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A review on application of nano-technology in food industry: Nano-encapsulation, nano-sensors and nano-emulsions

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Abstract
Nano-technology proved the recent innovative applications in the food industry. In the area of functional foods, nano-technology exposed to be an efficient method in the field particularly in the food industry. Nano-encapsulation is the most significant favourable technology having the possibility to ensure bioactive chemicals. Nano-sensor application in food industry is the booming applications for the food quality analysis and food tracing studies. Nano-emulsions display numerous advantages over conventional emulsions due to the small droplets size it contains high optical clarity, excellent physical consistency against gravitational partition and droplet accumulation, and improved bio-availability of encapsulated materials, which make them for food applications. This review paper highlights the applications of the current nano-technology research in nano-encapsulation, nano-sensors and nano-emulsions.

Keywords: Nano-particles, food safety, electronic tongue, colloids and liposomes

1. Introduction
Over the past few decades, nano-technology has increasingly been considered as to be attractive technology that has revolutionized the food sector. It is a technology on the nano-meter scale and deals with the atoms, molecules, or the macromolecules with the size of approximately 1-100 nm to create and use materials that have novel properties. The created nano-materials possess one or more external dimensions, or an internal structure, on the scale from 1 to 100 nm that allowed the observation and manipulation of matter at the nano-scale. It is observed that these materials have unique properties unlike their macro-scale counterparts due to the high surface to volume ratio and other novel physiochemical properties like colour, solubility, strength, diffusivity, toxicity, magnetic, optical, thermodynamic, etc. Nano-technology has brought new industrial revolution and both developed and developing countries are interested in investing more in this technology. Therefore, nano-technology offers a wide range of opportunities for the development and application of structures, materials, or system with new properties in various areas like agriculture, food, and medicine, etc. (Qureshi *et al*., 2012) [12].

The rising consumer concerns about food quality and health benefits are impelling the researchers to find the way that can enhance food quality while disturbing least the nutritional value of the product. The demand of nano-particle-based materials has been increased in the food industry as many of them contain essential elements and also found to be non-toxic. They have been also found to be sstable at high temperature and pressures. Nano-technology offers complete food solutions from food manufacturing, processing to packaging. Nano-materials bring about a great difference not only in the food quality and safety but also in health benefits that food delivers. Many organizations, researchers, and industries are coming up with novel techniques, methods, and products that have a direct application of nano-technology in food science (Dasgupta *et al*., 2015) [3].

The applications of nano-technology in food sector can be summarized in two main groups that are food nano-structured ingredients and food nano-sensing. Food nano-structured ingredients encompass a wide area from food processing to food packaging. In food processing, theses nano-structures can be used as food additives, carriers for smart delivery of nutrients, anti-caking agents, anti-microbial agents, fillers for improving mechanical strength and durability of the packaging material, etc. whereas food nano-sensing can be applied to achieve better food quality and safety evaluation. In this review, we have summarized the role of Nano-technology in food science and food micro-biology and also discussed some negative facts associated with this technology (Ezhilarasi *et al*., 2013) [13].

2. Nano-technology in food industry

Food nano-technology has its history from Pasteurization process, introduced by Pasteur to kill the spoilage bacteria (1000 nano-meters), who made the first step of revolution in food processing and improvement in quality of foods. Despite this, in the last two decades, the “nano-world” has caught the eye of the food industry creating a new range of materials and processes aimed for improving not only the organoleptic characteristics of food, but also to contribute with other features like their nutritional characteristics, their safety and packaging, among others. The food and beverage sector is a global multi trillion dollar industry. All the major food companies are consistently looking for ways to improve production efficiency, food safety and food characteristics. Extensive research and development projects are on-going with the ultimate goal of gaining competitive advantage and market share. A nano-material is defined as an “insoluble, bio persistent and intentionally manufactured material, with one or more external dimensions, or an internal structure, on the scale from 1 to 100 nano-meters. The understanding of taste receptors and flavour perception is leading to the development of an ‘‘electronic tongue’’ for describing the taste attributes of food. Indeed, the manipulation of substances so close to the molecular level has blurred the boundaries between a numbers of traditional food science disciplines (Cushen *et al*., 2012) [2].
Nano-technology is thus defined as the design and fabrication of materials, devices and systems with control at nano-meter dimensions. Encompassing nano-scale science, engineering and technology, nano-technology involves imaging, measuring, modeling and manipulating matter at this scale. The size of vital biomolecules such as sugars, amino acids, hormones and DNA is in the nano-meter range. Every living organism on earth exists because of these nano-structures. Applications with structural features on the nano-scale level have physical, chemical and biological properties which makes nano-technology beneficial on various levels (Kour *et al*., 2015) [9].

