Nanotechnology and Smart Packaging in Food Packaging

Anıl KIZEN[1], Zeynep TACER CABA[1*]

Abstract

Increasing consumer awareness of food safety and quality is driving researchers and the food industry to new trends. As a result of the developments in technology, the design and use of materials with different properties have become common today. Some of the developed materials can be modified and / or improved in functions of food packaging. The production of nanomaterials and their combinations with various materials to obtain composites are the most remarkable technologies in recent years and these materials are used in different fields. One of these areas is active and intelligent food packaging systems. Active and intelligent packaging makes more communication possible with the consumer and makes it possible to obtain packages that deliver food in a safer way to the consumer. This review aims to present a brief summary of nanotechnology applications in food packaging and legal regulations for intelligent packaging.

Keywords: *Food packaging, nanotechnology, active packaging, smart packaging, nanocomposites*

1. Definition of Nanotechnology

Nanotechnology is defined as a new industrial revolution of our era and it is thought to affect almost every area of our lives. "Nano" is defined as "a billionth of one physical size". Nanotechnology is the science of understanding and controlling the behavior of a substance at 1 to 100 nanometer dimensions. This degree of control leads to radical innovation in numerous areas [1]. Using new technologic strategies related to nanotechnology is vital in many different parameters including sustainability, environmental concerns, waste valorization, high availability and low prices.

It is not only the dimensions that separate nanoparticles from large materials. These materials also exhibit a different structure from the larger materials in terms of chemical reactivity, energy absorption and biological mobility. In recent years, these materials have begun to take place in the food industry. With nano-technological applications and use of nanocomposites, it is possible to obtain packages that communicate with the consumers and deliver the food in a safer manner to the consumer. However, also the challenges raise on a number of environmental and social issues. Especially, toxicity is one of these difficulties. Given the diversity of scientific studies on this issue, the main purpose of this study is to introduce this new science of nanotechnology, general toxicology concerns of nanomaterials and to increase the awareness of our colleagues [1, 2].

2. Objectives of Nanotechnology

- Analysis of nanometer scale structures,
- Understanding the physical properties of nanometer sized structures,
- Unusually different and superior material properties, production processes,
- More durable, lighter, faster,
- Less material and energy use.

3. Nanotechnology and the Possibilities Provided

One of the most important elements of nanotechnology that is interesting is the behavior of materials when they are nanostructured. Due to the quantum effects, the materials exhibit different properties in nanoscale. For example, while ingot of gold does not want to react with other

[1]*Istanbul Aydin University, Engineering Faculty, Department of Food Engineering, 34295 Istanbul, Turkey*
**Corresponding author: Z. Tacer Caba, zeynepcaba@aydin.edu.tr*

substances, the reverse is observed for gold in nano- scale. Due to this feature, scientists examine different cases in nanoscale materials and try to find solutions [1]. The benefits of nanotechnology can be summarized as follows:

- The possibility of placing each atom exactly at the desired place,

- The possibility of producing almost everything that physics and chemistry makes possible at atomic level,

- Economical production opportunity where production costs do not exceed raw material costs.

Nano-technological products are used within the fields of different sectors such as food, electronics, automotive, paint, textile, health as well as pharmaceutical industry. Current nanomaterials impart additional capabilities and features such as strength and flexibility, water-repellant and/or absorption, fragrance release, resistance to degradation. The production techniques used today are very crude techniques in the molecular sense. Casting, grinding, turning etc. are based on the movements of atoms in large quantities. By the use of nano-technological manufacturing techniques, the domination of nanoscale materials as stone which is capable of being assembled cheaply with the atoms linking system. With this development, the desired qualities in the food sector and more robust features such as the production of lighter and more sensitive packaging material become possible [3].

4. Packaging

Packaging is defined as a tool that acts as a barrier against external factors, aiming to protect the foodstuffs stored in the interior against deterioration and to introduce them to consumers untouched until the last consumer. Consumer demand in recent years is subject to change in the direction of food protection in its first day freshness by deducting the minimum level preservatives or less environmentally damaging materials with increases in shelf-life [2, 4]. Intelligent packaging technology is a new system used in the food industry and recently a new packaging system whose usage is increasing rapidly. The system is mainly used as an indicator for in-packaging and out-of-packaging to protect the quality of food during storage and to ensure food safety. It shows temperature change, O_2 and CO_2 content, etc. as the freshness bookmarks of food products [2].

