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Introduction to Nanotechnology-Enhanced Food Packaging Industry

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1.1 Introduction

Today creating biodegradable and natural materials based on biodegradable food packaging materials is a major global challenge for the environment. However, the use of bio-based packaging products such as food grade or biodegradable films from recycled sources could address the problem of waste in at least some way. The correct choice of products and packaging technology thus enables consistency and freshness of products to be maintained over the time required to be promoted and used. Even though, the availability of bio-based food packaging is limited in the market due to its low gas barrier and mechanical properties. As a result, these natural polymers were frequently mixed or chemically modified with other synthetic polymers to expand their packaging applications. Bio-based packaging has many essential features, including traditional packaging, such as the preservation and securing of products, ensuring nutritional integrity and health, and providing awareness to the consumers. Another nanotechnology that may help to minimize waste from the processing of packaged food is the use of nanocomposites in the processing. The use of nanocomposites that seek to facilitate the use of biologically degradable films protects fresh food and enhances the durability of it.

Nanotechnology involves the manufacturing, manipulating, and characterizing of nanosized objects, particles, and materials with a dimension of approximately 1–100 nm. Although the size of the material is reduced to the nanoscale range, its physical and chemical properties are magnified greatly from those of the macroscale structures made of the same material. Consequently, the nanoscale (1–100 nm) systems may have some implications, but successful implementations of the same for

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serving mankind are invaluable. Nanotechnology provides a range of significant improvements to enhance health, stability, and quality of life and to create assertive impacts on the environment [1, 2].

The packaging systems are protective shields that secure, manage, transports, store, retains, and marks any entity in the supply chain from raw materials to end users. These functions are required to accurately define any type of packaging, and how a variety of requirements, such as mechanical, thermal, and barrier characteristics, are preserved depending on the type of products to be packaged. Nanomaterials are gradually being used in the food packaging industry; therefore a variety of advanced nanomaterial technology is being researched and developed for packaging materials. There have been studies of approximately 500 nano-packaging materials for industrial use, while nanotechnology is expected to manufacture 25% of all food packings. Nano-packaging can also conceive antimicrobials, minerals, enzymes, flavors, and nutraceuticals to enhance shelf life and performance. In this line, antimicrobial films are used as packaging material to improve the shelf life of perishable foods like fruits and dairy products [3–6].

Nanotechnology's potential role in the food technology sector is probably the most exciting in the immediate future, and it is emerging as one of the fastest developing areas of nano-research of agriculture and food. New developments in food processing, labeling, nutraceutical delivery, quality assurance, and healthy food have also been seen. Many organizations, scientists, inventors, and industries are developing new technologies, protocols, and products, which directly apply nanotechnology to farming and food products. Companies are now designing packaging materials that prolong food and beverage life and boost consumer safety through the use of nanotechnology in daily-based consumer packaging [6]. Food processing and control are the main subjects of food industry-related nanotechnology research and development. Effective and intelligent packaging is the leading advancement of food packaging that aims to enhance product quality and consistency as well as to maximize product longevity. Most businesses and industrial design nano-packaging like time–temperature indicators (TTIs) can react to undesirable or damaging changes under the worse effects of climatic pollution. They can self-repair themselves, thus making this nano-packaging as "active and smart packaging."

Nanotechnology enhances the delivery of nutraceuticals, vitamins, or fragile micronutrients to everyday foods by creating small, edible capsules based on released nanoparticles to targeted locations in the body. Relevant health consequences are reduced frequency of cardiac disease, stroke, neurodegenerative diseases, and cancer [7, 8]. Nanoparticles are also used to introduce multiple functionalities such as color and odors as well as to be used as storage tanks for drug releases or fungicides. Despite considerable development in this area, nanotechnology remains a rare topic for food packaging, nanotechnology, and food science and technology. This chapter explores this knowledge gap by closely analyzing current developments in nano-package technology for food and drug systems and particular applications that gain immediate customer adoption and regulatory attention. This article examines this knowledge gap on the topics covered, which include bio-based packaging for environmentally safe biodegradable packaging; improved packages to enhance barrier properties, mechanical durability, and flexibility; active packaging of antimicrobials, flavor absorbers, and oxygen scavenging; and intelligent package features like freshness indicator, ripeness indicator, radio-frequency identification (RFID) , and TTI. This chapter concludes with a concise overview of future nano-packaging technologies possibilities.

