A review on Nanotechnology in food science: Functionality, applicability, and safety assessment

Abstract

With rising investment and market share, it is anticipated that the rapidly developing field of nanotechnology will change many facets of food science and business. A brief overview of recent uses of nanotechnology in food systems is provided in this article. To present a thorough overview of the advancement and safety evaluation of nanotechnology in the food sector, the functionality and applicability of food-related nanotechnology are emphasized. Food nanotechnology has a lot of potential applications, but because of its unique physicochemical characteristics, there are growing potentials. Consequently, a brief discussion is given to the safety issues and legal requirements pertaining to its production, processing, packaging, and consumption. This paper concludes with a discussion of the prospects for using nanotechnology in active and intelligent packaging.

Keywords

Food Science, Production, Packaging, Nanotechnology, Safety Evaluation

Introduction

A rapidly developing revolution, nanotechnology holds great promise for the food industry, medical, and mechanical sectors. When compared to large particles of the same composition, nanoparticles appear to pose higher biological and chemical activities, penetrability, catalytic behavior, enzymatic reactivity, and quantum properties because of their larger surface area and increased rates of mass transfer [1]. The nature, size, structures, and other attributes of nanomaterials are used to classify them. Nanoparticles with high surface volume ratio can demonstrate outstanding physicochemical features in terms of diffusivity, solubility, bioavailability, intoxicity, optics, thermodynamics and magnetism [2]. It is well known that nanoscale food additives, such as flavoring agents, preservatives, antimicrobial sensors, packaging materials, and encapsulated food components, can affect the nutritional composition of food products and enhance their flavor, texture, and shelf life [3]. By identifying food pathogens, it can potentially be used as an indicator of food safety and quality [4]. Food additives (such color and flavor) and nutritional supplements (like proteins, vitamins, bioactives, and antioxidants) can be nanoencapsulated to create nanocapsules that can be added to functional foods. Apart from acting as protective barriers, this also offers bad taste and off-flavor masking, controlled release of nutrients by smart/intelligent systems, and better dispensability of waterinsoluble ingredients via nanotherapy. Electrospun nanofibres are getting widespread attention as encapsulating materials or food packaging films [5].

Quantum dots (QDs), nanorods, nanoparticles, nanowires, nanoplates, etc. are the most common components of nanostructured materials. These materials mostly form multilayer films with atomic, and wire structures. Simply employing layer-by-layer procedures, nanostructures can be manufactured with food-grade substances (a cheap way). Three methods exist for creating various kinds of nanomaterials, mostly determined by the materials of interest [6]. One is the physical approach, which involves milling, homogenization, ultrasonic emulsification, and microfluidization. It also uses mechanical forces and evaporation in the synthesis of nanomaterials [7]. Certain advantages of chemical methods over physical ones include ease of use, synthesis at low temperatures (<300°C), easy conversion of liquid product to thin films or dry powder, multiple options for different sizes and shapes of nanoparticles, ability to incorporate useful minerals during synthesis, etc. [8]. Researchers are particularly interested in the third method, which is biological because of its many benefits. These include its safety, lack of use of hazardous chemicals, affordability, ease of scaling up, reproducibility in production, well-defined morphology, and so on. Several biosynthetic methods include the manufacture of nanoparticles using plant extracts and microorganisms such as yeasts, fungi, and bacteria [9, 10].

