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Application of Nanotechnology in Food Packaging

Merve Gozde COSKUN[1], Omer Utku COPUR[1], Perihan YOLCI OMEROGLU[1*]

[1]Uludag University, Faculty of Agriculture Engineering, Department of Food Engineering, Bursa/Turkey
[*]Corresponding Author: pyomeroglu@uludag.edu.tr

Abstract

Nanotechnology has been widely used in the fields of medicine, physics, chemistry, biology, molecular biology, food and food packaging. This technology is based on the manipulation of the material used at the atomic and molecular scale. Nanomaterial is defined as a material containing particles in the size range between 1 nm and 100 nm. Investigations have reported that the annual number of nanomaterials used in the market has reached 11 million tonnes. Application of the nanotechnology into food packaging prolongs the shelf life of the food product as well as improving its quality. The studies revealed that nanomaterial applied to packaging material improved its mechanical strength and permeability; therefore the packaging material protected the freshness of the product. While given the increase in human population and food shortages in our developing world, nanotechnology is an important step for the packaging industry. In the scope of this study, the history of the development of nanotechnology is addressed, the structure of nanomaterials and nanocomposite structures developed from these materials are defined, and the application of nanotechnology to foods and food packagings are reviewed. In this context, the use of silver, titanium dioxide, zinc oxide, silicon dioxide, MgO nanoparticles, polimer techonology, an antimicrobial nanocomposite film and nanosensorsis are explained. Moreover, the adverse effects of nanomaterials on human health as well as its legal regulations are also discussed.

Keywords: Food packaging, health risk, nanotechnology, nanomaterial, regulations.

INTRODUCTION

Nanotechnology has been widely used in the fields of medicine, physics, chemistry, biology, molecular biology, food and food packaging, agriculture, aquaculture and fisheries including fish biotechnology, genetics, and its reproduction. This technology is based on the manipulation of the material used at the atomic and molecular scale. Nanotechnology enables to create materials and systems with new features by manipulation of the matter at the level of atoms and molecules (Mura et al., 2014). Nanoparticles are the small object which acts as a whole unit in terms of transport and properties. The classification of the nanoparticles depends on their characteristics, size and structures. The size of nanomaterial ranges between 1 nm and 100 nm. Material science is applied to nanotechnology for developing novel materials with the nanoscale characteristics (Hatzigrigoriou and Papasyrides, 2011; Cushen et al., 2012; Otles and Yalcin, 2013; Chellaram et al., 2014).

According to the “Recommendation on the definition of a nanomaterial” adopted by the European Commission “nanomaterial” means “a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1-100 nm” (EU, 2011a).

It was reported that nanotechnology has been unknowingly applied since the 4th century BC, when gold nanoparticles were used in the manufacture of porcelain in China and Egypt and for medical purposes. Lycurgus cups, which were made during the Roman Empire by using colored glasses containing silver and gold nanoparticles, can be given to an example to the application of their optical properties. In 1959, the famous physicist Richard Feynman recommended applying nanotechnology to work on matter at the atomic and molecular scale, this highlighted its importance, and then many people started to interest (Mura et al., 2014).

Food nanotechnology has been dated back to Pasteurization process in which Pasteur killed the spoilage bacteria with 1000 nanometers size. It stands an important improvement in food processing due to its obvious effect in food quality (Chellaram et al., 2014). Moreover, Watson and Crick's model of DNA structure, which has two helix with in 2.5 nm diameter, was defined. The other reported development in nanoscience included the invention of carbon nanotubes, which is 1 nm in size (Chellaram et al., 2014).

Nanotechnology can deliver significant improvements in terms of reducing waste for global product diversification, increasing food quality to higher levels, and "sustainable intensification" of production in agriculture. The environmental pollution caused by the pesticides and fertilizers used causes the destruction of biodiversity and the development of harmful pathogens in agriculture. Nanoformulations can be created to prevent this. This also reduces harvest damage (Cushen et al., 2012).

Nanofood is defined as the food which is obtained by the application of nanotechnology techniques (Ötleş and Yalçın, 2013). The purposes of using nanotechnology in the food industry is to improve the shelf life, freshness, the quality and safety of food products, to detect pathogens and chemical contaminants, to increase the range of food texture, colour and taste, to improve the efficiency of nutrient supplements and natural health care products, to provide encapsulafion of flavour or odour enhancers and decrease the use of fat (Cushen et al., 2012; Ötleş and Yalçın, 2013; Lopes et al., 2013; Silva and Cerqueira, 2012; Rashid and Khasravi-Darani, 2011; Sözer and Kokini, 2011).