Nano-scale control over food molecules may lead to the modification of many macro-scale characteristics, such as texture, taste, other sensory attributes, process ability and stability during shelf life. The main developments of nano-technology, in food science, involve altering the texture of food components, encapsulating food components or additives, developing new tastes and sensations, controlling the release of flavours, and/or increasing the bioavailability of nutritional components. Nano-food is also related to the improvement of food colour, prolongation of shelf life and preservation, detection of germs and anti-bacterial characteristics, and intelligent packaging materials. In addition, nano-food includes not only the processed food category, but also entire areas from cultivation to packaging (Cushen *et al*., 2012) [2].

3. Nano-encapsulation

Particle encapsulation is a standard process in the food industry that consists of encapsulating particles in a protective layer, covering, or containment material to protect a sensitive ingredient or nucleus from adverse reactions. This consists of encapsulating small particle cores in a protective wall with the aim to preserve organoleptic and physico-chemical properties of the original products as well as to improve the palatability of volatile odorous ingredients. Encapsulation of flavours and aromas is a rapidly expanding process in the food industry. Many aroma compounds must to be converted into solid products before its use as flavouring agents. Nano and micro-encapsulation technology is a very promising area in food industry which will have a great impact on a wide variety of products including functional foods, packaging, preservatives, anti-oxidants, flavours and fragrances. Spray drying is a widely used technique to eliminate water and other solvents from solutions, emulsions and suspensions. Spray drying is a rapid, convenient and low cost method in comparison to other techniques as lyophilization (Fig. 1). This technology is one of the most common encapsulation methods used in the food industry because of its advantages, such as the wide availability of equipment, large-scale production, simple continuous unit operation, ease of manipulation and low process cost (Paredes *et al*., 2016) [11].

