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Recent Developments of Nanotechnology Applications in the Food Processing and Packaging Industry

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Abstract: With the fast technological evaluation, nanotechnology keeps a leadership role and largely contributes to the food industry in different aspects. The consumer preferences and market demand of the food industry are continuously changing with the current world trends and due to the increasing global population, new technological aspects need to be applied for food production and preservation. As an innovative technology, nanotechnology applies in food processing (nanoencapsulation, structural modifications, and quality improvement), food packaging (active packaging, smart and intelligent packaging, nanosensors, impermeable polymer films, nanofibers), and nutritional supplements (Nutraceuticals with high stability and bioavailability). The article delves into nanotechnology's influence in the domains of food processing and packaging, highlighting its latest advancements and implementations, as well as the methods it offers to prolong the food products' shelf life.

Index Terms: nanotechnology, food processing, nano packaging, recent applications

INTRODUCTION

Nanotechnology is an emerging advanced science that has an unbelievable capacity to impact the food production and packaging industry by small invisible particles called Nano-particles. “Nano food” is defined as a food product that is prepared in nanomaterials in an acceptable range and using nano techniques and tools related to the improvement of food color and flavors, prolonging the shelf life, and detection of germs and spoilage bacteria [1]. As a new frontier technology, Nanotechnology has become a key technology to keep leadership in various aspects of the food industry in the current world due to high consumer acceptance, market demand, prolonging the shelf life, and improving nutritional and safety quality of food. Nanotechnology uses 1-100 nm extremely small-scale Nano-particles which are invisible to the human eye though have numerous essential implications and applications to the current world [2], [3]. To achieve a healthy life, the involvement of nanotechnology is important to create food novelty, enhance sensory properties, and improve the safety and quality parameters of food [4]. According to the global

scale, Nano food market share is expected to increase by approximately USD 187.84 billion from 2020 to 2025 [5].

There are various conventional and modified, advanced preservation technologies existing in the food industry such as drying, roasting, fermentation, salting, cooling, smoking, canning, using chemicals and artificial preservatives and pressure treatments, radiation, and cold plasma technology as recent technologies. However, the main objective of using all these technologies is to avoid food spoilage and store food for a necessary period of time for consumption. Some evidence is found that smoking and sun drying were the oldest preservation methods in Egypt while pickling and fermentation were famous in Rome for prolonging the shelf life of food [6]. Ice and cold water were used to preserve meat in ancient peoples and then it became an artificial refrigerator system [6]. In 1862, the pasteurization method was introduced by Louis Pasteur for wine, beer, and milk products [7].

In the 21st century, nanotechnology applies to food preservation and maintains the food safety aspects as an innovative application to extend the food shelf life, track the food contaminants, and upgrade the food storage and value addition of food by incorporating antimicrobial agents into food [8], [9]. Nano green tea, fortified fruit beverages, Nanocapsules containing tuna fish oil in bread, and nanoceuticals slim shakes are the recently commercially available nanotechnology-based products in the USA, Japan, and Australia [10].

NANOTECHNOLOGY IN DIFFERENT ASPECTS OF THE FOOD INDUSTRY

STRUCTURAL MODIFICATION OF FOOD

Nanoparticles are used to improve the food structure through texture modifications and flavor improvements and prolong the shelf life. Dairy products, cereals, bread, and beverages are incorporated with vitamins, probiotics, antioxidants, and minerals to improve nutritional quality and structure. In the current world, nanoparticles such as TiO2, and SiO2 are also incorporated into food to modify the structure, liquidity, stability, sensory properties, and prolong shelf life [11]. Many multinational companies are applying nanoparticles for structural modification of food as Unilever, and Nestle. Nano-capsuled incorporated beverages have interactive color and flavor and nano-emulsifiers including ice creams, frozen desserts, and spreads have good creamy textures [12].

NANOENCAPSULATION

Nanoencapsulation is another vital perspective in the food industry that packs substances (vitamins, antioxidants, proteins, lipids, enzymes, probiotics, and pharmaceuticals) in capsules or miniature prepared using nanocomposites, nano emulsification, and covering to protect sensitive substances from adverse chemical reactions and improve the functionality of final food product. Nano encapsulation is supported to enhance the functionality and stability of food and novel food delivery systems have been designed

following this emerging technology. A novel application in nanoencapsulation is reported as the incorporation of probiotics into yogurt, and some fermented dairy foods such as cheese, puddings, and fruit beverages. Furthermore, previous studies reported that encapsulated nutrients or ingredients have a long shelf life. Doronio et al. [13] used this nanoencapsulation strategy to enhance the stability and preserve antioxidants extracted from garlic. Wrisany et al. [14] reported that applying nanoencapsulation to preserve volatile compounds in essential oils is an effective method and can improve water dispensability, chemical stability, volatility, and bioactivity. Moreover, encapsulation can be applied to convert liquid to powders.