1.2 Nanotechnology Applications in Food Processing

Nanostructured food ingredients are developed to facilitate sensory attributes like appearance, taste, texture, and flavor. Nanotechnology increases the durability of different foods and reduces food waste caused by microbial infestation. Nanocarriers are presently used as a supply system without interfering with their basic morphology to transport food additives into food products. The particle size can directly affect the delivery of bioactive compounds to different sites since some cell lines have noticed that it is efficient to absorb only submicron nanoparticles but not larger microparticles [9–13].

Nanotechnology provides effective distribution systems with all the functionality mentioned earlier for encapsulation formulation, emulsions, biopolymer matrices, clear solutions, and colloids. Nano-polymers are intended to replace traditional products for food packaging. Nanosensors may show the existence of pathogenic microbes, toxins, and adulterants in food [14]. Nanoparticles have greater characteristics of encapsulation and release performance than traditional embossing methods. By nanoencapsulation of the masks scent or taste, the interactions between active ingredients and the food network that govern the release of active agents can be monitored. This method guarantees the supply of desired food ingredients at the desired level of production, storage, and usage. This nano-packing method is consistent with other ingredients in the device against moisture, fire, chemicals, and biological degradation. Moreover, these nanotechnologies-based food nutrition delivery systems can reach deep into the tissues and effectively distribute active agents to the target sites in the body because of their smaller scale [15–18].

1.2.1 Nanotechnology Applications in Preserving Meat Density, Taste, and Presentation

Nanotechnology offers several options to improve meat quality and taste. Nano-encapsulation techniques have been widely applied to enhance flavor release and retention and maintain the balance of food. These bioactive molecules nanocarriers are popular for their safety and supply-based feature worldwide. Rutin is a popular dietary flavonoid, but its use is limited in the food industry [19]. Its low solubility and ferritin nanoencapsulation have improved the solubility and the thermal and UV stability of the ferritin-trapped routines compared with the free routine. Thus, nanoemulsions are widely used in producing lipid-soluble biological compounds that can be generated with easy processing methods utilizing natural foods and can also be engineered to increase water dispersion and bioavailability. Nano-packagings are important ways to boost the bioavailability of nutraceutical compounds because of their subcellular size, which contributes to higher bioavailability than large particles and produces faster and longer releases of encapsulating food nutrient compounds. Many metal oxides such as titanium dioxide and silicon (SiO_2) are widely used as colorants or flow agents in foodstuffs. SiO_2 nanomaterial is also one of the nanomaterials widely common in foodstuffs with flavors [20].

These nanotechnology-based applications of modern nanocarriers can help the food industry preserve the meat color and taste and make the food colorful, visually attractive, and presentable for the consumers.

1.2.2 Nanotechnology Applications for Maintaining the Food Nutrient Value

Many bioactive compounds like lipids, short-chain fatty acids, functional chelates, probiotics, and antioxidants are vulnerable to acids and enzymes in the stomach and duodenum. The encapsulation of these bioactive compounds allows them not just to avoid such adverse conditions but also to readily assimilate easily. In addition to that, small edible nanoparticles are developed for significant health gain to increase the regular supply of pharmaceutical items, probiotics, vitamins, and fragile micronutrients. The different strategies for encapsulating miniatures to include nutrients such as protein and antioxidants more useful for specific nutritional and health benefits include nanocomposite, nano-emulsification, and nanostructure. Polymeric nanoparticles are sufficient to secure and transmit bioactive compounds to specific bioactive compound encapsulation functions (flavonoids and vitamins) [21–23].

1.3 Nanotechnology Functions for Preserving or Shelf Life

In functional foods, the bioactive components are sensitive to external factors and eventually deteriorated during transport and storage; nanoencapsulation of these bioactive nanocomponents improves its shelf life. Especially, nanoemulsion-based edible coating controls the fruit ripening and extends the shelf life of perishable commodity. Also, consumable nanocoats could be a barrier to the moisture on various foods and could provide colors, flavors, nutrients, enzymes, and anti-brews [24–26].

