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Nanotechnology: Recent and Emerging Applications in Food Industry

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Abstract: ***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. Strategies to apply nanoscience to the food industry are quite different from these more traditional applications of nanotechnology. Food processing is a multi-technological manufacturing industry involving a wide variety of raw materials, high bio-safety requirements, and well-regulated technological processes. Four major areas in food production may benefit from nanotechnology: development of new functional materials, microscale and nanoscale processing, product development, and methods and instrumentation design for improved food safety and biosecurity.This article provides an overview of potential and up-coming applications of nanotechnology in the area of food science and technology and its advantages over conventional processing techniques.***

Keywords: Nanotechnology, nano-composite, nanoemulsion, nanoclay, nanotubes, nanolaminates, nanofibers

1. Introduction

A novel tiny particle added to packaging material that can improve barrier properties of film or minute bioactive ingredients incorporated in food stuffs that enhance their biological quality or very fine fibers that form matrix for the production of imitation foods. What do these three products have in common? They are all examples of food innovations made possible by the rapidly growing field of nanotechnology.

Nanotechnology focuses on the characterization, fabrication, and manipulation of biological and non-biological 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. 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. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale."

With the increased funding opportunities and interest in this field, the term "nano" is more frequently and often liberally used, which has led to some criticism within the scientific community. Whether justified or not, it should be understood that the entire field of nano science is essentially an eclectic derivative of established disciplines such as chemistry, interface science, micro-fabrication technologies, and so on. However, use of the term "nano" does allow researchers to highlight the fact that processes (for example, nano manufacturing) or material structures (for example, nano materials) are designed and optimized to use specific properties and behaviors at lengths of 10^{-7} to 10^{-9} m. The types of material produced by nanotechnology can be at the nanoscale in one dimension (very thin coatings), two dimensions (nanowires and nanotubes) or three dimensions (nanoparticles, such as very fine powder preparations). Nanotechnologies are not new – chemists have been making polymers based on nanoscale sub-units for many years and we are also exposed to nanoparticles in daily life (such as from vehicular exhaust emissions). "Nanomaterial" means a material that meets at least one of the following criteria:

- Is made of particles, including aggregates or agglomerates thereof, with one or more external dimensions in the size range 1 nm -100 nm for more than1% of their number size distribution, or
- Has internal or surface structures in the size range 1 nm – 100 nm, or
- Has a specific surface area by volume higher than 60 m^2/cm^3.

The fact that systems with structural features on the nanoscale have physical, chemical, and biological properties substantially different from their macroscopic counterparts is changing the understanding of biological and physical phenomena in food systems. Since foods are complex biological systems that are governed by many of the same basic mechanisms and principles that biologists and biochemists study, one would expect that the discoveries made in nanotechnology may eventually also impact the food industry. However, foods undergo a variety of postharvest and processing-induced modifications that affect the biological and biochemical functionality of the system. Nanotechnology allows scientists to measure, control, and manipulate matter at the nanoscale level to change those properties and functions in a beneficial way.

2. Potential Food Applications

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 and tracking of individual shipments.
- Systems that provide integration of sensing, localization, reporting, and remote control of food products (smart/intelligent systems) and that can increase efficacy and security of food processing and transportation.
- Encapsulation and delivery systems that carry, protect, and deliver functional food ingredients to their specific site of action.

Most nanotechnological research focuses on the development of applications in biosciences and engineering. Strategies to apply nanoscience to the food industry are quite different from these more traditional applications of nanotechnology. Food processing is a multi-technological manufacturing industry involving a wide variety of raw materials, high bio-safety requirements, and well-regulated technological processes. Four major areas in food production may benefit from nanotechnology: development of new functional materials, microscale and nanoscale processing, product development, and methods and instrumentation design for improved food safety and biosecurity.

