Review Article *http://www.alliedacademies.org/food-technology-and-preservation/*
ISSN: 2591-796X

Application of nanotechnology in food packaging: A review.

Harthika Mylvaganam*, Pasan Rathnayake

Department of Food Science and Technology, University of Peradeniya, Kandy, Sri Lanka

Abstract

Nanotechnology has proven its competence in almost all possible fields. But still, Food Nano packaging is an incompletely explored field of study both in Nano science and food science. The purpose of this paper is to reveal the applications of nanotechnology in food packaging. Bio based packaging is a one of the remarkable techniques to reduce the environmental pollution. It replaces the non-degradable polymers with biodegradable materials which reduces waste and can be altered to extend the shelf life, and enhance food quality. Next is improved packaging, which aims in producing packaging material with good barrier properties, mechanical strength, flexibility and stability. Smart packaging is about use of Nano sensors and Nano devices in the detection of freshness of food, contaminants in food, monitor changes and integrity of packaging material.

Keywords: Active packaging, Intelligent packaging, Nano composites, Nanotechnology.

Accepted on September 15, 2020

Introduction

Nanotechnology is the engineering of functional systems at less than 100 nm scale level. Nanotechnology applications are expanded in the numerous sectors in the industrial world so as in food industry. Nanotechnology acts a prominent role in food industry through helping to improve its number of sub sectors including food packaging. At present studies are being carried out to extend the shelf life and enhance food quality while reducing packaging waste. Thus, Nanotechnology applications in food packaging have led to large amount of innovations which are used in the packaging industry commercially.

This review covers the role of novel nanotechnology based food packaging methods in order to get better enhancement in Food Quality and Safety. Application of nanotechnology in development of bio based packaging such as starch and polylactic acid, improved packaging such as Nano laminates, Nano coatings and Nano clay, and smart/intelligent sector such as spoilage indicators, Nano-based sensors and active tags have been reviewed

Bio Based Packaging

The growing problem related to disposable of plastic in-turn has led to the development of bio degradable packaging. Bio based packaging are biodegradable packaging film that are capable of controlling moisture transfer and/or gas exchange in order to improve safety and preserve the nutritional and sensory quality. Bio polymers are used to produce these types of packaging films. Bio polymers have poor mechanical, thermal and barrier properties [1]. Particularly, high brittleness, low heat distortion temperature, high permeability of gas and vapored poor resistance to processing operations has limited their applications in food industry [2]. Thus nanotechnology has been applied to improve the properties of these biopolymers. Nano-composites are developed to overcome these limitations of the biopolymers through nanotechnology.

Generally, composites are composed of a continuous phase or a polymer matrix and a discontinuous phase or filler [3]. At Nano-scale level, the size of the filler is immensely reduced, leading to the significant increment in the surface area of the fillers. This is preferred because bio Nano composites depend on the high surface area of the Nano sized fillers which results in a large boundary or interfacial area between the matrix or biopolymer and Nano filler.

These types of alteration to biopolymers have improved the properties of it as food packaging materials. Biopolymers include plant-derived materials such as, starch, cellulose, other polysaccharides, and proteins; microbial products like polyhydroxylbutyrate and polymers synthesized chemically from naturally derived monomers such as, polylacticacid. Most reports focused on application biopolymer films as edible films [4].

Starch

Starch and derivate are the most commonly used type of biopolymers that has been studied to produce bio-Nano composite materials for food packaging applications. Studies reveal that starch is completely degradable and could induce biodegradability of non-biodegrable materials when mixed [1]. Unfortunately, the starch has some limitations, such as poorer mechanical properties and strong hydrophilic behavior (poor moisture barrier) [5]. To overcome this problem, incorporating inorganic materials and synthetic polymers has been proposed to improve water barrier property of starch.

If starch is processed in an extruder by both mechanical and thermal energy, it can be converted to a thermoplastic material. Here, plasticizers are used to reduce intra-molecular hydrogen bonds and to provide stability to product properties. But still thermoplastic starch (TPS) cannot meet all these requirements such as efficient mechanical, oxygen and moisture protection. To overcome this problem, clay was used as follows.

Clay has been used as a potential filler to improve the properties of TPS. Starch or clay Nano composite films have been obtained by dispersing montmorillonite(MMT) nanoparticles through polymer melt processing techniques [6]. Significant

improvements in the mechanical properties were obtained [7]. Addition of MMT reduced hydrophobicity of starch films, possibly due to the tortuous structure formed by the exfoliated clay.

Polylactic Acid (PLA)

Polylactic acid (PLA) is the most common synthetic biopolymer that has been studied till today. PLA has received attention as a biocompatible, sustainable, biodegradable material with better mechanical properties. Therefore, PLA provides more disposal options and its production is less environmentally burdensome than traditional petroleum-based plastics [8].