1.4 Nanotechnology in Food Packaging

In food packaging, monolayer films cannot satisfy all the requirement because different food commodities require different barrier and mechanical properties. Polymer nanocomposites are the latest materials aimed at solving this problem. Polymer nanocomposites are prepared by dispersing an inert, nanoscale filler in a polymeric matrix. The widely used filler materials are silica (SiO_2), clay, cellulose-based nanofibers, graphene, silicate nanoplatelets, starch nanocrystals, carbon nanotubes, chitin or chitosan nanoparticles, etc. The nanocomposite can enhance barrier properties, flame resistance, better thermal properties, and alterations in surface wettability and hydrophobicity. European Food Safety Authority approved that the nano-TiN to use in package material can contact with food material. It is widely used in processing aid and to improve mechanical strength of polyester (PET).

Intelligent and successful food nano-based packaging offers many advantages, including improved mechanical strength packaging products, barrier properties, antimicrobial film for nano-sensing (Figure 1.1) pathogen identification, and food safety warning over traditional packaging techniques. Nanocomposites can also be used as active ingredients in packaging and coating material to improve food packaging. Several researchers were involved in investigating the antimicrobial effects of organic compounds in polymeric matrices, such as organic acids, essential oils, and nisin. However, these compounds do not comply with the many processing stages that require high temperatures and pressures because they are highly sensitive to these physical conditions. The use of inorganic nanoparticles allows for good antibacterial activity at low concentrations and increased stability under intense conditions [27]. The use of these nanoparticles in antimicrobial food packaging was therefore very important in recent years.

Nanocor® supplies specially designed plastic nanocomposites (nanoclays) owned by AMCOL International. Durethan® is used in food packaging and medical fields. It provides excellent gas and moisture barrier properties, strength, toughness, and

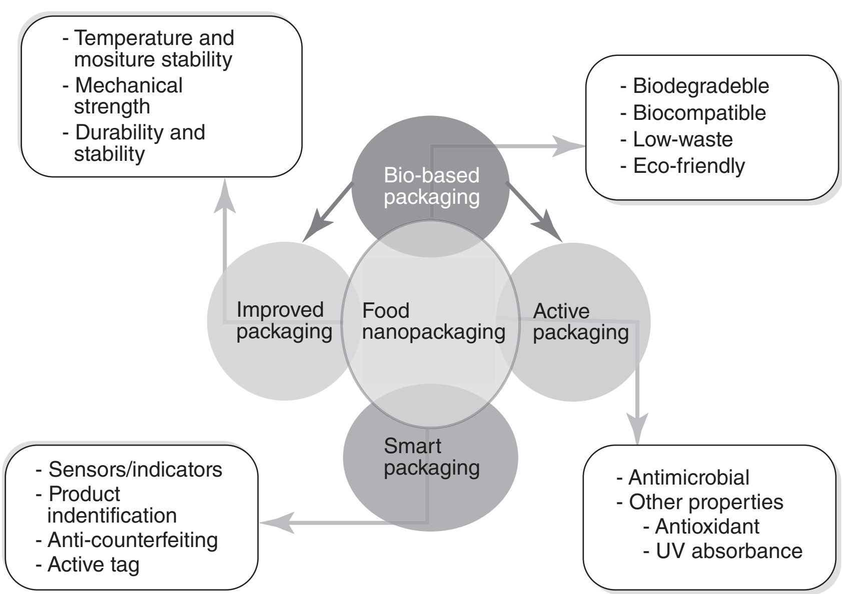

Figure 1.1 Features of food nano-packaging applied in the food industry [2].

chemical resistance. In South Korea, Hite Pitcher beer bottles were made out of Aegis™ OXCE (nylon 6 nanoclay composite) developed by Honeywell Polymer. It has high-oxygen barrier properties designed for alcoholic beverage and beer. A milk bottle and baby mug incorporated with silver nanoparticles have been developed by Baby Dream Co., Ltd., an infant product company in South Korea.