NANO TUBES

Nanotubes are also a new application in nanotechnology and food antimicrobial packaging [15]. Nanotubes have a 20 nm diameter, and several micrometers in length and were recently applied as a gelling agent for α-Lactoglobulin and to deliver nutrients and flavors [15]. Hashim et al. [16] observed that carbon nanotubes were able to penetrate the tomato seed coat and increase seed germination and growth. In 2011, Tripathi et al. [17] revealed that chickpeas using water-soluble carbon nanotubes increase in water absorption and retention. Recently, Nanotube fertilizer carriers have been introduced using cochleate structures. Small-scale cochleate structured nanotubes have been applied to improve the delivery of fertilizer, and pesticides for plants [18].

NANONUTRACEUTICALS

Nano Nutraceuticals are substances in food that can provide the prevention from diseases [19]. Nanoparticles are used as nutraceuticals in functional foods with many benefits such as high bioavailability, solubility, and delivery properties [19]. Recently, nanotechnology has been applied to Omega-3 fatty acids, lycopene, vitamin D2, probiotic bacteria species, and β-carotene as Nano Nutraceuticals [19].

NANOEMULSIONS

Nanoemulsions are small droplets with diameters of less than 100 to 500 nm that can be incorporated into functional food and developed in the decontamination of food packaging [20]. Caseinates are commonly used as an effective emulsion stabilizer for fats. Fathi et al. [21] discovered that nanoemulsions have the capability to deliver less water-soluble ingredients such as fish oil and lipophilic vitamins. In addition, they reported that proteins, polysaccharides, and phospholipids are widely used to manufacture nanoemulsions.

NANO FOOD ADDITIVES

The food industry including dairy production and the fruit and beverage industry applies nano-scale food additives as a novel application. Nano-cellulose can be used as a stabilizing agent, emulsifier, and

functional food ingredient in food processing and also in active packaging [22], [23]. The nano food additives are capable of developing new flavors and improving the bioavailability of nutrients in food [24]. Nutraceuticals and nutritional supplements containing nano additives are currently available as vitamins, antimicrobials, and antioxidants [25]. Cho et al. [26] reported that nano-food additives are used to enhance the vitamins and minerals in some processed foods and to speed the production time for meat processing.

NANOTECHNOLOGY IN FOOD PACKAGING

The main objective of packaging material is to prevent the inner material and maintain the quality and safety of the product during the food chain. Nanotechnology is widely focused on food packaging applications more than food processing. Nano food packages were able to meet industrial and consumer requirements as innovative, lightweight, strong, active, and intelligent packages. In the current world, nanocomposites or nano coatings are applied to improve conventional plastic materials and biodegradable polymers.

ACTIVE FOOD PACKAGING SYSTEM

Active packaging refers to packaging equipped with elements that deliberately alter the internal conditions, aiming to uphold the food's sensory attributes and quality, thereby extending its duration of freshness. [27]. Silver (Ag), titanium dioxide (TiO_2), zinc oxide (ZnO), magnesium oxide (MgO), and silicon oxide (SiO_2) have been infused into packaging materials for their antimicrobial properties. Similarly, elements like iron and cobalt, as well as compounds such as ascorbic acid, photosensitive dyes, sulfites, the glucose oxidase enzyme, and unsaturated hydrocarbons have been integrated into packaging as oxygen absorbers and antioxidants. Furthermore, anti-discoloration agents, flavor enhancers, and bioactive compounds have been introduced to active packaging via nanocarriers, all in an effort to extend the freshness duration of food [28], [29], [30].

