FRUITS FOR HUMAN USE IN VARIOUS ASPECTS

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CONTENTS

Preface

Fruits are among the essential elements of human nutrition. Although the first definition that comes to mind when talking about fruit is "edible products of trees", in fact, fruit is botanically described as "the organ that is formed by the development of the ovary in plants after the fertilization of the flower and carries the seeds". In other words, we call fruit the organ that flowering plants form in different ways from the ovary and that develops with or without seeds. The importance of fruits in human nutrition is mainly due to the large/primary molecules such as carbohydrates, proteins, and fats they contain, the vitamins and inorganic minerals that people must take from outside, and the polyphenols, fatty acids, and organic acids, which are called secondary metabolites that have many important functions although they are small in quantity. Since each type of fruit can be rich in only some of the mentioned components, a varied diet in fruits is very important for a balanced diet. The beginning topics covered in this book are the nutritional values of fruits and the different organs of some species. Recognition and dissemination of new fruit species greatly contribute to the provision of a broader spectrum diet. Some of the studies that have been carried out and can be performed in this context have been included in the book. Again, the effects of fruits and their cultivation on the formation and development of culture in a region were examined. The different uses of fruits and the technologies developed in these areas are presented at the reader's intention. In conclusion, this book will be a resource helping the reader to consider fruit and fruit growing from various perspectives.

Emrah GÜLER

Editor

CHAPTER 11

NEW TECHNOLOGIES USED IN FOOD LABELING

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1. Introduction

Food safety and traceability are today a constant concern for consumers and all actors in the food chain, including the fruit and vegetable sector. There is an increase in both the product variety and consumption capacity due to the innovative changes that occur during the applications in production, food processing, storage, distribution, and consumption. With this increase, consumers who consume food that reaches almost every corner of the world are concerned about the safety of the food they buy. In order to address these concerns, the labels on the foods function as the identity documents of the products (Akgüngör, 2011). Labels containing all the necessary information about the packaging, the manufacturer and the product are also used in the cash registers in the markets and in the barcode systems of the products of the manufacturers (Akgüngör, 2011).

Label is a tool that provides information about the product to be transferred to the consumer understandably and simply during the purchase of goods or services, identifying the product and containing information that can be printed in different ways (Aksulu, 1996). The labels on the foods are effective in people's choice of healthy foods. The extent of this effect is directly related to the type of nutritional label applied. The use of food labels depends in part on how comprehensible the information is. Plain logos, emblems, guiding labels, and adhesive labels are labels that make the message more understandable (Akgüngör, 2011).

Labels, which are beneficial in providing the consumer with the necessary information about the food and for the food to find a place in the sector, should be able to provide valuable and non-false information to the consumer. This includes helping protect the consumer's health, preventing misunderstandings, and taking precautions against danger and abuse. On the other hand, it regulates the competition between companies. The fact that the label manages and regulates such complex processes has necessitated new regulations by legislators. Although many benefits of labels have been mentioned so far, the most valuable contribution is undoubtedly the one related to protecting consumer health. The American Food and Drug Administration reports that 600-1200 people can be prevented from getting heart disease in a year if consumers follow the saturated fat levels on the labels and consume food (Consumer Report on Health, 2003).

Labels that carry valuable information about products have become increasingly crucial among consumers. According to Ekşi (2012), the rules such as labels, nutrition information, health information, and daily coverage rates on food packaging are to support people in choosing food according to their health status, regulate food prescriptions, and reduce chronic ailments depending on consumption. The increase in individuals' behaviors towards consuming products according to the label information on the products necessitates the labels to be more detailed. Because scientific studies have shown that with conscious consumption, there is an 80% decrease in diabetes, 80% in cardiovascular diseases, 70% in colon cancer and 7% in stroke (Bal, 2019). For this reason, new systems that can be understood more easily by the consumer in labeling are gaining importance.

The expressions of the nutritional elements on the labels are used to warn consumers against obesity, which is defined as one of the biggest health problems today. The display of diet products and high-calorie products facilitates the selection of these products. For this purpose, some countries have started to use traffic lights on labels. The Food Standards Agency, the authority on food in the UK, has started encouraging the application of traffic lights on food labels (Hawkes, 2010). These signs are in three colors as red, green and yellow and differ in color according to the total calorie of the product. This makes it easier for consumers to choose products according to their calories. Developing smart tags technology, according to its working principles; time-temperature indicators, freshness indicators, pathogen indicators, biosensors, gas concentration indicators and radio frequency identification (RFID) systems (Bal, 2019).