Antimicrobial packaging is not limited to antimicrobial products, but nano-compositions and nanolaminates are widely used in product packaging to resist intense mechanical and thermal shocks, which increase food shelf life. The incorporation of nanoparticles into packaging materials provides quality foods with longer durability. Moreover, to ensure the highest food-grading quality and standard, polymer composites are designed to supply both thermostable and usable packaging materials. Numerous inorganic or organic fillers are used to produce better polymer composites. The addition of nanoparticles in polymers has made it possible to develop robust, cost-effective packaging material.

1.4.1 Usages of Nanosensors in Pathogen and Adulterant Detection in the Food Industry

Nanomaterials for use in the development of biosensors include high responsiveness and other modern features. In dietary microbiology, nanosensors or nanobiosensors are used to detect pathogens in processing plants and foodstuffs, to measure accessible foodstuffs, and to alert customers and suppliers to food health. The nanosensor serves as an indicator of changes in environmental conditions, such as humidity or storage temperature, microbial contamination, or product degradation. To achieve potential biosensor applications, former researchers have studied specific nanostructures such as thin films, nanoparticles, nanorods, and nanofibers. These thin, film-based optical immunosensors have contributed to efficient and highly responsive detection systems for microbial or cell detection. These immunosensors are used to immobilize specific anticorps, antigens, or protein molecules on thin nanofilms or sensor chips that transmit signals for the detection of target molecules. Dimethyl siloxane combined with carbohydrate biosensors has been very carefully identified and used for microorganisms, contaminants, and other food and beverage-related items due to their quick identification, usability and cost-effectiveness. The contaminants connected to such nanotubes induce observable shifts of conductivity of waterborne contaminants in the identification of waterborne toxins. Therefore, the use of an electronic nose or tongue consisting of several nanosensors tracks food by communicating scents of foodstuffs or gas signals [28–30].

Adulteration is one of the key challenges faced in the food sector. Nanosensors have better sensitivity and accuracy than other sensors, for example, gold nanoparticles functionalized with cyanuric acid groups selectively bind to melamine, a common adulterant used to inflate the protein content in pet foods and infant formulas. Similarly, melamine adulteration in raw milk can also be detected up to 2.5 ppb using nanosensors.

1.4.2 Nanotechnology Applications in Food Safety Issues

In addition to all of the benefits for the food sector in nanotechnology, the protection in nanomaterials cannot be overlooked. Many researchers have tackled nanomaterial protection issues, with an emphasis on the potential transfer of nanoparticles from packaging to food and their impact on the health of customers. Nano-packaged food products must be acquired in more studies to determine the danger of its nanocomponents because its physicochemical properties in nanostats are completely different from those of macrostats. Furthermore, the small size of such nanomaterials will raise the likelihood of body and tissue bioaccumulation. Dissolution is caused by several influences including the composition of the soil, concentration, soil strength, aggregation, and adsorption of particles [3, 31, 32].

The value of the application of nanometer-scale structures in the food industry has also increased in recent years, and research efforts in this field have been strongly oriented. As nanobiotechnology advances, devices or materials dependent on this technology become less and more responsive. Its applicability in the fields of food packaging and food safety is well known. Promising findings were also obtained for food safety nanomaterials that can protect food against heat, contaminants, and harsh environmental conditions (Figure 1.2). They deliver excellent logistics systems for the delivery of bioactive compounds to the targeted body tissue sites. In the use of nanotechnology in the food system, consistency in the safety risks and environmental impacts should be the priority, and compulsory testing of the relevant nano-foodstuffs until they can be used in the market is necessary [2, 33].

