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The Role of Nanotechnology in Food Industries- A Review

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Authors' contributions

This work was carried out in collaboration between all authors. Authors IEA, SSDM and AAO drafted the manuscript. Author JDT wrote on 6.1 which are bioactive compounds in foods. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

This paper, points on the synoptic roles of nanotechnology in food industries which cover sectors such as food processing, encapsulation of nutraceuticals, food packaging, and food quality monitoring to enhance food safety and security. Nanotechnology refers to the engineering of material structures and sizes ranging from 1–100 nm to suit the need for different sectors. Nanotechnology possesses great potential to apply at all areas of the food sector, ensuring modification of color and flavor, nutritional values, increasing the shelf life of food, and monitoring the integrity of food via barcodes such as cold chain, i.e. whenever there is a slight change occur in food storage condition because of its submicroscopic nature. It can also modify permeation of materials by the incorporation of synthesized nanoparticles (zinc, silver, gold e.t.c) for better packaging system. From this review, it is evidently clear that the role of nanotechnology in food industries cannot be overemphasized. Currently, in nanotechnology, nanosensors serve as diagnostic devices to monitor food processes to meet the wholeness and safety of food.

Keywords: Nanotechnology; food processing; packaging; encapsulation; quality monitoring.

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1. INTRODUCTION

Nanotechnology is generally defined as the design, production, and application of structures, devices, and systems through control of size and shape of materials at the 10^{-9} of a meter scale [1].

Nanotechnology which is an emerging area of science has potentials to generate radical new products and processes in the food sector. Concepts in nanotechnology provide a sound framework for developing an understanding of the interactions and assembly behavior of food components into microstructure, which influences food structure, rheology, and functional properties at the submicroscopic scale [2].

There are many unveiled materials called 'nanomaterials' which are used for different food applications on an industrial scale. Titanium dioxide, which is a nanomaterial, is widely used as food additive and antimicrobial agent for food packaging and storage containers [3] and also proven to pose no toxic effect with an intermediate concentration on rats [4]. Silver nanoparticles (AgNps), are used as antimicrobial agents in food packaging, storage containers, chopping boards and refrigerators and also as health supplements [5]. Zinc and zinc oxide are used as nutritional additives and also as antimicrobial agents in food packaging [3]. Silicon dioxide and carbon have particles of a few hundred nm in size and are used as food additives and for food packaging [6]. Platinum and gold nano-wires are used as biosensors to improve food analysis [7,8], nanoproteins and nano polysaccharide and processed carbon particle are also used for packaging food [9-11]. Search for other nanoparticle and testing toxicity of unveiled nano-material with laboratory rat is the trend [8].

The food and bioprocessing industry is facing huge challenges with developing and applying systems that can produce high quality, safe foods as well as feed to an efficient, environmentally satisfactory, and sustainable person. While searching for the answer of these complex set of engineering and scientific challenges, innovation is needed for new processes, products, and tools in the food industry. Nanotechnology is gaining momentum and becoming a worldwide important tool for the food and bioprocessing industry in meeting up the world demand that results in increasing population growth and incomes in developing countries [12].

Nanotechnology has potential applications in all aspects of food chain including storage, quality monitoring, food processing, food packaging, improvement in the tastes, texture, flavor, enhanced nutrient absorption, improved packaging techniques and better pathogen detection system [13,14].

This review is generally aimed at revealing the potentials of nanotechnology in food quality monitoring using nanosensor, food packaging and encapsulation and delivery of food to ensuring the safety of food products.

2. SYNOPTIC APPLICATION OF NANOTECHNOLOGY IN FOOD INDUSTRIES

The food market demands technologies, which are essential to keep market leadership in the food processing industry to produce fresh authentic, convenient and flavourful food products, prolonging the product's self-life and freshness as well as improving the quality of food. Therefore, nanotechnology is considered as the key to promoting the food industry [3,15]. Its' synoptic application is shown in Fig. 1.

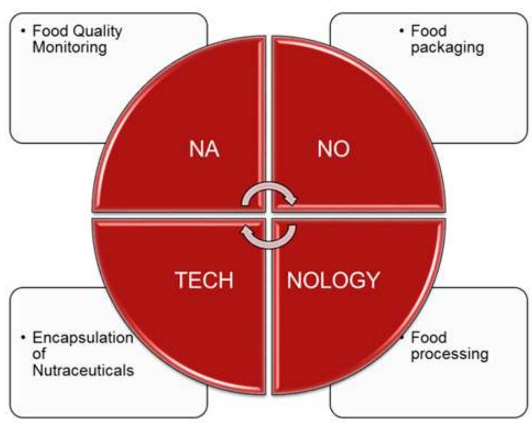

Fig. 1. Synoptic role of nanotechnology in food industries

3. NANOTECHNOLOGY IN FOOD PROCESSING

Nanotechnology has gained tremendous impetus because of its need in the food processing sector [1]. Many nutrients in food are destroyed by external conditions during processing and consumption. Hence, the need for seeking more nutritional supplements is expedient to bridge the loop holes in consuming better quality food [16].