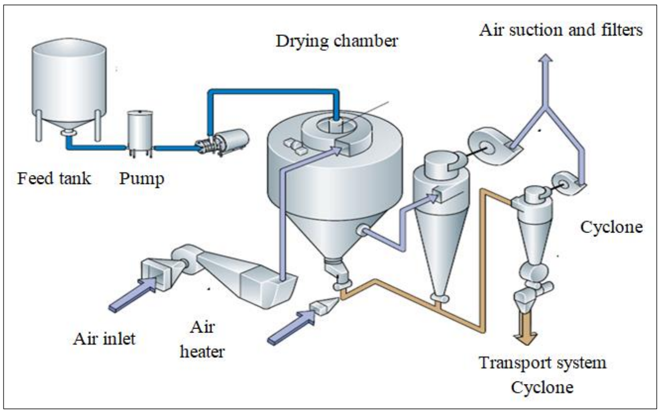

Fig 1: Conventional nano-spray dryer with different parts

Recent studies have begun to address the use of nano-encapsulation of active compounds such as flavours, vitamins, minerals, anti-microbial, drugs, colorants, anti-oxidants, probiotic micro-organisms, and micro-nutrients. Encapsulation is applied in food technology to mask odours or tastes, control interactions of active ingredients with the food matrix, control the release of the active agents, ensure availability at a target time and specific rate and protect them from moisture, heat, chemical, or biological degradation during processing, storage and utilization, and also compatibility with other compounds in the system (Weiss *et al*., 2006) [14]. Therefore, a large number of delivery systems such as emulsions, biopolymer matrices, simple solutions, and association colloids have been developed to maintain active compounds at suitable levels for long periods of time. Using targeted nano-carriers reduces the toxicity and the efficiency of distribution. Nanoparticles have better properties for encapsulation and release efficiency than traditional encapsulation systems (Roy *et al*., 1999) [13]. Functional foods can be encapsulated in these nano-particles (form food grade proteins or polysaccharides) and released in response to specific environmental triggers. In fact the change of solution conditions induces particle dissolution or porosity.

The efficiency of delivery systems can be increased by dendrimer (unique class of polymer) coated particles. Dendrimers which have regular, highly branched 3-dimensional structure can be applied as sensors, catalysts, delivery of drugs, and in gene therapy. The main criteria for using dendrimers as delivery system are their nontoxicity, non-immunogenecity and biodegradability. Cochleates are small-sized and very stable delivery system with a multi-layered structure consisting of a large, continuous, solid lipid bilayer sheet rolled up into a spiral (Fig. 2). They can be applied to encapsulate many bioactive materials such as compounds with poor water solubility, peptide, protein, drugs, and large hydrophilic molecules (Gould-Fogerite *et al*., 2007) [6].

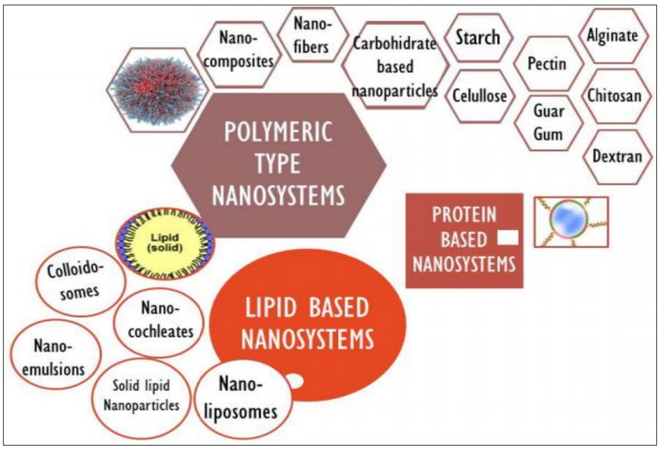

Fig 2: Wall materials used in nano-encapsulation of food ingredients

Aqueous solution of starch-based nanoparticles which behave like colloids can be applied in mixing, emulsifying, producing of paints, inks, and coatings (Fig. 3). Colloids also have been used for encapsulation and delivery of polar, nonpolar, or amiphilic functional ingredients. Micelles are spherical particles (5-100 nm diameter) and have the ability to encapsulate nonpolar molecules including lipids, flavorants, anti-microbials, anti-oxidants and vitamins. In 2007 the Meridian Institute reported a new product (Novasol CT) as a solution containing nanoparticles, which can be applied to add anti-oxidants into food and beverage. In this product, the nanoparticles called micelles carry anti-oxidants and can be used to introduce vitamins A, C, and E, and Q10 to food and beverages without changing substances (Weiss and McClements, 2002) [15].