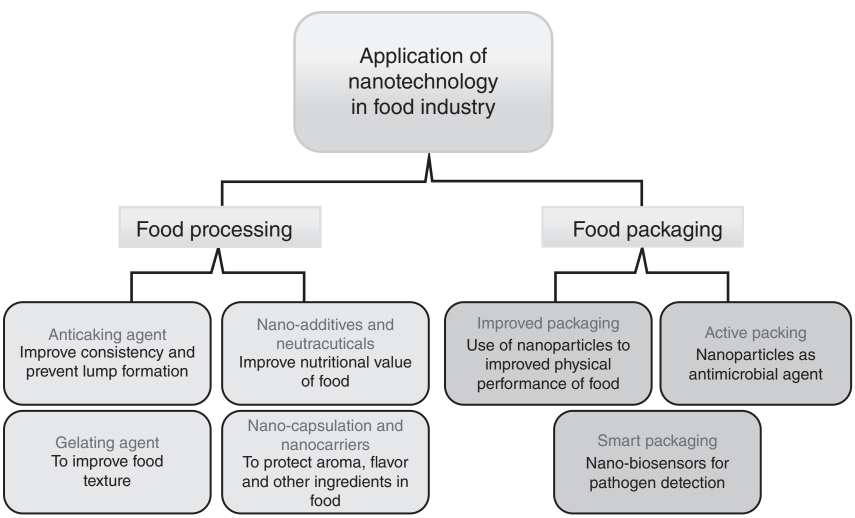

Figure 1.2 Diverse applications of nanotechnology in the food industry [3].

1.4.3 Bio-Based Nano-packaging in Food Industry

Bio-based nano-wrapping paper is a highly recyclable film used for food items for controlling moisture transfer and exchange of gas like CO_2 and O_2 for improved protection and for ensuring nutritional and sensory uniformity and reliability. Moreover, such type of materials in packaging are more socially friendly than conventional packaging films. As another type of packaging, biological packaging provides a barrier between consumer goods and their environment, thereby shielding them from harmful effects of microbes, relative humidity, and sunlight. The fundamental feature that separates biodegradable films from other packaging approaches is that the behavior of living things degrades these biodegradable sheets. This kind of body is the most common, as it is environmentally sustainable since all decomposition materials, e.g. carbon dioxide, biomass, and water, are fully reusable. Chemical packaging does not (or less) use fossil fuels to be used for consumer processing, and instead it uses green energy to recycle incineration power [34]. Therefore, nano-based bio-packaging sheets are very much popular these days due to their higher biodegradability than nonbiodegradable chemical sheets.

The promising design of bio-based nanocomposites for synthetic polymers drives new work on nanocomposites for use in food packaging. The classification of biopolymers is available in the literature. The use of nanotechnology on such polymers can offer new ways to improve both their properties and their cost-effectiveness. The most well-studied bionanocomposites are starch and derivatives such as polylactic acid (butylene succinate), polyhydroxybutyrate, and aliphatic polyester [35–38].

The three main applications of nanomaterial in food packaging were further described as the research trends in food packaging using nanotechnology, where nanoreinforcement, active nanocomposite packaging, and smart nanocomposites are mainly involved in food packaging. In active packaging, the well-known ingredients of antimicrobial packaging are silver, gold, and metal oxide nanoparticles. Silver nanoparticles found in several commercial applications are most widely studied. It may also be suitable for other active packaging fields, such as ethylene removers [39–43]. Nanosensors can respond to external changes in stimuli. The latest developments in smart food packaging polymer nanomaterials include indicators of oxygen, freshness, and pathogens [44, 45]. EcoSphere Biolatex® is a novel technology developed by the EcoSynthetix company. It is a biopolymer nanosphere with a granule size of 50–150 nm and a higher surface area than native starch. It possesses high solid dispersion in water. Native starch is replaced by EcoSphere Biolatex in adhesives. Instead of traditional adhesive, nanosphere starch is being used in McDonald's hamburger clamshell in the United States.

1.5 Nanocoating Applications in Food Industry

Food coating can be described as a thin film of an edible composite material to prevent mass transfer. Such coatings can serve as barriers to moisture and gases. Coatings are added directly and formed by applying a fluid film-forming solution or liquid compounds on the food component. Edible surface materials may be classified into two categories: soluble polysaccharides and lipids. Alginates, cellulose, pectin, starch, chitosan, and other polysaccharides are suitable polysaccharides. Many lipid compounds have been used for producing culinary films and clothes such as animal or vegetable fats, waxes, acylglycerols, and fatty acids, which can act as an appropriate lipid. Lipid films have outstanding moisture trapping properties or as binding agents for gloss applying to chocolate. Waxes are widely used to cover fruit and vegetables to slow ventilation and to prevent moisture loss [46].

