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Role of Nanotechnology in the Enhancement of Human Health – A Review

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Abstract

Nanotechnology, a promising interdisciplinary science has revolutionized the food industry with its various applications. Nanofood describes the food, which has been cultivated, produced, processed or packaged using nanotechnology techniques or tools or to which nanomaterials have been added. The use of engineered nanomaterials has enhanced the color, texture, flavor, shelf life, most importantly in proper bioavailability of nutraceuticals through targeted delivery systems for improving the quality of living and health of mankind. It has also prevented food spoilage caused by microbes and oxygen entry and had enhanced micronutrient and antioxidant uptake through food packaging. Nanosensors had been used in detection of food spoilage due to their ability to trace the internal and external conditions in food. In this paper, recent research, developments, applications and risks of nanomaterials in different sectors of food industry are reviewed.

Keywords:

Antimicrobes;
Nanoencapsulation;
Detection;
Nutraceuticals;
Toxicity.

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1. Introduction

Nanotechnology is defined as the understanding and controlling the dimension of matter between 1 and 100 nm, which enables new properties and functions [65]. These materials have unique properties compared to macro scale counterparts due to high surface to volume ratio, novel physical, chemical and optical properties [28].Nanotechnology holds within two main approaches: the top down approach, where large structure are brought into nanoscale while in bottom up approach, nanostructure are made from smaller building blocks such as atoms and molecules. While most extant technologies rely on top down approach, molecular nanotechnology holds breakthrough in manufacturing, health care and medicine, energy, biotechnology, information technology and national security [67].Nanotechnology is used in different aspects of food industry such as processing, packaging, detection of pathogen and spoilage of food, nanoencapsulation of bioactive food compounds and as vehicles for delivery of nutrients [73; 51]. The demands for consumers about the food quality and health benefits force the researchers to find out ways to improve the food quality without affecting the nutritional value. Therefore, nanotechnology offers a wide range of opportunities for the development and application of structures in the area of food science. Nanomaterials not only improve the food quality but also enhance one's health [72]. Hence many government organisations, scientists, and industries are coming up with new techniques and products that have direct application of nanotechnology in food industry [19]. This review summarizes the role of nanotechnology used in different sectors of food industry and health, including the risk factors associated with nanomaterials.

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2. Processing

Nanofood describes the food, which has been cultivated, produced, processed or packaged using nanotechnology techniques or tools or to which nanomaterials have been added [34]. Compared to traditional encapsulation systems nanoparticles have good encapsulation and releasing efficiency. Protection from heat, moisture, controlled release of active compounds, and availability of active ingredients to the target at specific rate and time can be made possible with nanoencapsulations [76]. Nanoencapsulations prevent chemical or biological degradation during processing, storage, utilization, and also exhibit compatibility with other compounds in the system [79]. Due to their smaller size these delivery systems have the ability to deeply penetrate the tissues and allow the delivery of active substances to target sites [38]. Encapsulation of bioactive compounds like carbohydrates, proteins, lipids, and vitamins enables them to resist the high acidic environment and enzyme activity of stomach and also allows them to assimilate in food products due to their low water solubility. Bioactive compounds are encapsulated using polymeric nanoparticles to ensure protection and target specific action [39] and also increase shelf life. Even after packaging is opened, the edible nanocoatings on various food materials act as a barrier to moisture and gas exchange and thereby increase the shelf life of manufactured foods [61; 79]. Metallic oxides such as titanium dioxide and silicon dioxide (SiO2) are used conventionally as color or flow agents in food items [53]. SiO2 nanomaterials are used as carriers of fragrances or flavors in food products [21]. During processing of food, nanoparticles are added to improve colour, flow properties and stability of food. In confectioneries, sauces and some cheese, anatase titanium dioxide is used as a whitener and brightener [4; 58]. Active ingredients used for fortification of cereals, bread, dairy products and beverages with vitamins, minerals, bioactive proteins, probiotics, antioxidants are now added in the form of nanoparticles to foods [71]. Nanoparticles and nanoscale emulsions are used in the manufacturing of salad dressing, chocolate syrups, sweeteners, flavoured oils and in processed foods [48]. The chemical degradation process of functional components can be slowed down by the process of encapsulation. The active and less stable bioactive component of turmeric was found to be stable at different ionic strength and pasteurization due to encapsulation [69].

