific environmental trigger. While it is difficult to engineer the interfaces to be completely impermeable to compounds in the bulk phase that may interact with the encapsulated compounds, the rate of permeation can often be significantly reduced, thus increasing the kinetic stability of the bioactives. Nanosizeemulsion-based ice cream with a lower fat content has been developed by Nestle and Unilever[33].

❖ Nano laminates

Nanotechnology provides food scientists with a number of ways to create novel laminate films suitable for use in the food industry. A nanolaminate consists of 2 or more layers of material with nanometer dimensions that are physically or chemically bonded to each other. Nanolaminates can give food scientists some advantages for the have a number of important applications within the food industry. Edible coatings and films are currently used on a wide variety of foods, including fruits, vegetables, meats, chocolate, candies, bakery products, and French fries [4 and 35]. 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. The basic functional properties of edible coatings and films depend on the characteristics of the film-forming materials used for their preparation. Generally, lipid-based films are good moisture barriers, but they offer little resistance to gas transfer and have poor mechanical strength. In contrast, biopolymer-based films are often good oxygen and carbon dioxide barriers, but they offer little protection against moisture migration[36]. Nanolaminates are more likely to be used as coatings that are attached to food surfaces, rather than as self-standing films, because their extremely thin nature makes them very fragile[37]. The composition, thickness, structure, and properties of the multilayered laminate formed around the object could be controlled in a number of ways, including changing of the type of adsorbing substances in the dipping solutions, the total number of dipping steps used, the order that the object is introduced into the various dipping solutions, the solution and environmental conditions used (pH, ionic strength, dielectric constant, temperature, etc.). In addition, the aforementioned procedure could be used to encapsulate various hydrophilic, amphiphilic, or lipophilic substances within the films by incorporating them, for example, in oil droplets or association colloids (such as micelles or liposomes). As a result, 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 nanolaminated coatings could be created entirely from food-grade ingredients (proteins, polysaccharides, lipids) by using simple processing operations such as dipping and washing.

❖ Nanofibers

Nanofibres 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 nanofibers are usually not composed of food grade substances, they have only a few potential applications in the food industry[28]. The food industry can use electro spun microfibers in several ways as under:

- 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 nanostructured and microstructured scaffolding for bacterial cultures.

As progress in the production of nanofibers from food biopolymers is made, the uses of biopolymericnanofibers in the food industry will increase[38].

❖ Nanotubes

Carbon nanotubes have been used nonfood application. The structures have been used as low resistance conductors or catalytic reaction vessels among other uses. [39]Certain globular proteins from milk (such as hydrolyzed α-lactalbumin) can be made to self-assemble to form nanotubes under appropriate conditions. Nanotubes made of the milk protein α -lactalbumin are formed by self-assembly of the partially hydrolysed molecule[40]. [41]Examined that at neutral pH and in presence of an appropriate cation, these building blocks self-assemble to form micrometre-long tubes with a diameter of only 20 nm. According to[42], the features of the α-lactalbumin nanotube makes it an interesting potential encapsulating agent. Because α-lactalbumin is a milk protein it will be fairly easy to apply the nanotubes in foods or pharmaceutics. These nanostructures promise various applications in food, nanomedicine etc.,[43].

❖ Nanocapsules

A number of new processes and materials derived from nanotechnology have the potential to provide new solutions to dairy and food processing fronts. 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[42]. [44]Casein micelles (CM) are in effect nano-capsules created by nature to deliver nutrients such as calcium phosphate and protein to the neonate.

❖ Nanostructures and Nanoparticles in food

The functionality of many raw materials and the processing of foods arise from the presence, modification, and generation of forms of self-assembled nanostructures[8]. 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[45]. 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 airwater 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[46]. 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 area that has led to most debate on nanotechnology and food is the incidental or deliberate introduction of manufactured nanoparticles into food materials.

❖ Nanoceuticals

The concept of "nanoceuticals" is gaining popularity and commercial dairy/food and food supplements containing nanoparticles are available [8 and 47].

The examples of food-related nanoproducts are:

- ✓ Carotenoids nanoparticles can be dispersed in water, and can be added to fruit drinks for improved bioavailability;
- ✓ Canola oil based nanosizedmicellar system is claimed to provide delivery of materials such as vitamins, minerals, or phytochemicals;
- ✓ A wide range of nanoceutical products containing nanocages or nanoclusters that act as delivery vehicles, e.g., a chocolate drink claimed to be sufficiently sweet without added sugar or sweeteners;
- ✓ Nanosilver or nanogold are available as mineral supplements;
- ✓ To prevent the accumulation of cholesterol some of the nutraceuticals incorporated in the carriers include lycopene, beta-carotenes and phytosterols.

❖ Nanoencapsulation

Nanoencapsulation is defined as a technology to pack substances in miniature making use of techniques such as nanocomposite, Nano emulsification, and nanoestructuration and provides final product functionality that includes controlled release of the core.