Edible coatings are used in a broad variety of products from nuts, herbs, poultry, sweets, cheese, candies, bakery, and fried food. Few research work has documented nanoparticles being incorporated into coating films to enhance their physical properties by enhancing the release of oxygen; montmorillonite clay was applied to pectins. Similarly, gelatin and montmorillonite-derived nanocomposites have been used to greatly change physical properties. There was also a considerable increase in chitosan/layered nanocomposites stability. Nanoparticles can be used as antimicrobial and additive carriers. It can also be used to stabilize additives and control their diffusion effectively in food and the various regions, e.g. surface vs. bulk of the food system. This control may be useful for long-term food storage or for conveying certain desired characteristics like flavor to a food system. In this way, the United States has also produced an edible antibacterial nanocoating that can be applied directly to baking products, released by the Sono-Tec Corporation [46–49].

The three main applications of nanomaterials in food packaging were also described as research trends in food packaging using nanotechnology, where nanoreinforcement, active nanocomposite packaging, and intelligent nanocomposite packaging are the main issues for food packaging. The presence of nanoparticles in the polymer matrix products increases the properties of the commodity in better packaging. In addition to barrier properties, strength, rigidity, dimensional stability, and material heat tolerance may be strengthened by inserting nanoclays or SiO_2 nanoparticles. Nanoparticles are specially developed for applications of antimicrobial packaging in active packaging as active agents, silver, gold, and metal–oxygen nanoparticles with the antimicrobial function being the most studied nanoparticles with silver nanoparticles already present in several commercial applications. This is suitable for other fields of active packaging such as ethylene layer removers. Nanoparticles may be used as reactive particles in packaging materials for smart packaging to warn about the quality of the drug packed. To interact and to classify the drug, the so-called nanosensors can respond to external stimulation adjustments to ensure its consistency and health. Recent developments in polymer nanomaterials are oxygen indicators, freshness indicators, and pathogenic in smart food packaging.

1.6 Nanocoats Used in Food Manufacturing

Edible coatings are either applied to or formed directly on foods, whereas edible films are self-supporting structures used to wrap food products and also located in between two food components. It is a fact that such coatings may act as a barrier to heat, moisture, and gas. Coatings are added and formulated either by applying a liquid film-forming solution or directly on the food component with molten compounds. Edible coatings may be divided into two categories: polysaccharides and lipids and both of these categories are hydro-soluble. The best lipids are waxes, acylglycerols, and fatty acids, and among them, lipid films have excellent moisture capture properties and are used to color gloss on candy products as coloring agents. On the other side, waxes are commonly used to cover fruit and vegetables to delay breathing and rising moisture shortages [50].

Today, an edible coating is used for a large range of foodstuffs including nuts, potatoes, poultry, candy, dairy, cookies, pastry, and French fried products. Nonetheless, few research studies have identified nanoparticles in coating films to enhance their physical properties. Montmorillonite clay has been applied to pectins to reduce oxygen diffusion. Also, nanocomposites prepared for gelatin and montmorillonite have been used to improve physical properties. The efficiency of chitosan-layered nanocomposites was also greatly improved [51].

1.7 Importance of Nanolamine in Food Business

Nanolamines offer food scientists with various directions to manufacture modern food industry nanolaminate films. A nanoclay consists of two or more layers of physically or chemically connected nanometer-like content. One of the most efficient nanolamine methods is based on a layer deposition technique that covers loaded surfaces with interfacial films composed of several nanolayers of different materials. Nanolaminates have some benefits over conventional manufacturing methods for edible coatings and films and can also be used for several essential applications in the food and milk field.

Specific layers of adsorbing substances can be created, such as proteins, polysaccharides, lipids, and colloidal particles. Films are prepared with some active functional agents, such as antioxidants, antibrowning agents, enzymes, flavorings, and colors. These nanolaminated lacquerings could be entirely produced with the same nanocoating by simple processes such as dipping or washing from edible ingredients. The composition, thickness, structure, and properties of the laminate formed around the object depends on the dipping and coating process. These include changes in the adsorbed substances type in dipping solutions, the total number of dipping steps used, the order in which the item is introduced through the various dipping solutions, the solution, and the environmental conditions used [51].