3. Packaging and Sensing

In packaged food, nanotechnology plays a major role by providing strong packaging materials, potent antimicrobial agents and also sensors to detect trace contaminants, microbes and gases [22]. Nanopackaging can be designed in a way to increase shelf life by release of antioxidants, enzymes, flavours and antimicrobials [12]. The major focus of food industry–related nanotechology research and development are food packaging and monitoring [10]. Presently, over 400 companies in the world are developing nanotechnology for its application in food and food packaging [51]. Application of nanocomposites as an active material for packaging and material coating can be used to improve food packaging [56]. Nanocomposites with clay nanoparticle composites have improved barrier properties are used for the manufacture of bottles for beer, edible oils and carbonated drinks and films [13; 11]. Coatings are applied on food to prevent decay or spoilage due to moisture or gas entry. By addition of a liquid film forming solution or by molten compound coatings are made and applied directly on the food product [7]. To improve the physical properties of food, nanocomposites prepared by gelatin and montmorillonite has been used [85]. Nanoclays have been used with biopolymer which enhances the packaging ability of the biopolymers [20;79]. The advantages of clay nanocomposites in packaging include increased shelf life, shutter proof, heat resistant and light weight and hence easy to carry [55; 59]. In active packaging the nanomaterials are directly allowed to interact with the food to render more protection. Kodak Company has developed and commercialized antimicrobial packaging for food products that can absorb oxygen [3]. Due to structural integrity and barrier properties antimicrobial nanocomposite films are prepared and used in packaging industry [63].Antimicrobial activity of nanomaterials allows them to be used as growth inhibitors, killing agents [17; 31]. Silver nanoparticle (AgNPs) based antimicrobial films are widely used in food packaging due to its strong toxicity to different microorganisms [37]. By addition of titanium nanoparticles (TiO2) to different polymers oxygen scavenger films were successfully developed [83]. Hence can be used for packaging a wide variety of oxygen-sensitive products.Photo catalytic bacterial inactivation has been reported by doping TiO2 with silver [60]. The combination of TiO2 /Ag+ nanoparticles in a nanocomposite with Poly vinyl chloride (PVC) resulted in good antibacterial properties [15].