Nanoencapsulation is incorporation of ingredients in small vesicles or walled material with nano (or submicron) sizes[48]. These nanomaterials offer several advantages such as, delivery vehicle for lipid soluble ingredients, protection from degradation during processing or in GIT, controlled site specific release, compatible with other food constituents, greater residence time and greater absorption[(8, 49 and 28)]. The protection of bioactive compounds, such as vitamins, antioxidants, proteins, and lipids as well as carbohydrates may be achieved using this technique for the production of functional foods with enhanced functionality and stability. Lipid-based nanoencapsulation systems enhance the performance of antioxidants by improving their solubility and bioavailability, *in vitro* and *in vivo* stability, and preventing their unwanted interactions with other food components. The main lipid-based nanoencapsulation systems that can be used for the protection and delivery of foods and nutraceuticals are nanoliposomes, nanocochleates, and archaeosomes[50]. Nanoliposome technology presents exciting opportunities for food technologists in areas such as encapsulation and controlled release of food materials, as well as the enhanced bioavailability, stability, and shelf-life of sensitive ingredients. Nanoencapsulation technologies have the potential to meet food industry challenges concerning the effective delivery of health functional ingredients and controlled release of flavor compounds. Zein, the prolamine in corn endosperm binds and enrobes lipids, keeping them from deteriorative changes[51]. Nanocochleates consists of a purified soy based phospholipid that contains at least about 75% by weight of lipid that can be phosphotidyl serine, dioleoylphosphatidylserine, phosphatidic acid, phosphatidylinositol, phosphatidyl glycerol and/or a mixture of one or more of these lipids with other lipids.Nanocochleates are nanocoiled particles that wrap around micronutrients and have the ability to stabilize and protect an extended range of micronutrients and the potential to increase the nutritional value of processed foods[52].

❖ Nano encapsulation of probiotics

According to FAO/World health organization (WHO) (2002), probiotics are defined as “live microorganisms which when administered in adequate amounts confer a health benefit on the host”. Probiotics are generally defined as live mixtures of bacterial species and can be incorporated in foods in the form of yoghurts and yoghurt-type fermented milk, cheese, puddings and fruit based drinks. Encapsulated forms of ingredients achieve longer shelf life of the product. They can be incorporated in fermented milk, yoghurts, cheese, puddings, fruit based drinks etc. Nanoencapsulation used to develop designer probiotic bacterial preparations that could be delivered to certain parts of the gastro-intestinal tract where they interact with specific receptors. These nanoencapsulated designer probiotic bacterial preparations may act as *de novo* vaccines, with the capability of modulating immune responses[53]. A stearin-rich milk fraction was used, alone or in combination with α-tocopherol, for the preparation of oil-in-water sodium caseinate-stabilized nanoemulsions. Immobilization of α-tocopherol in fat droplets, composed by high melting temperature milk fat triglycerides, provided protection against degradation[54].

APPLICATIONS IN FOOD PROCESSING

- **Nanofrying**

The US based Oilfresh Corporation has marketed a new nanoceramic product which reduces oil use in restaurants and fast food shops by half because of its large surface area[(16 and 55)].

- **Novel foods**

Kraft Foods and NanoteK consortium have plans to incorporate the electronic tongue (which is chemical change based biosensor) into foods to release accurately controlled amounts of the suitable molecules for the customized tailor-foods[(18and 56)].

- **Nanofiltration**

Nano Filtration separating materials of less than 0.001 microns (10 angstroms) in size and rejects divalent and multivalent ions[(57 and 1)]. It has application in desalination, milk, whey and juice filtration, demineralization, color removal, concentration of products, waste water treatment and water purification[58-62].

APPLICATION IN FOOD PACKAGING

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[63] (El Amin, 2006). Food packaging is considered to be one of the earliest commercial applications of nanotechnology in the food sector.[64] 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 applications as Food Contact Materials (FCMs) are anticipated to grow from a $66 million business in 2003, to over $360 million by 2008[65]. Applications for food contact materials (FCMs) using nanotechnology is as follow:

- ❖ FCMs incorporating nanomaterials to improve packaging properties (flexibility, gas barrier properties, temperature/moisture stability, light and flame resistant, transparency, mechanical stability).

- ''Active'' FCMs that incorporate nanoparticles with antimicrobial or oxygen scavenging properties.
- ''Intelligent''or "smart" food packaging incorporating nanosensors for sensing and signaling of microbial and biochemical changes, release of antimicrobials, antioxidants, enzymes, flavours and nutraceuticals to extend shelf-life.
- Biodegradable polymer–nanomaterial composites by introduction of inorganic particles, such as clay, into the biopolymeric matrix and can also be controlled with surfactants that are used for the modification of layered silicate[10, 13, 14, 16, 59, 66, 67].

✓ **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[(4, 35 and68)].

✓ **Nanolaminates**

Nanotechnology provides food scientists with a number of ways to create novel laminate films suitable for use in the food and dairy industry. According to[69], 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.

✓ **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.[70]A United States CompanyOxonicalnc, has developed nano-barcodes to be used for individual items or pellets, which must be read with a modified microscope for anti- counterfeiting purposes. Another trend in the application of nanopackaging is the nano-biodegradable packaging. The use of nanomaterials to strengthen bioplastics (plant-based plastics) may enable bioplastics to be used instead of fossil-fuel based plastics for food packaging and carry bags[71].

CONCLUSION

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 short term. Successful applications of nanotechnology to foods are limited. Nanotechnology can be used to enhance food flavor and texture, to reduce fat content, or to encapsulate nutrients, such as vitamins, to ensure they do not degrade during a product's shelf life. In addition to this, nanomaterials can 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. Many of the principles, applications, and techniques that are included in the term "nanotechnology" are the same or fairly similar to those that has already been widely understood and utilized. In particular, there are major areas of overlap between nanotechnology and the more traditional disciplines of colloid, interfacial, and polymer science. However, as this summary shows, one of the defining features of nanotechnology appears to be the emphasis on building structures on the nanoscale rather than on just understanding their properties (which was a major focus of more traditional disciplines).

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. It is important to note that nanofoods originate in the laboratory, hence are not the same thing as conventional nanofoods. However, nanotechnology food packaging was assessed as less problematic than nanotechnology foods. It is widely expected that nanotechnology- derived food products will be available increasingly to consumers worldwide in the coming years.

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