1.8 Antimicrobial Films Used in Food Industry

There is currently substantial focus given to the use in packaging products of antimicrobial substances (such as silver nanoparticles and silver coatings). Antimicrobial films may help monitor the production and spoilage of pathogenic microorganisms.

According to the accepted structural stability and barrier characteristics, the nanomaterials and the antimicrobial characteristics of the antimicrobials impregnated in the image; it is highly beneficial to create an antimicrobial photo. This film allows nanomaterials to add more powerful copies of biological molecules.

A layer-by-layer incorporation of antimicrobial peptides such as nisin may also contribute to the creation of antimicrobial films. Nisin acts as a depolarizing agent in bacterial membranes and creates pores in lipid bilayers. Nanofilm multilayer peptides intercalated different peptides charged at neutral pH, which was much more stable than when peptide film only stabilized electrostatic interactions.

There have also been records of nanoscale chitosan antibacterial action. A potential antimicrobial pathway includes interactions between the positive and the negative chitosan cell membranes, raising the membrane permeability and eventually contributing to the breakdown and leakage of intracellular content. The ineffectiveness of both rough chitosan and engineered nanoparticles at pH levels above 6 is consistent with observation given the lack of protonated amino groups [52].

1.9 Nano-scavenging Oxygen Film Used in Food or Eating Substances

Oxygen (O_2) is responsible either directly or indirectly for the deterioration of many foods. For example, direct oxidation reactions lead to fruit browning and vegetable oils rancidity. Degradation of food by indirect action of O_2 includes aerobic microorganism food spoilage. The inclusion of O_2 scavengers in the food kit will also hold O_2 rates very small, which are beneficial for many purposes because they will increase the food's life.

Successful production of oxygen scavenger films was achieved by applying titanium nanoparticles (TiO_2) to different polymers, which are used to pack a wide range of oxygen-sensitive products. In particular, the emphasis was on the photocatalytic behavior of ultraviolet nanocrystalline titania. Since TiO_2 acts by a photocatalytic mechanism, the requirement for ultraviolet absorption (UVA) light is its major drawback [53].

1.10 UV-Proof Processing of Foods Using Nanometal Oxides

The film based on nanocrystalline titanium (TiO_2) is the commonly used material for UV absorption. During the exposure to sunlight, the effectiveness of TiO_2-coated film exposure to sunlight inactivates TiO_2 visible photo- catalytic absorption in the context of UV irradiation. Doping TiO_2 with silver has been reported to have greatly improved photocatalytic bacterial inactivation. The resulting combination was good antibacterial properties of nanoparticles $TiO_2/Ag+$ in a polyvinyl chloride (PVC) nanocomposite.

1.11 Nano-intelligent Food Labeling

In smart/natural, nanomaterials are used to monitor biochemical or microbial modifications in products, such as the identification of particular food contaminants or unique food spoilage markers. Nanoparticles may be used as reactive particles in packaging materials as regards smart packaging to notify the state of the packed product. To interact, warn, and classify the drug, the so-called nanosensors can respond to external stimulation adjustments to ensure its consistency and health. The latest innovations for smart food packaging polymer nanomaterials include spoilage triggers, oxygen markers, detection of items, and traceability [54].

1.12 Nanotechnology-Aided Freshness and Spoilage Indicators

The chemical interactions of nanosensors with spoilage components produced during the deterioration of food resulted in color change and state the level of freshness. The electrical, electronic, magnetic, and optical properties of polymers or electrically active conjugated polymers play an important role in chemical or electrical oxidation. Particularly electrochemical-polymerized conducting polymers may switch from oxidized (doped) to reduced (undoped) isolating state, which is the basis for many applications. The product indicator includes polyaniline film, which responds to several fundamental volatile amines released by noticeable colors during fish spoilage. Color variations were well linked in terms of overall volatile amine concentrations and microbial fish sample development rates in terms of the gross polyaniline (Milkfish) color variation [55].