Many uncertainties about risk features characterize the current scientific regulation of food nanotechnology. The spectrum of applications for food nanotechnology is determined by its functionality. Based on its functionalities, food nanotechnology can impact food's bioavailability and nutritional value [10]. It is acknowledged that the physicochemical parameters of nanomaterials play a major role in determining their biological features, including their toxicological consequences [11,12,13]. Boosting food security, prolonging shelf life, boosting flavor and nutrient delivery, enabling pathogen/toxin/pesticide detection, and providing functional foods are, in fact, the main connections between nanotechnology and the food sector. Foods and food packaging are among the aspects of the food systems where advancements have been made [14]. The majority of studies focus on controlling nanotechnology in food processing and packaging [15]. Regretfully, there is currently no thorough analysis of the possible dangers connected to the usefulness and functionality of food nanotechnology. In this review, we primarily address the features of food nanotechnology's functionality and applicability, as well as the state of its regulation and risk/safety evaluation. Specifically, certain nanomaterials function as antimicrobials or oxidant scavengers and are hazardous to both people and animals [16], [17]. Furthermore, the effects of nano-composites might vary greatly depending on how they are used in processing, packaging, and as real food additives. Thus, it is imperative to have a comprehensive understanding of the possible risks related to their functionality and applicability in order to provide additional recommendations on the safety of food nanotechnology.

Applications of Nanomaterials in Food Sector

Food preparation and storage

Nano particles are changing the structural makeup of food; for instance, foods high in fat are being replaced with foods with creamy textures because of the introduction of nano-structured lipids. These fats are found in ice cream, frozen sweets, dairy spreads with nanostructured mayonnaise, etc. Another possibility that offers opportunities for the sequential release of several bioactive chemicals is nano-encapsulation. Functional foods employ a variety of additives in nano-encapsulated forms, such as synthetic lycopene, enzymes, lutein, ß-carotene, ascorbic acid, citric acid, isoflavones, fat-soluble vitamins, omega-3 and omega-6 fatty acids [13]. The functional chemicals with nanostructure are encapsulated in either oil- or protein-based carriers (liposomes) or micelles.

The odd smells and odors of any peculiar addition can be concealed by the nano-carriers, which can also aid in preventing thermal deterioration [14]. Inorganic nanomaterials comprising various transition metals and their oxides (e.g. iron, silver, titanium dioxide and others), nonmetals (e.g. selenium, silicates, etc.), and alkaline earth metals (e.g. magnesium, calcium, etc.) find direct applications in health food products [15]. It is claimed that adding nano selenium to tea can increase its antioxidant activity and redox equilibrium [16]. The Food and Drug Administration (FDA) in the United States has approved SiO_2 (E551), MgO (E530), and TiO_2 (E171) for use as flavor carriers, coloring additives, and anti-caking agents. TiO_2 (E171) is used as a colouring ingredient in gums, candies, cake icings, pudding pies, and white sauces [17].

Silver nanoparticles are widely used as an antibacterial agent and as a source of micronutrients (Woodrow Wilson International Centre for Scholars, 2008). As a result, its use in antimicrobial packaging and health foods is becoming more significant. It has been demonstrated that antibacterial nanosilver particles are efficient against a variety of Gram-positive and Gram-negative bacteria, including species that are resistant to antibiotics. Aluminosilicate nanoparticles were discovered by Ashwood et al. to be suitable as anti-caking additives [18].

Food packing

Applications of nanotechnology in food packaging offer fresh possibilities for enhancing its usefulness and efficiency. As an active packaging strategy supporting food product preservation, antioxidants and antibacterial nanoparticles are being added to the package material. By altering the penetration activities of foils and providing heat resistance, nanomaterials are utilized to wrap food goods, enhancing the mechanical, chemical, and microbiological barrier effects [19]. The USFDA has approved bentonite and montmorillonite as "generally recognized as safe," and they are included in the effective Food Contact Substances (FCS) list [20]. Silver and zinc oxide nanoparticles were used for their antibacterial properties, titanium dioxide and nitrides for their mechanical strength and UV protection, and nanoclay particles for their enhanced gas-barrier properties embedded in plastic polymers [21].

Numerous studies have confirmed the efficacy of using active nanopackaging to target effective nutrient release into food and edible coating materials in order to reduce spoiling and increase shelf life. Because of their enhanced barrier qualities, antibacterial capabilities, and regulated nutrient release, metal nanoparticles are used in edible coating materials.