With rapid spreading technology, conventional methods for processing food are being improved by new techniques. Nano wires are currently in use for the purification of water against the conventional filtration technique [8] and nanoclay is employed to bind mycotoxins in animal feeds [17] thereby extending the shelf life of the feed. Undoubtedly, nanotechnology will continually play a major role in this improvement. In food processing, such techniques may improve food processing yields and decrease waste or depletion of nutrients [18].

3.1 Nanotechnology in Animal Production / Reproduction and Animal Nano Feed

Among applications of nanotechnology is improving the feeding effectiveness and nutrition of agricultural animals, reducing losses from animal diseases, and turning animal by-products and waste and environmental concerns into value-added products [19].

Surface-functionalized nanomaterials called ‘nanoclay’ and nanosized additives are currently in use to bind and remove toxins or pathogens from processed food to yield better nano feed. Other processed nano feed (a food supplement for animals) encourages the activation of the animal’s own self-healing forces, equal to improved resistance against diseases, acts as an antioxidant to maintain healthy cell activity and overall animal health, improved bone growth, improved phosphate utilization, and reduction in mortality rates [17].

Nanotechnology promises to improve current agricultural practices through the enhancement of management and conservation of inputs in crops, animal production, and fisheries [20].

4. NANOTECHNOLOGY IN FOOD QUALITY MONITORING

The development of chemical sensors and biosensors over several decades has been investigated resulting in novel and very interesting sensing devices with great promise for many areas of applications including food technology. The incorporation of such sensors into the food packaging technology has resulted to what is called ‘smart or intelligent packaging’ [21]. Recent research has shown that luminescence oxygen biosensor is more compactible, relatively cheaper than another biosensor, in packaging materials for food monitoring [22].

The principles of smart packaging engage the use of chemically or biologically made a sensor to monitor the quality, integrity, wholeness, and safety of food from the producers to the costumers via delivery chain. This technology can result in a variety of sensor designed to change its coding when there is a breach of set parameters like pathogens invasion, leakage, carbon dioxide, oxygen, pH, time or temperature change. Thus, this technology is needed as on-line quality control and has great potential in the development of new sensing systems integrated into the food packaging, which are beyond the existing conventional technologies, like control of weight, volume, color and appearance [23].

Quality assurance in food and bioprocessing industry is of utmost importance because consumers demand safe and wholesome food, as well as governments, impose stringent regulations to ensure food safety and feed hygiene. Sensors or detection systems for -rapid detection of spoilage of product components, for quality control, and for abuse detection at the source and during production chain is possible through nanotechnology [1].

4.1 The Use of Nanosensor in Food Quality Monitoring

Nanosensors are engineered material of nano size material used for the detection of pathogens, toxins, early spoilage or contaminants in food. Nanosensors can provide quality assurance by tracking microbe throughout food processing chain through data capture for automatic control functions and documentation [1]. It also detects if food is wholesome because of its high sensitivity [24].

The advantage of nanosensor system is that thousands of nanoparticles can be placed on a single sensor to accurately detect the presence of insects or fungus inside stored grain bulk in bins [25] and can be deployed and distributed into the crevices of grain bulk, where the stored product pests often hide [1].

Table 1. Role of nanoparticles, mechanism and action in food

Nanosensors	Function(s)	Mechanism of action	Reference
Nanosilicate	It reduces spoilage possibility and rancidity	It act as gas and moisture barrier in films	Neethirajan and Jayas, 2007 [45]
Zinc oxide nanosensor	Reduces changes in colour and flavour of foods	Blocks ultra violet light	Neethirajan and Jayas, 2007 [45]
Specified protein on silica chip	Detects specific pathogen in foods	Detect specific pathogen by luminescence	Homer et al. 2006
Luciferase nanosensor		Dye attaches with *Salmonella* and *Campylobacter* which emit light or florescence	Fu et al. 2008 [28] Stutzenberger et al. 2007 [29]

4.2 Pathogen Identification in Food Quality Monitoring

This technology has provided food quality assurance via several methods among which is the detection of a pathogen such as *Escherichia coli* in a food sample by measuring and the amount of scattered light by the mitochondria of the cell using high tech spectrometer. This sensor works on the principle that a protein of a known and characterized bacterium set on a silicon chip can bind with any other *E. coli* bacteria present in the food sample. This binding will result in a nanosized light scattering detectable by analysis of digital images [26].