4.1. Nanotechnology Applications in Food Packaging

Nanoscience and nanotechnology have a research field with physics, chemistry, biology and engineering branches to process materials in molecular and atomic dimensions. Since the implementation of nanotechnological applications in foods are concerned, the term “nano-food” is defined as the use of nanotechnology techniques or apparatus during the handling, packaging, food production, breeding, etc. Nanotechnology has the potential to be used in all areas of the food industry, from food production to agriculture, food packaging and food supplements [2].

In recent years, most of the nanotechnological research and applications in the food industry are seen in the field of food packaging. In addition, nanotechnology is used for masking the unwanted taste of vegetables, controlling the release of encapsulated active ingredients, vitamins and flavorings, protecting them from oxidation, to identify pathogens and to analyze food safety. The addition of nanoparticles to food packaging for various purposes, package distribution and controlled release of active substances, packaging with antimicrobial agent at the nanometer level, product nanotechnology during transport and distribution, or traceability through packaging containing nanoparticles are among the active and / or smart packaging applications of nanotechnology [2, 6]. In food packaging, nanocomposites usually refer to materials containing generally low additions of some kind of nanoparticles. This application is of particular interest for nanocomposite films containing nanoparticles or modified nano-clays having an active particle typically containing 1–7 weight % and finds wide application in the smart packaging food industry [2].

4.2. Smart Packaging and the Techniques of Smart Packaging Concepts

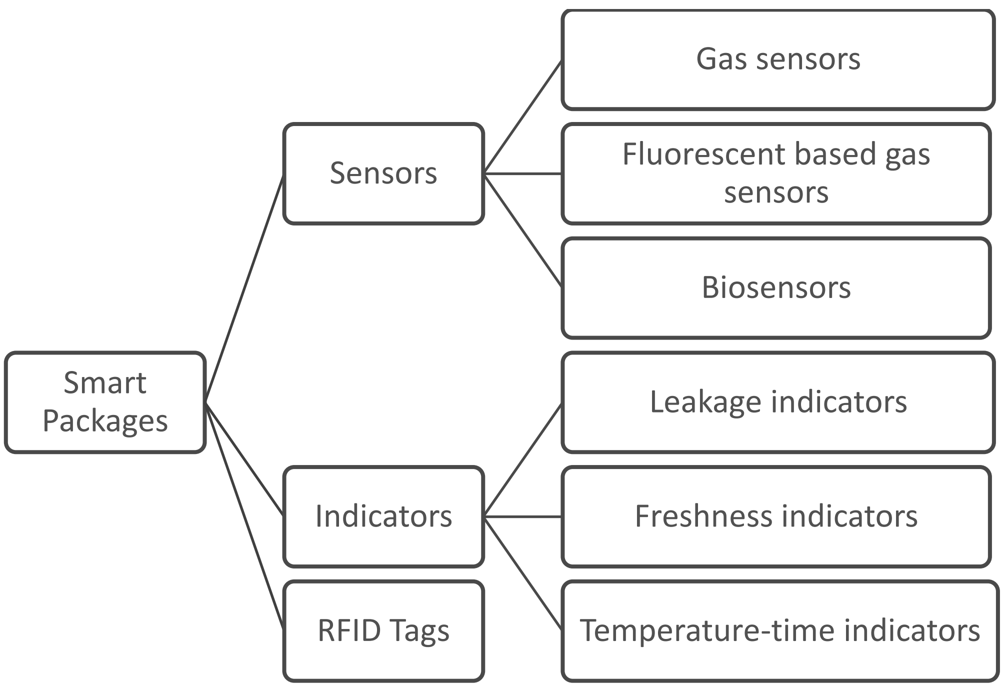
"Smart Packaging" or "Smart Food Contact Materials " is defined as the materials that track the conditions of the surrounding environment of the packaged food. It is designed to convey information about the status of the food to the consumers [2]. Basically, two types exist 1) showing the external conditions of the package and 2) directly measuring the quality of the available food [7]. Smart packaging materials are composed of labels or plugs attached or printed on to the inner or outer packaging material, therefore they provide information related to food. Not only physical features, but also the quantity, type, and amount of data they can carry differ from each other in how they capture and distribute the data. A combination of multiple smart packaging tools can be used in food packaging. In recent years, the use of intelligent packaging has gained importance in order to be able to notice the changes that may occur in food in the early period after the production of foods until reaching the consumer. The classification of major smart packaging that have different structural features are given in Table 1.