In their widest sense, nanotechnology and nanomaterials are a natural part of food processing and conventional foods, because the characteristic properties of many foods rely on nanometre sized components (such as nanoemulsions and foams). However, recent technological developments lead the way for manufactured nanoparticles to be added to food. These could be finely divided forms of existing ingredients, or completely novel chemical structures. Nanotechnology and nanomaterials can be a natural part of food processing and conventional foods, and the characteristic properties of many foods rely on nanometre-sized components (such as nanoemulsions and foams). Below are few examples of nanomaterials which have potential to be used in food industry:

2.1 Nanoclay

The mineral montmorillonite (also called as bentonite) has potential use in a variety of food packaging applications, such as in packaging for fruit juices and dairy products or bottles for beer and carbonated drinks, to provide a better barrier to gases and extend shelf-life. Plastic beer bottles that incorporate a layer of nanoclay are reported to be in use in some countries.

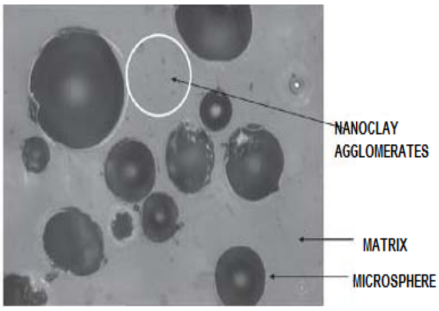


Figure 1: Microscopic view of Nano sized clay

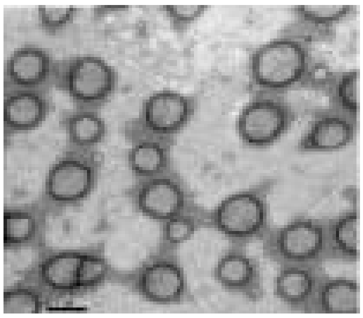
2.2 Nanosilver

Items such as re-useable food containers having nanosilver as one of the components are available in few countries and function to inhibit the growth of microorganisms.

Picture 2: Encapsulated nano-silver particles

2.3 Nanodispersions and Nanocapsules

Functional ingredients (for example, drugs, vitamins, antimicrobials, antioxidants, flavorings, colorants, and preservatives) are essential components of a wide range of industrial products, including pharmaceuticals, health-care products, cosmetics, agrochemicals, and foods. These functional ingredients come in a variety of different molecular and physical forms such as polarities (polar, nonpolar, amphiphilic), molecular weights (low to high), and physical states (solid, liquid, gas) and are being produced in the form of dispersions or capsules using nanotechnology.



Picture 3: Microscopic view of nanodispersion

2.4 Biopolymeric nanoparticles

Particles in the nanometer-sized range can often be produced using food-grade biopolymers such as proteins or polysaccharides [1]-[2]. These particles may be formed by promoting self-association or aggregation of single biopolymers or by inducing phase separation in mixed biopolymer systems, for example, using aggregative (net attraction) or segregative (net repulsion) interactions. Functional ingredients can be encapsulated in nanoparticles formed and released in response to specific environmental triggers by altering the solution conditions to induce complete particle dissolution or changes in particle porosity.

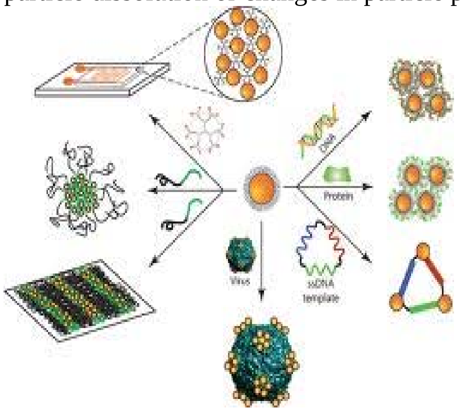


Figure 4: Formation of various biopolymeric nanoparticles

2.5 Nanofibers

The production of fibers with diameters of less than 100 nm is now feasible with the invention of the electrospinning process. Electrospinning is a manufacturing technology capable of producing thin, solid polymer strands from solution by applying a strong electric field to a spinneret with a small capillary orifice. The food industry can use electrospun microfibers in several ways:

- 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.

While the number of applications that make use of electrospun fibers is increasing at an exponential rate, the applications for food and agricultural systems are relatively few. This is probably because fibers are not typically composed of biopolymers used in food and agriculture; they are made primarily from synthetic polymers. As progress in the production of nanofibers from food biopolymers is made, the use of biopolymeric nanofibers in the food industry will likely increase.