In this section, information is given about new technologies used in labeling, as well as how consumers can access detailed information about products by examining product label information, how to make retrospective traceability, and how to learn about the freshness and quality of products.

2. Identification and Labeling of Foods

The identification and numbering of commercial objects and the processing of these numbers into barcodes provide accuracy and practicality in logistics applications such as goods acceptance processes, inventory processes, preparation, and shipment of products in areas such as production places, warehouse and logistics center. The codes and barcodes on the commercial product provide the automation of all the process steps that occur from the production stages of that product to the end consumer, thus enabling these steps to be done in the electronic field (electronic commerce) (Cebeci, 2006).

Good traceability: It is the ability to trace and track plant and animal products, food and feed, the animal or plant from which the food is obtained, a substance intended or expected to be present in food and feed, throughout all stages of production, processing and distribution. Traceability covers all stages from primary production to final consumer sales, including production and distribution stages, and aims to protect human health at the highest level in the relevant food. The traceability system defines all products and inputs, units, or lots; It includes the stages of collecting and storing information about where, when and where they move, and the establishment of a system that will associate these two data with each other (Yaralı, 2018).

Food definitions are divided into primary and secondary definitions. The primary definition of food traceability is the identity of the food, which is determined by some anatomical, physiological, and biochemical biological processes. Secondary or tag (data carriers) based identification consists of techniques that use a series of alpha-numeric character sequences to identify the product (Yaralı, 2018). Secondary data includes data stipulated by EC 178/2002, 1830/2003,

EUREP-GAP, IFS, HACCP, ISO9000, BRC, GLP, GMP, GHP and similar standards, application guidelines and different legislation (Verdenius and Koenderink, 2003; Cebeci, 2006). Links to the primary identifier can be made from the secondary identifier, especially from domains where the primary identifier is stored as a knowledge base or database. Metadata (metadata) can be used to support the automatic identification of the source of the food being produced and to separate the types of information (Cebeci, 2006).

3. Smart Packaging Methods

Smart packaging, which has started to develop rapidly since the 2000s (Vanderroost et al., 2014), can be defined as a packaging technique that displays some characteristics of the environment or food in which the packaging is kept and informs the manufacturer, retailer, and consumer about the status of these features (Dobrucka, 2013). In another definition, it can also be defined as labels or markers printed on packaging or packaging material that provide information about the quality and safety of food and contain an internal or external indicator (Huff, 2008; Kocaman and Sarımehmetoğlu, 2010).

In recent years, the use of smart packaging has started to gain importance to be able to detect changes that may occur in food in the early period after the production of food until it reaches the consumer. One of them, CheckPoint ®, is a simple label affixed to food packages to check product freshness (Figure 1). These labels respond to time and temperature in the way the food product reacts, thus giving a signal about the freshness status and remaining shelf life. The initially green dot gradually turns yellow as the product approaches the end of its shelf life. The reaction is irreversible and proceeds faster as the temperature increases and more slowly as the temperature decreases (Kuswandi et al., 2011). The classification of the main smart packaging with different structural features is given in Table 1 (Karagöz and Demirdöven, 2017).

Barcodes, RFID tags, indicators and biosensors are used in smart packaging because of their potential to sense, monitor and signal (Üçüncü, 2011). Smart packages, which enable foods' physical, chemical, or biological deterioration to be noticed before the product is sold, are divided into three according to their working principles. These are packaging based on sensors, indicators and radio frequency recognition systems (Table 1). All of these helps reduce possible food-borne risks, protect the seller's reputation, and ensure that the end user receives healthy and quality products (Kokangül and Fenercioğlu, 2012).

Sensors, widely used in food packaging, transmit the oxygen and carbon dioxide amounts released in the product as a signal to the reader, as a result of the physical and chemical changes that occur in the food in the package, with its receiver and converter properties. In this way, they provide food safety and help the end consumer to reach quality products (Aday and Caner, 2010).