4.3. Parts that make intelligent function in packaging

4.3.1. Indicators

Indicators are placed in a two-part pouch and chosen as food-specific. The wall which separates the two parts from each other, dissolves after activation and the parts become united, followed by a color change. As shown in Figure 1, before activation, the first part of the label is white and the part where the indicator is located is green. When the product is exposed to undesirable conditions, a mixed, transition color is observed and the irreversible final color is obtained. After this color is observed, the product must not be consumed as food [8].

Table 1. Classification of smart packaging [7].



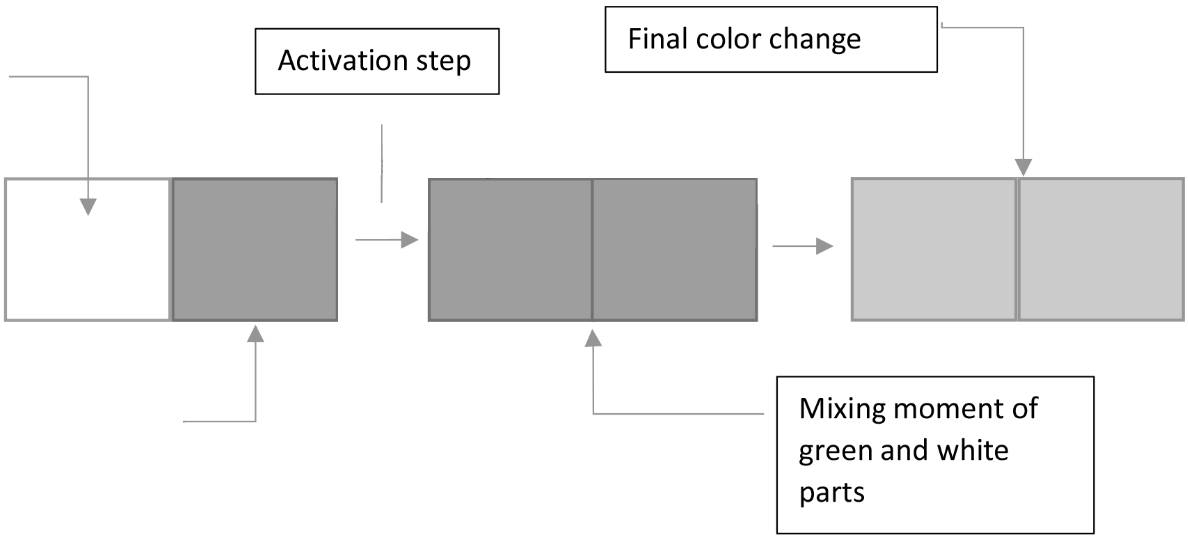


Figure 1. Color change of the indicator at the center [5].

4.3.1.1. Time Temperature Indicators (TTI)

There are available time–temperature indicators that provide time-integrated information about the entire temperature history of the product. Such indicators allow more accurate assessment of the remaining product shelf life [9,10].This indicator can be used effectively through the control of cold chain system. Especially frozen foods, fresh meats, poultry meat, frozen fruits and vegetables, fish, milk and dairy products are highly susceptible to microbial, chemical and physical deterioration resulting from increased temperature. Time-temperature indicator (TTI) systems are divided into the following groups based on working principles [8]: Critical Temperature Indicators (CTI), Critical Time-Temperature Indicators (CTTI), Diffusion Based Indicators (based on Molecular Diffusion), and Polymer Based Time-Temperature Indicators.

4.3.1.2. Freshness Indicators

Working principle of freshness indicators is based on the color change of the label on the food packaging due to the resulting metabolites after microbial degradation in foods. Examples of such metabolites are organic acids, glucose, volatile nitrogen compounds, ethanol, carbon dioxide, biogenic amines, toxins, sulfur compounds, enzymes and sulfur. Such labels are generally used in products that use MAP (Modified Atmosphere Packaging) technology. Freshness indicators are divided into four categories based operating principle [8]. These are as follows:

1) Freshness Indicators Sensitive to pH Change,

2) Freshness Indicators Sensitive to Volatile Nitrogen Compounds,

3) Freshness Indicators Sensitive to Hydrogen sulfide (H2S) and

4) Freshness Indicators Sensitive to Various Microbial Metabolites.