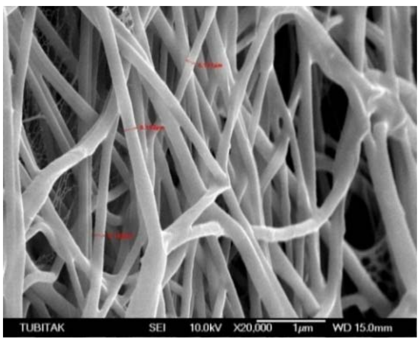


Figure 5: Microscopic view of nano fibers

2.6 Nanotubes

Carbon nanotubes have been widely used as a nonfood application of nanotechnology. These structures have been used as low-resistance conductors or catalytic reaction vessels among other uses. It has been shown that certain globular proteins from milk (such as hydrolyzed α-lactalbumin) can be made to self-assemble into similarly structured nanotubes underappropriate environmental conditions [8]-[9]. This technique is applicable to other proteins as well and has been explored to assist in the immobilization of enzymes.

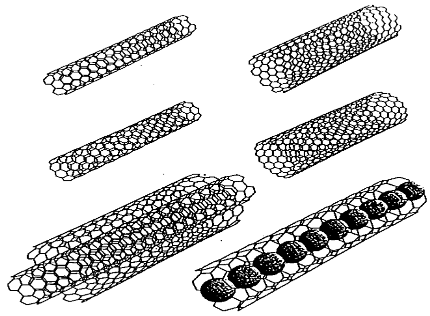


Figure 6: Schematic representation of Carbon nano-tubes

2.7 Nanolaminates

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 advantages for the preparation of edible coatings and films over conventional technologies and may thus 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 (Morillon and others 2002; Cagri and others 2004; Cha and Chinnan 2004; Rhim 2004). Kotov (2003) stated that 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.

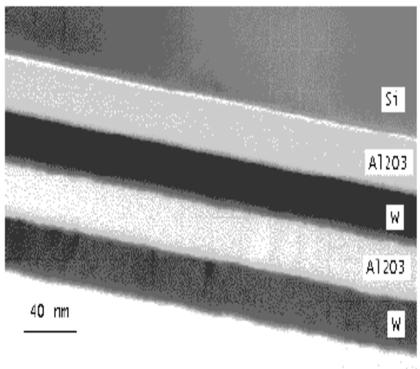


Figure 7: Cross sectional view of Nanolaminates

3. Nanoencapsulation and Future Trends

3.1 Nanomers

Nanomers are surface modified montmorillonite minerals available for a range polymer resins from commodity polyolefins to specialty polyamides. Incorporation into these resins forms a nanocomposite plastic. Because nanomers are used at low addition levels, significant property improvement is achieved with lighter part weight. Due to Nanomers platey morphology and propensity to accelerate polymer crystallization, gas barrier enhancement is a common feature. Depending on the specific resin, gas barrier property can be improved dramatically. Nanocomposite plastics are potent char formers, making them a valuable tool in creating improved fire retardant materials.

Nanocomposites are prepared by dispersing a Nanomer nanoclay into a host polymer, generally at less than 5wt% levels. This process is also termed exfoliation. When a nanoclay is substantially dispersed it is said to be exfoliated. Exfoliation is facilitated by surface compatibilization chemistry, which expands the nanoclay platelets to the point where individual platelets can be separated from another by mechanical shear or heat of polymerization. Nanocomposites can be created using both thermoplastic and thermoset polymers, and the specific compatibilization chemistries designed and employed are necessarily a function of the host polymer's unique chemical and physical characteristics.