Because of the altered respiration mechanism, fruits and vegetables coated with nanosilver remain active during storage and transportation. Food scents can be eliminated and oxygen and CO2 barrier qualities can be increased with the nylon nanocomposite [14]. Thinner hybrid edible films (less than 100 µ thick) improved food items' shelf life and sensory qualities while also enhancing CO_2, oxygen, and moisture barrier properties, according to Flores-Lopez et al. [22]. Graveland-Bikkera et al.'s research [23] examined the migration of probiotics, micronutrients, and minerals in food as well as the measured release of functional components from the nanocomposites in the packaging material. Nanosilver particles were found to have antibacterial properties against molds, yeast, protozoa, and some viruses by Kumar and Munstedt [24]. Metal nanoparticles' antibacterial properties were linked to their size, shape, exposed surface area, internalization of the particle, and chemical activities [25]. The antifungal effect of chitosan impregnated with nanosilver on strawberries was assessed by Moussa et al. [26]. The fungal deterioration of coated samples was around 10% after 7 days of storage at room temperature (25°C), compared to 90% for uncoated samples. The impact of an alginate coating impregnated with silver-montmorillonite nanoparticles on the shelf life of carrots packaged in polypropylene (PP) bags was studied by Costa et al. [27].

They discovered that the fresh cut carrots' shelf life was increased to over 70 days when combined with PP bags, as opposed to just 4 days for the uncoated samples. Among the uses for nanosensors are the detection of heavy metals, toxicants, pathogens, pollutants, allergens, non-nutritional parameters, and microclimatic elements (humidity, light, temperature, etc.) [28]. With the lowest detection limits, most portability, and enhanced sensitivity, nanosensors can rapidly identify, detect, and quantify pathogens, decomposing materials, and allergy-causing proteins [29]. Fluorophores and quantum dots were shown to reduce apparatus size and increase detection sensitivity by Goldschmidt [30]. These nanodevices could therefore have a significant impact on food security. Colorimetric assays and nanoparticle-based molecular mimicry have been used to study toxin detection; cholera toxin detection has shown promising results [31]. By employing antibody-doped silica nanoparticles for fluorescence-based bacterial quantification, a single bacterium may be isolated in under 20 minutes [32]. As a result, this analytical methodology was able to reduce the usual 16–18 hour plating process to only a few minutes. Moreover, it was able to detect the presence of certain specific cellular contaminants, something that is not possible to do with conventional methods. In order to precisely identify different pollutants in food and to monitor both the inner and exterior characteristics of the product, food packaging frequently uses nanosensors [33].

Additionally, nanosensors are becoming more and more popular as an effective tool for tracking how food and packaging materials interact while being stored. Any interaction results in a reaction from the nanosensor, which is an electric and visual signal that indicates the food product's state. Commercial acceptance of nanobarcodes for food authenticity has already occurred [13].

Possible Health Dangers, Safety Questions, Toxicological Problems, and Other Related Difficulties

Creating safe edible delivery systems with economical processing processes is a difficult task [34]. Eating food that has come into touch with nanopackages could be a route of exposure and present a significant health concern because the food could then migrate or leach particle nanomaterials from the packaging. This effect is undoubtedly influenced by the kind of packing matrix utilized, the toxicity of the nanomaterial used, the degree of migration, and the rate at which the specific food is absorbed [35]. Increased concentrations of these substances absorbed through the skin or breathed offer a serious risk to human health, especially when it comes to long-term toxicity [36]. These nanoparticles may accumulate in the stomach, small intestine, kidneys, liver, and spleen, among other organs [37]. One oral dose of ZnO nanoparticles may result in issues such as liver toxicity, lung damage, and kidney damage [38]. The environment and human health may suffer as a result of the use of titanium oxide and its subsequent disposal [39].