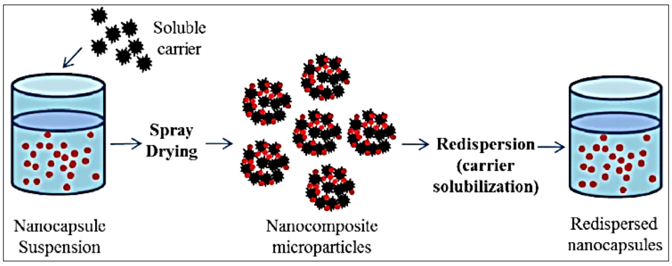

Fig 3: Spray dried nano-capsule suspension and re-dispersion

4. Nano-emulsions

Nano-emulsions are produced by high-pressure value homogenizers or micro-fluidizers with a droplet diameter less than 100-500 nm. Functional food ingredients can be incorporated within the droplet, the interfacial region, or the continuous phase to reduce the chemical degradation process. Multiple emulsions can be used as delivery system with novel encapsulation and delivery properties including oil in water in oil (o/w/o) and water in oil in water (w/o/w) emulsions. The multilayer emulsions can produce novel delivery systems containing oil droplets surrounded by multilayer interfaces (nano-meter thick layers consist of different polyelectrolyte). They have more stability against environmental stresses than conventional oilin-water emulsions with single layer interfaces. In these systems, functional ingredients (e.g., polysaccharides, proteins, and phospholipids) are trapped within the core of a multilayer emulsion delivery system (Gu *et al*., 2005) [7].

Liposomes or lipid vesicles are extremely suitable systems to deliver a broad spectrum of substances in functional food, agricultural, biological, biochemical, pharmacological, etc. They are closed, continuous bi-layered structures made mainly of lipid and/or phospholipid molecules and can be prepared by the heating method in which no harmful chemical or procedure is involved. Lipid vesicles can be made of uni- or multi-lamellar, containing one or many bilayer shells, respectively. An overview of eight different liposome-derived nano-carriers with respect to their characteristics, preparation methods and application had been presented. Liposomes can be used for controlled delivery of functional ingredients including enzymes, vitamins and flavours in different food applications. Liposomes can encapsulate enzymes to increase the speed of cheese ripening and vitamins to increase the nutritional quality of dairy products. Lee and Martin (2002) [10] reported that degradation of retinol entrapped in liposomes was decreased by the addition of vitamin E (α-tocopherol). These studies show that the use of liposomes can increase the protection of bioactivity of nutrients against degradation in food (Fig. 4).

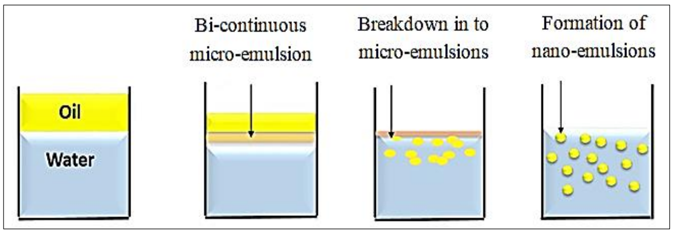

Fig 4: Nano-emulsion with oil droplet and emulsifier

5. Nano-sensors

Biosensors may be applied for detecting gases, pathogens, or toxins in packaged foods. Using nano-biosensors have been reported for the detection of pathogens in processing plants or alerting consumers, procedures, and distributors on the safety status of food (Helmke and Minerick, 2006) [8].

An electrochemical glucose biosensor was nano-fabricated by layer-by-layer self-assembly of polyelectrolyte for detection and quantification of glucose. Liposome nano-vesicles have been applied for detection of peanut allergenic proteins in chocolate and pathogens. Using universal protein G-liposomal nano-vesicles and an immouno-magnetic bead sandwich assay can simultaneously detect E. coli O157:H7, Salmonella spp, and Listeria mono-cytogenes. Electronic nose is a device which is applied for identifying different types of odours. Gas sensors are the main components in an E-Nose and composed of nano-particles, for example, zinc oxide nano-wires. Immuno-sensing of Staphylococcus entrotoxin B (SEB) in milk was reported using poly (dimethyl siloxane) (PDMS) chips with reinforced, supported, fluid bilayer membranes. Anti-bodies to entrotoxin were attached to the bilayer membrane in PDMS channels from a biosensor (Dong *et al*., 2006) [4].