It has been reported that by using nanotechnology, shelf life of seafood products can be prolonged by detecting bacteria in packaging and by increasing the barrier properties of the packaging material. Therefore such a healty food can be benefited by consumer safely (Buzby, 2014).

Nanoparticles can also be used as active and intelligent food packaging materials. According to European regulations 1935/2004/EC and 450/2009/EC, active materials and articles are defined as ‘‘materials and articles that are intended to extend the shelf life or to maintain or improve the condition of packaged food’’. On the other hand, intelligent food contact materials are defined as ‘‘materials and articles which monitor the condition of packaged food or the environment surrounding the food’’ (Mihindukulasuriya and Lim, 2014; EU, 2004; EU, 2009].

There are different types of nanosystem applied in food industry such as nanoencapsulation, nano-emulsion, spontaneous structure, nano-filtration, nanotechnology sprey, nanocoating and nano feed additive, and edible nano coating. Nano-encapsulation includes nanospheres suitable for food hydrophobic materials encapsulated to moisture or pH sensitive bioadhesive microspheres.

Those encapsulation system provides benefits including ease of use, increase stability, protection against oxidation, retention of volatile ingredients, taste masking, moisture and pH controlled release (Lopes et al., 2013). Nano emulsion system consists of a lipid phase dispersed in an aqueous continuous phase surrounded by a thin interfacial layer of emulsifying molecules (Ranjan et al., 2014). The use of nano emulsions in food products provides less oil use without losing cream. As example include low fat nanostructured mayonnaise, spreads and ice creams (Cushen, 2012). A firm is reported to be developing nanosize emulsion-base dice cream with low fat content but that standardizes texture and flavor (Alfadul and Elnesh, 2010). Spontaneous structures include sturucte of proteins, starches and fats that may change during food processing at the nanometer and micrometer scales. As an example can be given denaturation of milk proteins during yoghurt formation, homogenized milk with sized droplets of 100 nm, ice cream, and whey proteins (Ranjan et al., 2014). Nano-filtration is a membrane separation method between ultrafiltration and reverse osmosis. It is used to remove bacteria, viruses, organic residues and hardness applications in food such as in whey and juice filtration and water purification (Mamin et al., 2013). Nanotechnology sprey is used to enhance the uptake of vitamin B12 and the use of other supplements in foods (Mamin et al., 2013). Nano-coatings and nanofeed additives are used in poultry meats with nano-titanium dioxide (TiO_2) to oxidize and destroy bacteria (Prasad et al., 2014). Edible nano coatings include a nano-laminate with improved moisture and gas barrier properties. Since they are physically or chemically bonded to each other, they can be used to encapsulate different type of substances, active functional agents including antimicrobials, antibrowning agents, antioxidants, enzymes, flavors, and colors, these agents may increase the shelf life and quality of coated foods (Dobrucka, 2014).

In this study, firstly, the development of nanotechnology in the historical process is addressed, the structure of nanomaterials is defined, and nanocomposite structures developed from these materials are investigated, the effects of nanotechnology on packaging and its applications are mentioned. In this context, the use of silver, titanium dioxide, zinc oxide, silicon dioxide, MgO nanoparticles, polimertechonology, an antimicrobial nanocomposite film and nanosensors are explained briefly. Finally, the effects of nanotechnology applications on health and the legal regulations in EU are discussed.

APPLICATION OF NANOTECHNOLOGY INTO FOOD PACKAGING

The packaging process is used to protect the food product from humidity, physical action, heat and light source deteriorations, to prevent microorganism, to protect against external pollution, to provide ease of transportation, to facilitate presentation, and to show content (Robertson, 2012).

There are some important points that should be considered when choosing the packaging materials including glass, paper, metal and plastics. These includes characteristics of the food products, the exact fit between the packaging material and the product, the content of the information given on the packaging material, the cost of the packaging material, and the visual and functional design of the packaging (Robertson, 2012; Silvestre et al., 2011).