Intelligent package has the potential to improve food safety and reduce food bone illness. Food spoilage is induced by microorganisms whose metabolism creates volatile compounds that can be identified by the conduction and/or recognition of micro-orientations dependent on gas emissions and food-freshness detections through performing polymer nanocomposites or metal oxides. Polymer nanocomposite-based sensors are used to conduct particles that are integrated into the polymer insulation matrix. The sensor resistance changes establish a pattern that adapts to the studied material. Conducting polymer nanocomposite sensors in black and polyaniline carbon were designed for the detection and identification of foodborne pathogens by producing a specific response pattern for each microorganism (for example, Salmonella sp., Bacillus parahemolyticus). For example, chicken freshness was analyzed based on the fragrance using a neural network to analyze metallic performance results such as tin and indium oxide gas sensors. In food packaging, a device that has several nanosensors, which are extremely susceptible to spoilage markers, creates a color change that indicates when the food is harmed.

1.13 Nanotechnology-Aided Oxygen Indicators in Food Industry

Metal nanoparticles can be easily used to generate oxygen and to cultivate aerobic microorganisms during the storage of food. There has been growing interest in developing nontoxic and irreversible sensors of oxygen in food-free, oxygen-free systems such as vacuum or nitrogen packaging. A UV colorimetric oxygen indicator was developed with UVA light that uses titania nanoparticles (TiO_2) to photosensitize the reduction in polymer encapsulation of methylene blue by triethanolamine. The sensor bleaches through UV irradiation and stays colorless before oxygen is added to the initial blue light. The survival time is relative to the amount of access to oxygen [4, 56].

1.14 Application of Nanotechnology in Product Identification and Anti-counterfeiting

Nanoparticles can be used as some smart food packaging as a food safety tracking device or to avoid falsification. BioMerieux has developed the Food Expert ID® multi detection test for nano-monitoring responses to food scares. Nanobarcodes for individual objects or pellets were produced by the US Oxonica Inc., which must be interpreted using a modified microscope for anti-counterfeiting purposes. Commercially available nanobars are made of inert metals, such as nickel, platinum gold, and silver, by electroplating into templates that define the particle diameter, which then releases stripped nanorods from templates [1–4].

1.15 Usages of Nanotechnology in Traceability and Active Tags in Food and Drug Industry

Radiofrequency recognition usually involves package stickers in food and drug or pharmaceutical industries. The brands are electronic radio-frequency sensor-based mechanisms used for transferring data from a tag connected to an object and automated recognition of the object. RFID is an improvement on previous manual tracking systems or bar codes. It is extremely robust and can work at extreme temperatures and pressures and can be detected over 100 m, and many tags can be played at the same time. Nanotechnology also allows for cost-effective RFID tags in sensor packaging. Smaller, more compact nano-enabling tags may be placed on thin labels [1–3, 55]. It is a fact that when concerning public health, an evaluation of the possible migration into food of packaging components and an evaluation of their potential danger are critical for a thorough risk assessment. However, very little research has been conducted so far on the impact of nanomaterials on absorption or possible association of food contact materials with nanomaterial-dependent food components [56]. Thin film transistor is the key part of RFID tags, and it can be embedded in food packages; a researcher came upon with cheaper printable thin film transistor made up of carbon nanotube-filled inks. It can be easily printed on papers and plastics [57].

1.16 Conclusions

In the last ten years, nanotechnology offers enormous opportunities for creative food packaging technologies that favor customers and businesses alike. Even at an early stage of improvement of the material properties of packaging, nanotechnology will have significant advantages and will require continuing investments of nanotechnological applications in packaging materials. Nanotechnology may offer a range of advantages in the context of advanced functional properties to render food packaging. Nanotechnology can improve food safety, making it convenient and creating modern product processing and innovative product and storage functions. However, all technologies are still at an intermediate level, and most of them, at least in the short term, are looking for good quality products. Also, nanomaterials can be used for the production of packaging, which keeps the product fresher indoors for longer food life and improves food safety. Smart packaging with nanosensors can also provide customers with inside knowledge of the food condition. Sensors can warn or inform consumers of the exact nutritional status contained therein before the food is spoiled. Nanotechnology is transforming the production of the entire packaging company.

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