SMART-INTELLIGENT FOOD PACKAGING SYSTEM

Smart or intelligent food packages are new innovative packages in the food packaging industry that can be used to monitor biochemical, chemical, and microbial changes inside the package and surroundings. Nano sensors are included in these smart packages to detect gas content and microorganisms, identification of allergy-causing substances and food poisoning materials, also detect off-flavors and off-colors. Several types of nanosensors are applied in the food packaging industry now as nanoelectronic noses, array biosensors, Nano cantilevers, nanoparticle-based sensors, and nano-test strips. Nanoparticle-based sensors can detect oxygen and moisture leakages inside the packages, avoid mold growth in refrigerator conditions, and detect toxins, pesticides, and spoilage [31]. Currently, Nestle and some multinational-level companies are applying chemical sensors to detect color changes in food [32]. Intelligent packaging is also known as

smart packaging barcodes and Radio Frequency Identification Tags (RFID) which can be used to identify information on food quality and safety [33]. In 2007, a colorimetric hydrogen sulfide sensor was introduced which was made up of gellan gum-capped silver nanoparticles to identify the spoilage stage of the chicken breast and silver carp [34].

NANO EDIBLE COATINGS AND FILMS

Many recent studies found that nano edible coating and films are a new advanced technological aspect in the food packaging industry to eliminate package wastage. Antimicrobial-incorporated edible coatings and films are used in fruits, vegetables, meat, cheese and chocolate, and confectionery products to prolong the shelf life and enhance the storage quality [35]. Recently, 5mm thin nano edible coatings and films have been manufactured [36]. Rojas et al. [37] developed edible food films for apple puree and Oregano oil which are capable of killing the E. coli bacterial population.

NANOFIBERS

Nanofibers are used in the green food packaging industry as structural components. 10-100nm range nanofibers apply as polymer solutions in the packaging industry and as nanostructures for antimicrobial delivery, drug loading, and direct absorption of drugs [38]. The quality of nanofibers depends on temperature, the surface tension of the solution, and viscosity. Nanofibers have the potential to deliver antimicrobials [39]. However, because these nanofibers are not food-grade bio-polymers, there are limited applications in the food packaging industry. A previous study stated that ultrasound (US) treatment reduced ZnO particle size and dispersed ZnO nanoparticles coated the bacterial cellulose (BC) Nanofibers [15]. Sheikh et al. [15] observed that polyurethane Nanofibers containing copper nanoparticles have a good antibacterial effect against *E. coli* and *B. subtilis*.

NANO CLAYS

Polymer Nano clay composites are used as novel food packages in the current world due to their lightweight, high tensile strength, heat resistant properties, and good barrier properties against oxygen, carbon dioxide, and moisture to preserve the quality of food [40], [1]. The distribution of nano clays with the 100-1500 ratio and the extremely high surface-to-volume ratio of 700-800 m^2/g was recorded to improve the mechanical and gas barrier at low filler content as below 5% by weight [41]. Recently, enzymes incorporating nano clays have been used in the food packaging industry [42].

CHALLENGES AND TECHNOLOGICAL CONSTRAINTS OF NANO PROCESSING AND PACKAGING

Although there are many obstacles, nanotechnology offers a significant potential to create novel products

and procedures in the food industry. Producing edible delivery systems with cost-effective processing methods and safe formulations for human consumption is the main problem. To maintain the wholesomeness of foods, it is extremely important to prevent the migration and leaching of nanoparticles from packing materials into food products. The NSMs, whether they are contributed directly or indirectly, can occasionally become isolated as a result of emigration from other systems. At the nanoscale, the behavior of the materials is completely different, and our technical understanding of its analysis is still limited. The full comprehension of the functions at the nanoscale and the toxicity of nanomaterials will improve their practical application and safety standards. It is necessary to examine the effects of nanoparticles, potential risks, related toxicological concerns, and environmental difficulties. It has been documented that nanoparticles can pass the biological barrier and penetrate cells and organs. Different chemical processes used in the synthesis of nanoparticles have negative side effects and produce harmful, environmentally harmful byproducts that seriously pollute the environment. Hence, in the creation, packaging, and consumption of food products infused with nanotechnology, it's essential to prioritize a detailed risk evaluation, set regulatory guidelines, ensure biosafety, and address public apprehensions beyond just market demand and acceptance. Before introducing these products commercially and crafting nanoparticles with eco-friendly materials that have antibacterial properties, rigorous studies—both in vitro and in vivo—that analyze nanoparticle interactions with biological entities are imperative. [43], [33].

CONCLUSION

According to this review, nanotechnology has the potential to improve the quality and safety of food production and packaging. Recent applications of nanotechnology in the food processing and packaging industry have been reviewed under this study concerning several areas such as nanostructural modification of food, Nanoencapsulation, nanotubes, Nano Nutraceuticals, nano food additives, active packaging systems, smart-intelligent food packaging systems, nano edible coating and films, nanofibers, and nano clays. Nanotechnology plays an important role in becoming a sustainable food system with tremendous novel applications.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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