Food packaging prevents permeability and acts as a barrier. In addition, the most important aim of food packaging is to prevent unwanted changes, flavor, odor and sensory properties. Application of nanotechnology to the packaging material increases the functionality of the material (Sözer and Kokini, 2014). There are different nanomaterials to be used for food applications, as well as industrial scale atomic measurement.

POLYMER NANOTECHNOLOGY

The polymer nano technology is an industrial activity involving all the processes of producing polymeric materials filled with particles under 100 nm in size. Recently, the use of polymers has increased. Polymer materials with application of nanotechnology have very good properties such as permeability, flexibility, hardness. (Silvestre et al., 2011).

In order to prevent the biodegradability of the packaging materials, inorganic particles such as clay are added to the biopolymer structures. The use of inorganic particles helps improve the transmission of fragile micro nutrients in edible capsules (Silva and Cerqueira, 2012).

ANTIMICROBIAL NANOPACKAGING

There are nanoparticles that enhance antimicrobial properties of the food packaging. They provide antimicrobial activity by inactivating the microorganisms present in the food (Ötleş and Yalçın, 2013).

Silver nano particles (AgNPs) used in polimeric films are widely benefited in antimicrobial food packaging. Surface area of the nano silver particles to contact with bacteria or fungi is very high. Food packaging, storage containers, chopping boards, refrigerators and health supplements are some of the usage areas of the silver nano particles as antimicrobial agents. The antimicrobial capacity of AgNPs on the meat was investigated, when the meat was packaged with a low density polyethylene (LDPE) based plastics blended with nano antimicrobial masterbatch. Delay in lipid oxidation was also observed (Yang et al., 2016).

Zinc oxide nanoparticles have become a useful material in many areas as UV absorbers. In a study, zinc oxide nanoparticles were prepared as active packaging material for the inactivation of Salmonella typhimurium and Staphylococcus aureus. The film was used as an active packaging material against the same pathogens in poultry meat. It has been observed that the daily bacterial workload is reduced to zero from seven. In another study, a zinc oxide filled bio-nanocomposite film was prepared and the effect of the film against *E. coli* was examined, it was observed that the results were very positive. These properties have shown that ZnO-nanoparticles based bio-nanocomposites are a potential packaging material (Yang et al., 2016).

Titanium dioxide (TiO_2) is an environmentally friendly, non-toxic, inexpensive material with a high refractive index. The photocatalytic reaction of titanium dioxide inactivates microorganisms by causing the oxidation of phospholipids in cell structures of microorganisms. TiO_2 constitutes a basis form any works due to its lower cost. It was reported that a TiO_2-PE film was developed to inactivate *Escherichia coli* or *Staphylococcus aureus*. It has been observed that it exhibits an effective antibacterial activity for the microorganisms. Titanium dioxide is used as an antimicrobial additive in food packaging (Yang et al., 2016).The other research study reveals that *E. coli* activity was stopped after the packaging films were coated with titanium dioxide. However, since it requires UV for disinfection, its use is not preferred (Hatzigrigoriou and Papasyrides, 2011). Also, it has been observed that TiO_2 coated folies subjected to UV can neutralize fecal coliforms in the water (Dasgupta et al., 2015). Disinfection is used with silver to improve the process (Ötleş and Yalçın, 2013).

Magnesium oxide (MgO) nanoparticles have high conductivity and antibacterial effects. A study has shown that *E. coli* and anthraquinone are inactivated by MgO (Yang et al., 2016). In another study, it was observed that (MgO) was most effective in killing microorganisms (Mihindulasuriya and Lim ,2014).

Metal nanomaterials are also of interest. It has its own unique antimicrobial properties like silver and gold (Sözer and Kokini, 2011).

Silicon dioxide and carbon are 100 nm in size, like other nanoparticles, and packaging is also used as a food additive. Gold and platinum nanoparticle biosensors can be used in the packaging material to make up the food. Also, in these contexts, ontmorillonite clay, polyethyene nylon polyvinyl chloride and starch are also used extensively (Lopes et al., 2013).

ANTIMICROBIAL NANOCOMPOSITE FILM

To increase product's shelf life and to control the growth of both pathogenic and spoilage microorganisms, materials with antimicrobial activity can be used. An antimicrobial nanocomposite film can be used for those purposes and it may solve shelf life problems of the foodstuffs by providing acceptable structural integrity and barrier properties. Those properties may be obtained from both nanocomposite matrixes and the natural antimicrobial agents impregnated within the structure (Hatzigrigoriou and Papasyrides, 2011).