Biosensors detect and quantify pathogenic organic compounds, other chemicals, alteration in food composition, and also preserve fruit or vegetables [23]. Nanosensors used in the food packaging industries include nanopaticles based sensors, electronic noses, array biosensors, nanocantilevers, nanoparticle in solution, and nano-test strips. Nanosensors are used to trace the external and internal conditions of food products, pellets and containers throughout the food supply chain. In plastic packaging nanosensors detects gases in food when gets spoilt and packaging itself changes the color to alert the consumer. Films packed with silicate nanoparticles can reduce the flow of oxygen into the package and prevents leakage of moisture out of package and keep the food fresh [54]. Nanosensors can be used in the detection of toxins, pesticides and spoilage [82]. Nanosensors, in food packaging, can detect some chemical compounds, pathogens, and toxins in food, which can be used to eliminate the need for inaccurate expiry dates, hence providing freshness to food [40]. Nanosensors have the ability to detect environmental changes like temperature or humidity in storage rooms, levels of oxygen exposure, degradation products or microbial contamination [8]. Carbon nanotubes based nanosensor have several advantages over conventional detection methods. Nanosensors based on carbon nanotubes is rapid and have high-throughput detection, it is simple and cost effective, requires less power and can be easily recycled. Moreover, a multiwalled carbon nanotubes based biosensor have been developed that can detect microorganisms, toxic proteins, and degraded products in food and beverages [49]. It is reported that microrrganisms can be detected from the response pattern produced by sensors made of conducting polymers. Based on this bacteria such as *Bacillus cereus*, *Vibrio parahemolyticus and Salmonella spp*. were identified [2]. Immunosensors made of nanofilms have the ability to detect microbial organisms. The safety status of food can be made sure using nanobiosensors as well as helps in the pathogen detection [6; 14]. Allergic peanut protein in chocolate can be detected using nanoliposomal vehicles [80]. Zinc oxide nanowires are used as gas sensors which are the main source of an E nose [30]. A study suggests thiol modified DNA probe coated on electrode with gold nanoparticles have the property to sense cDNA sequences [41; 24]. Nanotubes coated with toxin antibodies have the property to detect water borne toxins which can be marked by a change in conductivity [78]. Nanosensors play a major role in food microbiology by reducing the time required for pathogen detection from days to minutes. The discovery of microfluidic sensors has led to its application in different fields like medicine, biology and chemical sciences for analytical purpose. The peculiarity of these sensors is that, it requires only samples in microliters, from which required compounds can be detected [77; 43]. Another class of biosensors namely nanocantilevers through the mechanism of electrochemical or physical signaling can detect several biological interaction such as antigen antibody, enzyme substrate [29]. A study has reported the ability of nanocantilevers in detection of *Ecoli* an indicator of fecal pollution in water or food products [26].

4. Bioavailability and Nutrient delivery

Nanocarrier systems are utilized in food nanotechnology to stabilize the bioactive ingredients to improve their bioavailability against the different changes in the environment. Nanoliposomal encapsulation of enzymes in cheese results in good texture and flavor [62]. Nanoliposomes are used to enhance the bioavailability, stability and shelf life of sensitive ingredients and also have the ability to add antimicrobials to protect the food. Nanoliposomes are applied in diary industry in encapsulation of food preservatives [75]. α lactalbumin nanotubes created from milk proteins can be used as carrier for nanoencapsulation of nutraceuticals [27]. Appropriate vehicles are required to supplement active phytochemicals which are unstable and poor in oral bioavailbility. Nanoemulsions which are class of small droplets of emulsions can be used as delivery systems to enhance the bioavailability of nutraceuticals. Curcumin nanoemulsions had shown 85% inhibition of 12-O-tetradecanoylphorbol-13-acetate (TPA) induced mouse ear inflammation compared to dibenzoylmethanenanoemulsion which has increased the oral bioavailability by thrice .Nanoemulsions created from food grade ingredients are used in the delivery of lipophilic components like oil, soluble vitamins and nutraceuticals [45]. High stability, clarity and greater bioavailability of lipophilic components are the properties of nanoemulsions [46]. Edibile nanoemulsions are utilized in the food and beverage industries for the delivery of lipophilic functional components like carotenoids, flavonoids [47]. Nanonutrients have the ability to decrease tumor growth switching on the mechanism of apoptosis [70]. Nanoparticulate formulation of coenzyme Q10 can be delivered orally to treat hypertension[1]. Nanoencapsulated omega 3 fatty acids can be incorporated into pork meat by ultrasonication [52]. Antioxidants have the ability to protect the body against chronic diseases as well as to ensure the nutrient quality of food. Nanoliposomes can be used as antioxidant carrier in food [48]. Nanoencapsulated nisin, an antimicrobial protein have the ability to target bacteria, *Bacillus subtilis and Pseudomonas aeruginosa*[18]. Based on suitable lipid antimicrobial combination, stable nanoparticulate aqueous dispersion of protein antimicrobials can be produced to stabilize microbes in food products [81]. Nanoencapsulation of nutraceuticals like curcumin, green tea polyphenol, quercitin have been proved to be used in the prevention and chemotherapy for cancer treatment [50]. Polysachharide nanoparticles have the potential to be used in chemoprevention due to its ability to deliver natural antioxidants which can inhibit apoptosis [64]. Cochelates are solid particulates made of continuous bilipid layer sheets rolled upto spiral structures with no aqueous phase internally. Nanocochelates are used as delivery vehicles of protein and DNA for application in vaccines and gene therapy [25]. They have the ability to fuse with cell membrane thereby act as therapeutic carrier of drugs [68]. Vaccines, DNA, oligonucleotides, low molecular weight drugs can be delivered using protein nanoparticle as carriers. Prepared egg albumin nanoparticles have the ability to act as vehicles to carry low molecular weight drugs [74]. To provide health benefits, edible capsules are created to improve the delivery of medicines or micronutrients [84; 36].Hence fabrication of nutraceuticals carrying nanoparticles can be done through different techniques like lipid formulation, natural nanocarriers, food grade nanoparticles [32].