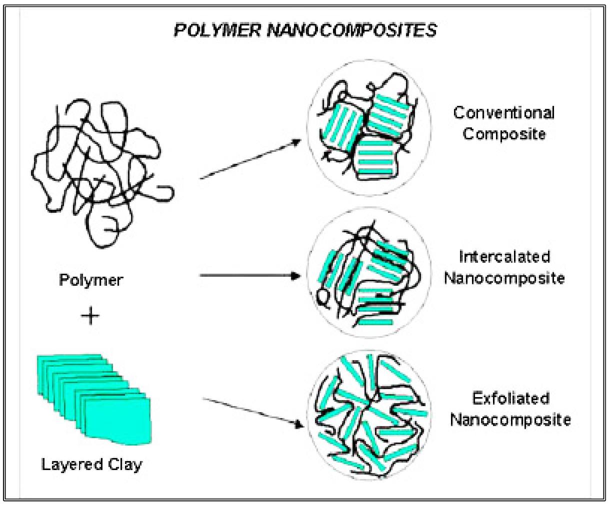


Figure 8: Forms of nano-composites

3.1.1 Advantages over conventional methods:

- In general, nanocomposites exhibit gains in barrier, flame resistance, structural, and thermal properties yet without significant loss in impact or clarity.
- Because of the nanometer-sized dimensions of the individual platelets in one direction, exfoliated Nanomer nanoclays are transparent in most polymer systems.
- With surface dimensions extending to 1 micron, the tightly bound structure in a polymer matrix is impermeable to gases and liquids, and offers superior barrier properties over the neat polymer.
- Nanocomposites also demonstrate enhanced fire resistant properties and are finding increasing use in engineering plastics.
- Provides source reduction and/or improved sustainability relative to EVOH & PVDC
- Excellent barrier up to 80% RH
- Large enhancements of moisture barrier when coated on flexible packaging films
- Meets compostibility standards on bio-derived films
- Compliant with US and European food contact standards
- Targets dry food applications such as salty snacks, nuts, coffee
- Can be applied at high speeds using standard gravure coating methods
- No halogen, VOC's, or hazardous materials

3.2 Nanoencapsulation

The global food encapsulation market is projected to reach about $39 billion by the year 2015, according to a report from Global Industry Analysts, Inc. (GIA) and here, nanoencapsulation is going to play a crucial role. Organic constituents that are naturally present in foods such as protein, carbohydrate and fat can vary in size from large polymers to simpler molecules in the nano range. Organic nanomaterials can be synthesised for specific purposes such as the encapsulation of nutrients to increase bioavailability, enhance taste, texture and consistency of foodstuffs or mask an undesirable taste or odour. Work has been done by Francisco *et.al*. [10] on nanoencapsulation of various bioactive compounds, for instance β-carotene, production of microencapsulated xanthophyll for improving solubility and stability by nanoencapsulation [11], nanoencapsulation of essential oils to enhance their antimicrobial activity in food and so on.

One of the remarkable developments done by Gökmen*et. al.*[12] in this field is development of functional bread containing omega-3-fatty acid in which high amylose corn starch was used to form nanosized complexes with flax seed oil that was converted to powder of microparticles by spray drying followed by incorporating in the bread dough.

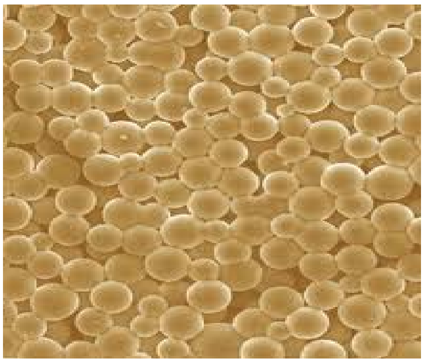


Figure 9: Nano-encapsulated oil droplets

3.3 Nano-Emulsions

The use of nanoemulsions is an example of how a nanotechnology can be applied to an existing process which can prove beneficial for the food industry. The small droplet size gives nanoemulsions unique rheological and textural properties which render them transparent and pleasant to the touch [13]. Using nanoemulsions in food products can facilitate the use of less fat without a compromise in creaminess, thus offering the consumer a healthier option. Products of this type include low fat nanostructured mayonnaise, spreads and ice creams [14].