NANOSENSORS

Nanosensors are the application area of nanotechnology to intelligent packaging. They can be used either as coating in food packaging. They ensure the integrity of the package, since they can detect leaks; indicate the time–temperature variations, or microbial safety. They can detect some chemical compounds, pathogens, and toxins in food. By application of nanosensors, real-time status of food freshness has provided and then real expiration dates have observed. In addition, studies are being made to develop smart packaging technology (Sözer and Kokini, 2011).

Nanobiosensors are advanced devices that digitally output all the changes of the food. It is used for the detection of materials such as drought, temperature, humidity, pathogen, insect, pollutant. Because of these features, farming in agriculture provides great convenience. Helps farmers have an idea about harvest time (Prasad et al., 2014).

HEALTH RISKS

The nanomaterials in corporation into food present a whole new array of risks for the public, workers in the food industry and farmers (Mamin et al.,2013). Due to the increasing use of products containing NPs, the ecotoxicology of NPs became of an increasing importance in last years. In general, the toxicity of NPs is determined by their particle size, shape and biodegradability. Based on the particle size and biodegradability of NPs these can be classified into four classes: (i) size > 100 nm and biodegradable; (ii)size> 100 nm and non-biodegradable; (iii) size < 100 nm and biodegradable; (iv)size < 100 nm and non-biodegradable (Dasgupta et al., 2015). Particles smaller than 70 nm can enter cell and cause impairment of DNA replication and transcription.

Of course, non-biodegradable materials, which can remain in the body, accumulate and stimulate the immune system, represent an increased risk of toxicity.Therefore long term exposure can cause variety toxic case in human body (Mamin et al., 2013). Morries et al. (2017) states that harmful effects of nanoparticiles still remains an unknown issue, eventhough enorumous studies has been conducted and reported based in the literature.

REGULATION

In European Union, there is not a direct regulations for nanomaterials for food packaging. However, producers should comply with the related regulations on food packaging. In the European Union (EU), Regulation (EC) No 1935/2004 sets up the criteria which aims to provide safely use of food contact material and articles which includes food packaging as well (EU, 2004). The regulation states that materials and articles, including active and intelligent materials and articles, should not release their chemical ingredients in to food in a concentartion which is harmfull to health and the chemical migration should not change the organoleptic properties of the food. Plastic materials and articles intended to come into contact with food are regulated by Commission Regulation (EU) No 10/2011. Annex I of Commission Regulation (EU, 2011b) No 10/2011 contains the Union list of authorized monomers, other starting substances, macromolecules obtained from microbial fermentation, additives and polymer production aids (EU, 2011).There are two migration limit set for plastic based materials and articles including specific migration limit (SML) for individual authorized substances fixed on the basis of a toxicological evaluation and overall migration limit – 10 mg of substances/dm² of the food contact surface for all substances that can migrate from food contact materials to foods (EU, 2011b). It is reported that titanium nitride is the only nanoparticle which is authorized under the regulation EU 10/2011 (Hoekstra, 2014).

Bumbudsanpharoke and Ko (2015) and Störmer et al. (2017) summarized the studies on migration of nanomaterials from food packaging in to foods. It is stated that there is a probable migration from those type of material in to foods; eventhough the concentration is lower than that is specified in the regulation.

Nanomaterials used as active and intelligient materials are regulated according to Regulation (EC) No 450/2009 (EU 2009). If a nanomaterial is released into food, it requires to be authorised as food additive under Regulation (EC) No 1333/2008 (EU, 2008).

Moreover, if a food contain engineered nanomaterials, it should be stated on the food labeling (EU, 2011c).

CONCLUSIONS

Nanotechnology is a major technology that increases the quality of life in many areas. In this article, the areas used (especially in packaging) are examined. Packaging applications have effects such as being a mechanical barrier, protecting against physical effects, lengthening the shelf life of food, and improving taste-quality, antimicrobial effect. The chemical migration of nanomaterials from packaging materials in to foodstuff is important, when considering the health and safety risks of food and human beings during its application. Like in European Union, the legal limits of this technology in our contry are not obvious, so its application is few in practice. If more risk studies are undertaken to assess the negative effects of this technology, which increases the quality of food, its applicability will be positively increased.

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