A quartz crystal micro-balance based biosensor has been reported using 50 nm gold nano-particles as amplification probes for DNA detection. 1-Dodecanethiolencapsulated colloidal gold array has been used to establish DNA-based nano-electronic devices (Fig. 5). A recent report suggests that complementary DNA sequences could be sensed by immobilizing thiol-modified DNA probe onto gold nano-particle coated electrode. A gold nano-particle coated quartz crystal micro-balance based DNA sensor has been reported for the detection of E. coli O157:H7 synthesized oligonucleotides. The use of nano-particles amplifies the signals and improves the detection limit for pathogenic bacteria detection. Micro-fluidics coupled with micro-arrays, micro-motors, and micro-heaters generate low power consumption devices which could be applied for in situ detection of food pathogens in different samples with very high degree of sensitivity and specificity (Arora *et al*., 2006) [1].

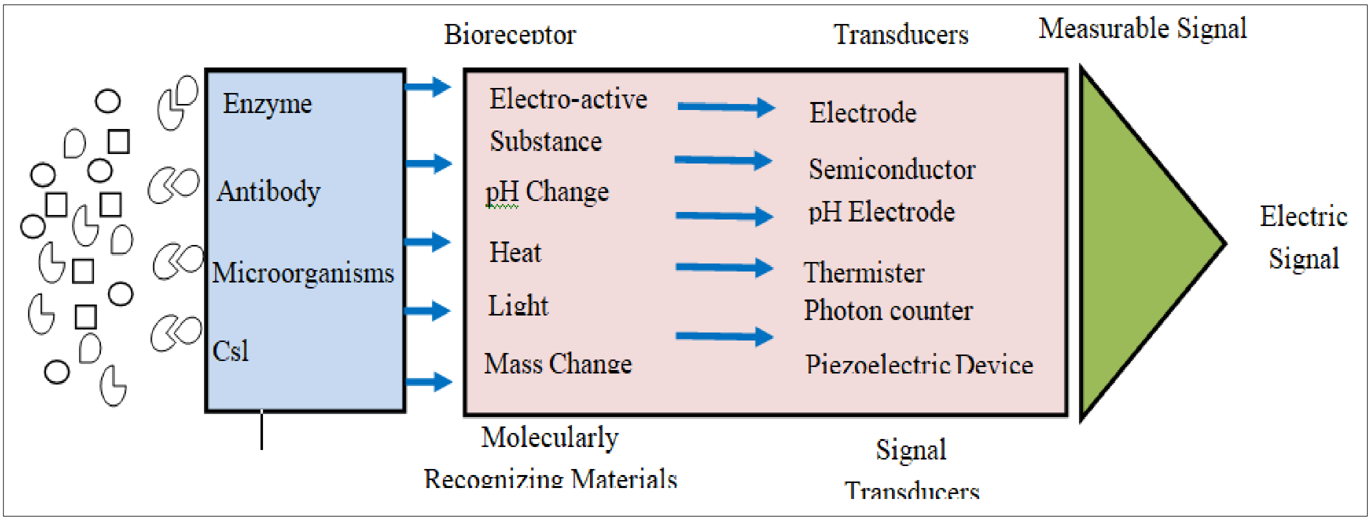

Fig 5: Nano-sensor with components

6. Conclusion

Nano-technology may develop devices for rapid identification deficiencies of nutrients and the presence of pathogens in food. Numerous applications of nano-technology in food systems and processing have been developed in many countries, some of which include nano based-food additives, Nano-sensors, nano-capsules, nano-based smart delivery systems, nano-packaging and health care and medicine. Nowadays people fairly identified and accepted the effects of using nano-technology in their life. The potential of nano-technology make it suitable for developing countries because these countries could potentially engage some of the new markets for new nano-materials and production processes. Nano-technology can improve public awareness. Many government departments paid more money towards research and development of functional food, nutrient delivery systems, colour, flavour and consistency, food packaging, and detection of nano based nutrients and metabolites structure. Base on the above descriptions, nano-foods would be produced by the use of nano-technology techniques and devices for cultivation, processing, packaging, production, suitable detection of fine food molecule structure, or molecular interactions on nano-scale and food quality. Finally, nano-technology enables to change the existing food systems and processing to ensure products safety, creating a healthy food culture and enhancing the nutritional quality of food.

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