The most important limitations for the applications of PLA in food packaging are its poor hardness, slow degradation, poor gas barrier properties, and hydrophobicity [8]. Nanotechnology can be applied to improve this property through the usage of Nano composites.

Solvent casting of mixtures of PLA and organophilic clay in chloroform resulted in materials with an improved crystallization tendency and increased Young's modulus. The PLA layered silicate Nano composites, developed by simple melt extrusion, exhibited significant improvement of material properties in both solid and melt states compared to the matrix without clay [2]. The oxygen barrier properties of Nano composite of amorphous PLA mixed with chemically modified kaolinite had improved by 50%. The combination of PLA and MMT layered silicate may result in a Nano composite with barrier properties appropriate for food packaging applications [4].

Improved Packaging

In the improved packaging development, nanomaterials are mixed into the polymer matrix to get better barrier properties and to improve temperature and humidity resistance of the packaging [4]. Such new packaging materials have excellent barrier properties to prevent the migration/diffusion of O_2, CO_2, water vapor, and flavor compounds. This will have a high impact on the shelf life of fresh and processed foods. In many occasions, it has been reported that the barrier properties of this new packaging film can be improved by about 50% compared to the properties of the neat polymer. This is due to the creation of a maze structure results in a tortuous path for gases and other molecules and by that reducing their permeation rate [9].

Nano Coatings

Coating in food can be defined as thin film of edible material placed between food components to provide a barrier to mass transfer. Edible coatings are currently widely used on a variety of foods, including vegetables, fruits, chocolate, meats, cheese, bakery products, candies and French fries [6].

Up to now number of researches has been carried out in order to improve the physical properties of these edible films by the integration of Nano-particles. In order to lower the migration of oxygen, clay MMT has been incorporated into pectin. Anoticeableraise in stability of chitosan layered Nano composites was obtained [6]. The inclusion of inorganic Nano fillers such as, TiO_2, ZnO and ZnS, and carbon nanotubes has enhanced the retention of flavor, acids, sugars, color and texture, increased stability during shipping and storage, improved appearance and reduced spoilage [8].

Nano Laminates

A Nano laminate is made of two or more layers of material with nanometer dimensions that are physically or chemically bonded to each other. Nanolaminatesprovidesome advantages over conventional technologies for the preparation of edible coatings and films and therefore have a number of vital applications within the food industry [10].

A range of different adsorbing substances could be used to develop the different layers, such as; natural poly electrolytes (proteins, polysaccharides), charged lipids (phospholipids, surfactants), and colloidal particles (micelles, vesicles, droplets) [11,12]. It would be beneficial to incorporate active functional agents such as antioxidants, antimicrobials, enzymes, anti-browning agents, flavors, and colors into the films. These functional agents would increase the shelf life and quality of coated foods [6]. These Nano laminates could be created completely from food-grade ingredients (proteins, polysaccharides, lipids) by using easy processing operations such as dipping and washing [11].

Nano Clays

Nano clays are bi-dimensional platelets with a very minute thickness ($\sim$1 nm) and several micrometer lengths Those are high performance, highly available and low cost materials. Thus significant number of scientific researches has been done about nanoclays.Interaction between the Nano clays and polymers are considered as the primary theory for Nano based packaging. According to the existing scientific researches; two types of Nano scale composites are created by the interactions between Nano clays and polymers, named as intercalated Nano-composites and exfoliated Nano composites.

Beer packaging gives precise examples on Nano clay applications in packaging sector. In the past, plastic was not used as a packaging material in beer industry because of the oxidation and undesirable flavour development. Nanotechnology has given a practical solution using Nano composites to overcome the problem. This led to employment of plastic materials in beer bottling and this material gives 6 month shelf life for beer. This technology can be also applied in packaging of soft drinks (ETC group 2004). In addition to beverages, certain food items such as processed meat, cheese, confectionary, and boil-in-bag foods can also be packaged according to this technology.

Other than the shelf life extension, there are numerous other advantages in Nano clays and Nano-crystals based packaging. As an example, the weight of the Nano-based packaging is considerably less and thus it leads to cut-off the transportation cost. Significant increase in film strength is also can be achieved in these types of materials and this leads to ensure the protection of the food stuff which is inside the packaging. The most considerable limitation of this technology is that the Nano clays on polymers reduce the transparency of the packaging.

Intelligent/Smart Packaging

Intelligent packaging helps in detection the properties of the enclosed food and its existing environment and aids in providing

basic idea to the retailer, customer and manufacturer about the condition of these properties. The most important function of intelligent packaging is to monitor both internal and external condition. Another function is assessing the quality of the food product directly within package.