At the nanoscale level, the materials exhibit widely varied behaviors, and our understanding of their technical analysis is still limited. Enhancing practical uses and safety requirements of nanoparticles can be achieved through comprehension of their hazardous properties and nano-range capabilities. The production of hazardous, non-ecofriendly byproducts during the synthesis of nanoparticles using various chemical processes has unfavorable effects and seriously contaminates the environment [40]. Concerns about biosafety, regulatory rules, risk assessment programs, and public awareness must all be considered during the manufacturing, packaging, and consumption of food items based on nanotechnology [41, 42]. Moreover, in vitro and in vivo studies on the interactions of nanoparticles with living things are necessary before the commercial use of nanoparticles [43].

Concerns about Safety

The potential of nanotechnology in food science and industry grows along with the amount of research being done on its application in the food business, and this leads to an increase in human exposure to these compounds [44]. There is no way around many ways, planned or unplanned that human exposure to nanoparticles will increase. However some research has examined the possible toxicity of food nanomaterials by examining food samples that were utilized in food packaging and additives/ingredients. The final toxicity of nanomaterials following exposure is unknown, as are their bioavailability, biodistribution, and routes of passage. Above all, human organs are directly contacted by nanoparticles that are used as food additives.

Depending on how much of the meal is consumed and how concentrated it is, exposure levels could become greater. A growing number of public and government sectors are paying close attention to the growing usage of nanomaterial compounds in food as flavor or color additives [45]. Over 93% of the TiO_2 in chewing gum with a sugar coating is nanosized, according to a study on the material [46]. TiO_2 can be released surprisingly easily, absorbed by a gum-chewing person, and progressively deposited in the body [47]. Similarly, eating meals containing E551 is probably going to expose the gut epithelium to SiO_2 nanoparticles [48],

[49].

Furthermore, by means of oral ingestion, nanoencapsulation permits direct interaction between humans and nanomaterials. Furthermore, by means of oral ingestion, nanoencapsulation permits direct interaction between humans and nanomaterials. One of the most popular food nanoparticles, SiO_2, has been investigated for usage in food products as a flavor or aroma carrier [51], [50]. Additionally, lipid-based nanoencapsulation systems are being developed to improve the solubility and bioavailability of antioxidants [52], as well as to entrap bioactives for efficient absorption and tailored site-specific administration [53]. However, there is still a lack of research on the safety of nanoencapsulation, which necessitates additional risk assessment [54], especially with regard to long-term toxicity [55], [56].

Since they allow for direct human exposure to nanoparticles, nanoscale edible coatings have become a popular substitute for preserving food quality, extending shelf life, and preventing microbial decomposition [57], [58], [59], [60], [61].

Conclusions

It is believed that nanotechnology is a rapidly developing field that has the potential to completely transform food systems. Applications of nanotechnology in food science and research have advanced enormously. Nanotechnology has improved almost every aspect of the food processing industry, from product shelf life to sophisticated microbe isolation to better food storage and safety to tracing and tracking of contaminants/pollutants to detection of toxins/pathogens to nutritional or functional supplements through food. The majority of the direct uses involve combining coloring agents, odorants, antioxidants, nanopreservatives, and bioactive substances like fatty acids, polyphenols, and vitamins. The use of nanomaterials in packaging, the development of nanosensors, and the use of catalysts in the hydrogenation of lipids are examples of indirect applications. Recent developments in the field of nanoscience-based applications have demonstrated opportunities to redefine food preferences, reorganize the production chain, reframe the processing line, and encourage the conservation of natural resources. These developments will ultimately have a significant impact on the agri-food systems and the quality, safety, storability, and security of food, which will benefit both producers and consumers and influence the prognosis for the economy. On the basis of cautious considerations, additional research is yet required, especially with regard to NSM migration patterns in food matrix, human cytotoxicity of nanoparticles, and their possible implications on consumer safety and health as well as the environment. It is necessary to address potential dangers, toxicological concerns, and environmental factors. The relevant laws and guidelines must be established in order to address the numerous safety issues that currently exist; only then will they govern the whole food industry.

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