Indicators used in smart packaging are leakage, freshness, and temperature-time indicators (Karagöz and Demirdöven, 2017). Leakage indicators are systems that change color due to chemical and enzymatic reactions occurring in food, indicating the presence or absence of some food-derived gases. The most commonly used leak indicators are oxygen and carbon dioxide indicators (Yezza, 2008; Özçandır and Yetim, 2010). Another indicator used in a publication is the freshness indicators. They are used to prevent freshness-related losses that affect the quality of food, such as chemical, biochemical, physical or physicochemical, throughout the shelf life of the food. Today, as freshness indicators; There are indicators sensitive to pH, volatile nitrogen compounds, hydrogen sulfide and microbial metabolites (Üçüncü, 2011). Temperature-time indicators, on the other hand, are measurement tools that provide a visual indication of the temperature history of the food with irreversible reactions throughout the entire food distribution chain (Purma and Serdaroğlu, 2006). These indicators are used primarily for perishable foods (such as meat and meat products, fish, dairy products, and frozen foods) (Kocaman and Sarımehmetoğlu, 2010). Changes in critical temperature in such foods put the product’s safety at risk. For example, while structural changes occur with thawing in frozen foods, it is also possible for pathogenic microorganisms to form (Kuswandi et al., 2011). Producers can easily control the temperature changes of the foods in the production area with the systems and technologies they use. However, there is a food safety risk in processes such as logistics, storage and display for the food leaving the production area. Temperature-time labels used to eliminate these risks are an essential factor in ensuring the continuity of food safety, observing temperature changes during shipment and storage, and maintaining quality (Gün and Orhan, 2011). RFID technology, another indicator, is a transponder technology (Figure 2), and it is used in health, livestock, education, library, security, etc., including supply chains. It is a technology that can be applied in many areas (Maraşlı and Çıbuk, 2015; Yaralı, 2018). Unlike barcodes, RFID allows the data on a product package to be read automatically by a reader; It is based on electromagnetic wave techniques at different wavelengths such as microwave and long wave (Cebeci, 2006).

Figure 1. An example of a smart tag that provides information about food safety and freshness (Kuswandi et al., 2011).

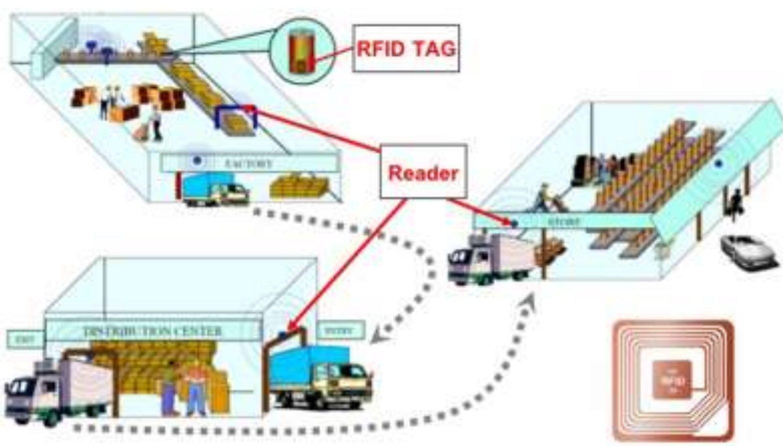

Figure 2. RFID technology (Yaralı, 2018)

Table 1. Smart packaging classification (Karagöz and Demirdöven, 2017).

Classification		Working Principles	References
Sensors	Gas Sensors	They are devices that respond by changing the physical parameters of the sensor in the presence of the gas being analyzed and are monitored by an external device. The system cannot be used for commercial products since the integrity of the packaging is compromised in the use of these sensors. It is not inconvenient to use the same packages with back-sealing for subsequent analyses.	Kerry et al., 2006
	Fluorescence-Based Gas Sensors	Fluorescent or phosphorescent dyes are placed inside polymer molds. The gas in the food package penetrates the polymer in question by diffusion, reaches the fluorescent dye and makes the package glow. The amount of gas in the environment is quantified by measuring the luminescence parameters.	Shimoni, 2001; Gök, 2007
	Biosensors	They are devices that detect, record, and transmit biological reactions occurring in packaged foods. Biosensors consist of a bioreceptor (enzyme, antigen, etc.) and an energy converter (transducer). The "Food Sentinel SystemTM" (FSS) is a biosensor system capable of continuously detecting pathogens in food packaging.	Kerry et al., 2006
	Nanosensors	It consists of a series of nanosensors sensitive to the gases produced by food spoilage and indicates whether the food is fresh or not according to a color scale.	Kocaman and Sarımehmetoğlu, 2010