Freshness/Spoilage Indicators

Identification of food spoilage during its market chain is essential to prevent any food borne diseases and to provide quality and safety product to the consumers. Recently polymer Nano composites are used to detect microbial gas emissions with regard to food spoilage. Such packaging can monitor the spoilage and display it by changing the color. Spoilage indicators can also be installed at the packaging plant, so that they can detect the microorganisms that regularly infest the food. Thus, the packaged food products do not need to be sent to the lab for sampling. These sensors alert the consumers regarding the quality of the food product with the help of color changes [13].

Another example is Opal, which makes polymer opal films by adding 50 nm carbon black nanoparticles to use as biosensor that can change color in response to the food spoilage (Qureshi et al.,).The electronic tongue sensors are developed to detect spoilage by changing the color if it comes in contact with any food spoilage thus declaring that the food is not fit for consumption [14].

Nano-Based Sensors

Environmental changes leads to the deterioration of food product and also leads to increase the microbial activity on food stuffs and toxicant generation. Nano particles and Nano composites can be used to food packages which can be act as reactive particles and identify undesirable changes. These types of materials are considered as nanosensors.Nanosensors can detect specific chemical compounds, pathogens and toxicants, with response to their level of occurrence in food stuff. Time temperature integrators, gas detectors for food spoilage and O_2 sensors are the common kinds of Nano sensors applied in food packaging.

As an example, Scientists at Kraft, Rutgers University and the University of Connecticut, have designed the “electronic tongue” to detect pathogenic microorganisms and other substances in parts per trillion with the help of embedded Nano sensors in the packaging materials using nanotechnology. The sensors can detect color changes in the package when the food products start to spoil [15].

Active Tags and Traceability

At present, there is growing demand to build up standardized traceability systems from the raw material to the sale of goods. Thus, Nanotechnology is applied in the food packaging sector in order to improve traceability of the food chain. As an example, Nanotechnology based tags which can be used for individual items or pellets have been developed recently [15].

Nanotechnology is also developed sensor packaging to incorporate cheap Radio Frequency Identification (RFID) tags. This RFID tags alert the consumers if products have reached their expiry date. The Nano-enabled RFID tags are much smaller, flexible and can be printed on thin labels. Therefore the tags are versatile and can be produced with reduced cost [16].

Some researchers recently have discovered a low-cost printable transmitter that can be fixed in packaging in an invisible manner. It is based on a carbon-nanotube-infused ink for ink-jet printers. The thin-film transistors are made of ink; this is a vital element in RFID tags that can now be printed on plastic or paper.

Product Identification and Anti-Counterfeiting

Anti-counterfeiting has been developing concept in food and industries since recent past. Counterfeiting can be happen in each part of the food chain due to its high availability. Thus, the food industry has an increased vulnerability on this phenomena and come up with innovative solutions is essential.

Nanotechnology plays a major role in overcoming counterfeiting issue. Nano-based smart packaging provides applicable solution on detection of counterfeit food products. A multi-defection test for Nano surveillance, response to food scares has been developed as a solution for this problem. In addition anion-based tracking technology for monitoring pathogens has been introduced to the market. A united state company OxonicaInc has developed Nano-barcodes to be used for individual items or pellets, which must be read with modified microscope for anti-counterfeiting purpose [17].

Conclusion

Researches reveal that nanotechnology is a promising technology that helps in innovative developments in the food packaging. Application of nanotechnology in food packaging shows significant improvements in the processing, shelf-life, health and packaging functionalities, transportability, and reduced costs. Nanotechnology can be applied in food packaging in many ways. Most of this applications are still in the experimental or elementary level and some are only limited to high-value products.

Bio based packaging is one of such application. Increased interest in environmental pollution made bio based packaging an indeed technology. Bio based packages have replaced the non-degradable polymers. The problems associated with these biopolymers are performance, processing and cost. The Nano composite is developed to overcome these limitations of the biopolymers through nanotechnology. In starch to improve its quality Nano composite is produced using MMT clay as Nano filler. The combination of PLA and MMT layered silicate results in a Nano composite with better barrier properties suitable for food packaging.

Improved packaging is a trending new technology. In improved packaging development, nanomaterials are mixed into the polymer matrix to improve its properties. The incorporation of clay MMT and inorganic Nano fillers such as, TiO2, ZnO and ZnS, and carbon nanotubes shows significant improvements in Nano coating. A Nano laminate is produced using two or more layers of material with nanometer dimensions that are physically or chemically bonded to each other. Smart packaging

is a modern aspect of the Nano based packaging and these approaches should be improved furthermore.

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***Correspondence to:**

Harthika Mylvaganam
Department of Food Science and Technology
Faculty of Agriculture, University of Peradeniya, Kandy, Sri Lanka
E-mail-mharthika@gmail.com,
Tel-+94715745360