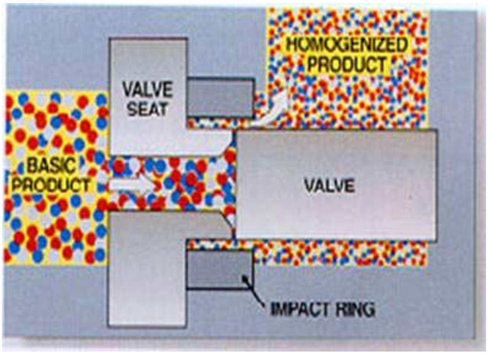


Figure 10: Production of Nano-emulsion

3.4 Nutraceutical at Nano-Scale

Nutraceutical compounds such as bioactive proteins are used in functional foods to impart a health benefit to consumers in addition to the nutrition that the food itself offers. Shegokar and Muller [15] in their study showed that reducing the particle size of bioactives may improve the availability, delivery properties and solubility of the bioactives and thus their biological activity because the biological activity of a substance depends on its ability to be transferred across intestinal membranes into the blood. The prospect of the production of nutraceuticals at the nanoscale, which will have increased stability throughout the processing chain, will be of significant interest to food processors trying to maximise nutrient content and hence will ultimately be of benefit to consumers.

3.5 Colour Enhancement

Nanotechnologies in relation to food colour are not well researched. However, the use of the oil-soluble pigment compound β-carotene to colour aqueous based foods may now become possible using nanoemulsion technology [16]. The formation of nanosize structures using alginic acid and calcium ions may allow the natural fat-soluble colourant to be used in a novel way. However, the idea of color effect of nanotechnology is still under developed.

4. Recent Work and Innovation

Imafidon and Spanier [17]by their study revealed that an important area where food nanotechnology is increasingly used is in the design of functional food ingredients such as food flavors and antioxidants. Ultimately, the goal is to improve the functionality of these ingredients in food systems, which may minimize the concentrations needed. These new functional ingredients are increasingly integrated into the food matrix development process [18]. Food ingredients such as nanoparticulate lycopene and carotenoids are becoming commercially available. Bioavailability and the ability to disperse these compounds are typically higher than that of their traditionally manufactured counterparts.

Work has been done by Moreira *et.al.*[19] on the development of bioactive edible films based on pectin as a dietary matrix and magnesium hydroxide ($Mg(OH)_2$) nanoplates as a reinforcing filler. Nanocomposites of high-methoxyl (HM) and low-methoxyl (LM) pectins were prepared using the casting method at concentrations of $Mg(OH)_2$ ranging from 0.5 to 5 wt %. These nanocomposites can release magnesium hydroxide by contact, demonstrating their potential for magnesium supplementation in bioactive packaging.

Some nanoparticles incorporated in the packaging material have also shown antibacterial activity against certain bacteria. Incorporating solid triclosan/cyclodextrin inclusion complexes (TR/CD-IC in poly(lactic acid) (PLA) nanofibers via electrospinning has resulted in better antibacterial activity against *Staphylococcus aureus* and *Escherichia coli* bacteria compared to PLA nanofibers containing only TR without CD-IC [20].

Woranuch S and Yoksan R[21] studied the possibility of using eugenol-loaded chitosan nanoparticles as antioxidants for active bio-based packaging material using thermoplastic flour (TPF) as biobased plastic. Results revealed that TPF containing eugenol-loaded chitosan nanoparticles exhibited superior radical scavenging activity and stronger reducing power compared with TPF containing naked eugenol. Similar study was carried out by Martelli *et. al*[22] in which over-ripe peeled banana puree was used as raw material for films processing containing pectin and glycerol as plasticizer and chitosan nanoparticles in small concentrations. This combination promoted noticeable improvement of the mechanical properties and acted in reducing the water vapor permeation rate of the film.

5. Conclusion

Food processing is a multi technological manufacturing industry involving a wide variety of raw materials, high biosafety requirements, and well-regulated technological processes. Four major areas in food production may benefit from nanotechnology: development of new functional materials, microscale and nanoscale processing, product development, and methods and instrumentation design for improved food safety and biosecurity. Nanotechnologies must be made more accessible to industry and to do this must be presented at later stages of development i.e. “ready to go” ideas and products. How-ever, regulatory issues must be addressed before industry adoption. To generate these well-developed ideas and products, production and/or importation of nanomaterials must be facilitated and regulated based on the principles of risk assessment.

In summary, there are a large number of potential applications of nanotechnology within the food industry; however, many of these may be difficult to adopt commercially because they are either too expensive or too impractical to implement on an industrial scale. There are limited numbers of nanotechnology applications that may have commercial potential in the near future. Most likely, the limited application of nanotechnology to the food industry will change as nanofabrication technologies become more cost-effective.

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