Over the decade, biosensors have been produced to meet a specific need. 60 nm diameter fluorescent nanoparticles for in situ pathogen quantification in ground beef samples using antibody-conjugated silica has been developed [27].

It was also a landmark when fluorescent dye biosensor particles attached to anti- *Salmonella* antibodies on a silicon/gold nanorod array was developed by Fu et al. [28]. Its' mechanism was based on the visibility of the biosensor particle if *salmonella* bacteria is present in the food. Unlike the time-consuming conventional lab tests that are based on bacterial cultures, this biosensor can detect the s*almonella* in food instantly.

Stutzenberger et al. [29] paved path in bacteriology of *Campylobacter* bacteria. They developed bioactive nanoparticles in the chicken feed specifically designed to bind to the biomolecular structures on the surfaces of c*ampylobacter* sp. while two years later, Cheng et al. [30] demonstrated speedy identification of *Escherichia coli* in food using synthesized biofunctional magnetic nanoparticles (about 20 nm in diameter) in combination with adenosine triphosphate bioluminescence (ATP). This is briefed in Table 1.

5. NANOTECHNOLOGY IN FOOD PACKAGING

Nanotechnology offers higher hopes in food packaging by promising longer shelf life, safer packaging, better traceability of food products, and healthier food. Polymer nanocomposite technology holds the key to future advances in flexible, intelligent, and active packaging. Intelligent, smart, and active packaging systems produced by nanotechnology would be able to repair the tears and leakages (self-healing property), and respond to environmental conditions; change in temperature and moisture. Intelligent food packaging can sense when its contents are spoiling, and alert the consumer [31-33].

Currently, researchers are using silicate nanoparticles to provide a barrier to gasses (for example, oxygen), or moisture in a plastic film used for packaging. This could reduce the possibility of food spoiling or dry out. Zinc oxide nanoparticles can be incorporated into plastic packaging to block UV rays and provide antibacterial protection while improving the strength and stability of the plastic film. This will allow for frequent testing at a much lower cost than sending samples to a lab for analysis. This point-of-packaging testing, if conducted properly, has the potential to dramatically reduce the chance of contaminated food reaching grocery store shelves [1].

5.1 Antimicrobial Packaging

Antimicrobial nanoparticle coatings in the matrix of the packaging material can reduce the development of bacteria on or near the food product, inhibiting the microbial growth on non-sterilized foods and maintain the sterility of pasteurized foods by preventing post-contamination because of its degree of sensitivity of zone of inhibition. Antimicrobial packaging includes adding a synthesized antimicrobial nanoparticle into packaging sachet and other materials, coating bioactive agents on the surface of the packaging material, or utilizing antimicrobial macromolecules with film-forming properties or edible matrices [34] depending on the type of packaging material [22].

Decades ago, the nanoparticles such as gold and silver nanoparticles were synthesized via chemical methods before its incorporation into polyethylene, now, recent studies reveal that these nanoparticles can be biosynthesized by microbes such as *Fusarium* sp, *Penicillium* sp, *Pseudomonas aeruginosa*, *Pseudomonas struzeri*, for antimicrobial packaging [35,36].

The nanostructured film can effectively prevent bacteria invasion into food to ensure safety of food [15]. With this nanoparticle packaging materials, consumers will be able to "read" the food inside if its' safe or not and provide a better option if to accept, discount, or reject.

The discovery by Rodriguez et al. [37] has shown that foods like cheese, sliced meat, and bakery that are prone to spoiling on the surface can be protected by contact packaging imbued with antifungal active paper packaging which enables the incorporation of cinnamon oil with solid wax paraffin using nanotechnology as an active coating.

5.2 Improved Food Storage

One leading cause which leads to deterioration, discoloration, changes in texture, rancidity, off-odor, and flavor problems in packaged foods is the presence of oxygen due to oxidation of fats and oils and growth of microorganisms [33]. In 2009, active packaging films for selective control of oxygen transmission and aroma affecting enzymes have been nanotechnologically developed by Rivett and Speer, [38]. Oxygen absorbing sachet reduces the entrance of oxygen and other gasses, and the exit of moisture thereby preventing food spoilage [38]. The clay nanoparticles or nanoclay is embedded in plastic bottles which stiffen the packaging, reducing the permeability of gas, and minimizes the loss of carbon dioxide from the product as beer, and the ingress of oxygen to the bottle, keeping the beer fresher and increases the shelf life [39].