4.3.1.3. Leakage Indicators

Leakage indicators are grouped into two categories of 1) oxygen indicators (generally used in the food sector) and 2) carbon dioxide indicators (used in the pharmaceutical industry). Oxygen indicators ensure that oxygen absorbers operate correctly. They are usually rich in oxidative enzymes. Such indicators often provide information on the leaks of gases that are used in modified atmosphere packaging.

4.3.1.4. Pathogen Indicators

Subsequently, these indicators are used for products infected with pathogenic microorganisms such as *Salmonella* spp., *Campylobacter* spp., E.

coli O157: H7, and Listeria spp. If the product is contaminated, antibodies that are presented as immobilized in the package react with the bacteria and a warning that can be seen by the consumer on the package or the food outer surface is formed.

4.4. Nano-sensors or Nano-biosensors Used in Food Packaging

Sensors used in food packaging provide information about the freshness of products, microbiological deterioration, changes caused by oxidative sting and temperature, and they are most commonly used in biotechnological applications. Sensors basically consist of two parts, the receptor and the transducer. Receptors convert the physical and chemical information they acquire from the source to the energy appropriate for the transducer measurement. Sensors perceive electrical, optical, thermal and chemical signals. They are mainly grouped into three categories; 1) Gas sensors, 2) Fluorescence based sensors and 3) Biosensors.

The sensors of oxygen and carbon dioxide gases are among the most commonly used gas sensors to monitor the quality of the food. These sensors are required to contact with the gaseous medium in the package and thus are in direct contact with the food. In fluorescence based sensors, the oxygen polymer in the food package penetrates through diffusion and ensures the luminescence of the package. The oxygen level in the medium is determined by measuring the luminous parameters. Ruthenium, phosphorus palladium (II) and platinum (II) -phosphorine complexes are used in fluorescence based sensors. Biosensors may be defined as bioanalytical devices developed by combining biological molecules or biological systems with modern electronic technical systems that are composed of a bio-receptor and a transducer [5].

4.5. Nanomaterials Toxicology

Unlike larger particles, nanoparticles can easily migrate from skin and similar biological membranes. Thus, they penetrate into various cells, tissues and organs in the body. They can also be transported to other vital internal organs and tissues, when mixed with blood. According to the hypothesis; when a large number of nanoparticles enter the body, they overload the phagocytes and trigger stress reactions, which leads to inflammation and weakens the body's defense mechanisms. In addition, they increase the formation of free radicals due to increased chemical reactivity, which can cause damage to proteins, membranes and even DNA (which can cause mutations in cells and subsequent cancers, like other DNA damage-causing materials). Today, however, nanomaterial toxicities and effects on the organism are still undefined for many. The information is still an assumption [12]. Moreover, dosage is another concern since nanoparticles are involved in food in quite small amounts that are considered as under limit [13].

4.6. Legislation in Intelligent Packaging in Turkey and Europe

Packaging laws and regulations are generally grouped into three categories throughout the world: safety of packaging materials, labeling of packages, and environmental impacts of packaging [14]. Although in Turkey; there are still no regulations on the toxicology of nanomaterials; most of the developed countries in the world, including the European Union and the US, conduct a lot of research on nanotechnology and prepare legal regulations with the finest detail. However, because Turkey is a country in the EU accession process, the standards and directives published are to harmonize, their environmental conditions to Turkey. Preparation of the mentioned regulations is inevitable for the Ministry of Industry and Commerce and Labor and Social Security, as well. At the moment, there is a very limited compulsory labeling of products containing nanoparticles and they are quite new since they have just been prepared after the legal authorities issued a guidance and/or recommended a definition on nanoparticles [12].

5. Results and Recommendations

Freshness in foods from production to consumption and quality control of the other features may not be always assured. Intelligent packaging technology is useful for both the protection of the consumer's health and avoidance of economic losses. With intelligent packaging technology and nanotechnology, information about the freshness of the food and whether the proper temperature - time is applied in the storage can be obtained at all stages of distribution and storage.

However, with the many new advantages of this technology, the disadvantages or other health effects have not yet been fully understood. For this reason, the national and international legal regulations required for the production, control and safety of nanotechnology products must be brought to life in the shortest possible time. Thus, the concerns due to the use of these products may be resolved and maximum benefit from these products will be provided.

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