5.Risk factors

The physicochemical properties of the engineered nanoparticles are found to be the main reason to exhibit altered physiological response or cytotoxicity [57]. A study reveals Engineered NanoMaterials (ENMs) results in mast cell degranulation and contributes to exacerbation of allergic diseases [33]. Zinc oxide nanoparticles(ZNPs) are used in the dietary supplements but studies report it can cause immunomodulatory effect. Studies show systemic exposure to ZNPs enhances specific antigenic immune reactions [66]. Another study reports the ZNPs' potential to cause oesinophillic airway inflammation [35]. People with chronic respiratory diseases are susceptible to toxic effects of inhaled nanoparticles. A study suggests engineered silicon nanoparticles can enhance allergen sensitization by exposing secondary allergens [9]. Inhalations of silver nanoparticles are toxic and cause allergenic responses. It is reported that AgNPs accumulate in lungs and elevates the allergic markers which results in allergy [16]. Silicon oxide nanoparticles are found to be accumulated in the gut epithelium. A study reports the use of silica as anti-caking agent in food is found to be cytotoxic in human lung cells [5]. Studies reveal that polystyrene nanoparticles are potent enough to disrupt iron transport and chronic exposure had resulted in remodeling of intestinal villi, suggesting its potential to affect nutrient absorption [44]. Nanoparticles being small have the property to cross blood brain barrier and causes neurotoxicity. It is shown that nanosized TiO_2 have increased the production of reactive oxygen species in immortal microglial cells [42].

6. Conclusion

This review has focused on the applications of engineered nanomaterials in different sectors of food industry and also the risk factors associated with their use in human welfare.The emerging application of nanotechnology in food industry includes processing, microbe identification, quality assessment, active packaging and nanoencapsulation of bioactive food compounds. Food processing helps to improve the colour, flavor, texture, avoids early degradation and also increases shelf life of food. The quality and bioavailability of food is improved by using various nanocarriers. Among these, nanoencapsulation are mainly used for site specific delivery of nutraceuticals.Another food sector which utilizes nanotechnology is during packaging of foods. Strong packaging materials which are microbe resistant and those having oxygen scavenging capacity are used. These nanomaterials act as potent barriers and protect the food from external contamination.Moreover, nanosensors are being exploited in the food industry. Nanosensors unlike conventional biosensors are developed in such a way that, they can trace the internal and external conditions existing in food and hence help in detecting spoilage of food. The mechanism of physical or electrochemical signaling in nanosensors is utilized in other fields of science for analytical purposes.Though this interesting and promising technology has the power to improve the quality and health of man, it also has associated risks, mainly due to the ability of the nanoparticles to cross blood brain barrier and cause neurotoxicity. Therefore creating anawareness about the pros and cons of nanotechnology for its acceptance amongpeople and society.Mechanisms are to be developed to study the toxicity of engineered nanomaterials and also concerened authorities should develop standards for commercial products to ensure the quality, health, safety and their impacts on health and environment, else this technology will become a double edged sword.

7. Conflict of Interest

The authors confirm that this article content has no conflict of interest.

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