5.3 Role in Tracking, Tracing, and Brand Protection

Nanotechnology can help food industries in providing authentication, and track and trace features of a food product for avoiding counterfeiting, thus preventing adulteration and diversion of products destined for a specific market [40].

Its' mechanism is based on generating complex invisible nanobarcodes with batch information which can be encrypted directly onto the food products and packaging. A nanobarcode detection system created by Li et al. [41] that fluoresces under ultraviolet light in a combination of colour that can be read by a computer scanner has been tested on some food and biological samples containing various combinations of *E. coli*, anthrax, and tularemia bacteria, Ebola SARS viruses and several pathogens – and they were clearly distinguished simultaneously by different colour codes.

This nanobarcode technology offers food safety by allowing the brand owners to monitor their supply chains without having to share company information to distributors and wholesalers. By altering the stripe orders, different codes can be created and be assigned to every food item providing brand and authenticity in tracing food batches. NanoInk, Skokie, has developed a patterning technique called Dip-Pen Nanolithography to encrypt information directly onto food products or pharmaceutical pills and on packaging [42]. However, Barcode, a registered company in US, is currently using this detective tool for traceability to ensure wholeness.

6. NANOTECHNOLOGY IN ENCAPSULATION AND DELIVERY OF ACTIVE INGREDIENT IN FOOD

The nanoencapsulation system offers plenty of benefits including ease of handling food products, enhanced stability and integrity, protection against oxidation and rancidity, retention of volatile ingredients, taste masking, pH-triggered controlled and moisture-triggered

Fig. 2. Animated Nanoencapsulation for food delivery [1]

controlled release, consecutive delivery of multiple active ingredients, change in flavour character, long lasting organoleptic perception, and enhanced bioavailability and its efficacy [43].

It is based on harvesting materials like polysaccharide which is engineered into a new material called 'nanomaterial' [44]. Nanosilicas, a nanomaterial have also been sourced from plants. This can be used for encapsulating enzymes that in turn can be used in drug delivery or nutrient release systems [24].

So far, it is known that Nanocapsules have been used by George Weston Foods, Australia, to mask the taste and odor of tuna fish oil (source of omega-3 fatty acids) which is integrated into bread. The nanocapsules break open only when they reach the stomach and hence the unpleasant fish oil taste can be avoided. Nanocapsules have been used for the protection and controlled release of beneficial live probiotic species to promote healthy gut function [45].

6.1 Bioactive Compounds in Foods

Nanotechnology has enhanced solubility, improved bioavailability, and protected the stability of micronutrients and bioactive compounds during processing, storage, and distribution. Bioactive compounds such as beta-carotene from carrots, lycopene from tomato, beta-glucan from oats, omega-3 acid from salmon oil, conjugated linoleic acid from cheese and isoflavones from soybeans, are extra nutritional constituents that typically occur in small quantities in foods, however, now with the emergence of nanotechnology, the delivery of nutraceuticals and bioactive compounds in functional foods is possible [13].

The viability of probiotic organisms including *Lactobacillus acidophilus*, *Lactobacillus casei, Lactobacillus rhamnosus,* and *Bifidobacterium* spp within freeze-dried yogurt can be improved by nanoencapsulation with calcium alginate [33].

Milk protein, casein, was used to make nanosized micelles and has been employed as a vehicle for delivering sensitive health-promoting ingredients including vitamin D2 [46].

Biopolymer *Zea mays* protein nanofibers prepared by electrospinning technique for encapsulating beta-carotene demonstrates the potential of nanotechnology in food and nutraceutical formulation and coatings, bioactive food packaging, and food processing industries. Nanotubes, designed and engineered from α-lactalbumin, acts as nanoencapsulation for nutrients and pharmaceuticals and bioactive [47].

7. CONCLUSION AND RECOMMENDATIONS

From this review, nanotechnology can improve to the areas of food processing, packaging and quality monitoring of food and its products to ensuring safety and wholeness. However, because of its exponential applications, we recommend the following;

1. Packaged nanofood should be labeled as such to give the customer freedom to choose products that suit their need.

2. Though application of nanoparticle in food and its products is ongoing, more research should be done to ascertain the toxicity of nanoparticle and possible environmental hazard it can cause.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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