Indicators	Leak Indicators	Leakage indicators change color as a result of chemical and enzymatic reactions. Ageless-Eye® branded oxygen gas indicators can be given as an example for this. When the oxygen gas level in the package in which this indicator is placed falls below 0.1%, the color of the indicator label turns pink, and when it exceeds 0.5%, it turns blue.	Purma and Serdaroğlu, 2006; Yezza, 2008; Özçandır and Yetim, 2010
	Freshness Indicators	It is based on the principle of observing the color change in response to pH, volatile nitrogen compounds, hydrogen sulfide and various microbial metabolites, which are formed due to freshness due to the reactions of foods throughout their shelf life.	Üçüncü, 2011
	Temperature-Time Indicators	It is based on mechanical, chemical, electrochemical, enzymatic, and irreversible color changes. These change rates depend on temperature; As the temperature increases, the color change rate also increases.	Gök, 2007; Üçüncü, 2011
RFID Tags		It is a system that identifies with radio waves and allows remote product monitoring. The tag in the RFID system responds to the signals it receives from a reader antenna and transmits the numbers back to the reader. RFID tags can hold simple information (such as barcode numbers) or more complex information such as temperature and relative humidity data, nutritional information, and cooking instructions.	El Matbouly et al., 2022

3.1. Sensors

Sensors are units that can detect and transmit changes in the product, the environment within the product or the package itself. It consists of sensor, receptor and transducer units (Biji et al., 2015).

3.1.1. Gas sensors/Indicators (Leak Indicators)

Different gas-sensing smart label solutions track the spoilage gases created by some foods when they deteriorate or follow the packaging gases. Modified Atmosphere Packaging (MAP) system, one of the common standard used in packaging foods, as the name suggests, is a method of packaging foods by changing the atmosphere we normally breathe. Gas sensors are systems that show the presence or absence of some gases used in modified atmosphere packaging and provide information about packaging integrity and leaks (Özçandır and Yetim, 2010). As a result of leakage, the atmosphere inside the protective package is destroyed, and microorganism is transmitted from outside to inside. Therefore, it shows the shortening of the shelf life and deterioration in quality by changing color depending on the amount of oxygen and microorganisms that enter due to the opening or destruction of the packaging. The leakage indicators used are of two types. These; They are oxygen and carbon dioxide indicators and are based on the principle of irreversible color change as a result of chemical or enzymatic reaction (Çelik and Tümer, 2016). Gas sensors/indicators (Figure 3) are equipment that tries to ensure the continuity of quality and safety by showing the gas feature of the packaging vehicle and/or the environment. Gas composition in the package; often changes as a result of food activity or packaging leaks, depending on the package's nature and the package's environmental conditions (Yam et al., 2005). In general, oxygen and carbon dioxide indicators are preferred to monitor food quality. However, they can be used as leak indicators, to test package integrity, or to confirm the effectiveness of scavengers such as oxygen scavengers used in active packaging systems. These indicators must be in contact with the gaseous environment in the package and thus are in direct contact with the food (De Jong et al., 2005).

Gas sensors are used in the package to detect gases such as O_2, CO_2, water vapor, ethanol, ethylene, and metal oxide. For their detection, optochemical sensors consisting of fluorescent-based, pH-sensitive, or absorption-based colorimetric indicators are used (Ahmed et al., 2018). There is no literature on the application of these sensors in fresh fruits and vegetables. CO_2 and O_2 sensors are the most used systems commercially (Çelik and Tümer, 2016).

In smart packaging, CO_2 is considered as an indicator of spoilage caused by fermentation or microorganism. Many systems have been developed to detect the amount of CO_2. Some of those; include (I) non-dispersive infrared (NDIF) sensor, (2) Severinghous electrochemical type, (3) wet optical CO_2 sensor (pH-based), (4) fluorescent CO_2 sensor, (5) dry optical CO_2 sensor, (6) thin suspension gel (sol-gel) based optical CO_2 indicator, (7) photonic crystal sensor, (8) anhydrase catalysis CO_2 sensor and (9) IrOx pH electrode-based sensors. Especially optical CO_2 sensor technologies are one step ahead of others.

This is because of its higher chemical and mechanical stability (Ergun, 2016). The CO_2 sensor usage area is generally designed for meat and meat products and is not yet used for fresh fruits and vegetables (Meng et al., 2014). Moreover, at the end of the harvest, fresh fruits and vegetables produce little or much CO_2 due to respiration, depending on the species, and it is not possible with current technology to distinguish it from microorganism origin (Ergun, 2016).

It is stated that gas indicators are used for water vapor, ethanol, hydrogen sulfide and other gases. There are also many different forms of O_2 indicators (Yam et al., 2005). Typical oxygen indicators; consists of redox dye (methylene blue), reducing substances (reducing sugar), and alkaline compounds (sodium hydroxide) (Purma and Serdaroğlu, 2006). Indicators; It can be in the form of tablets, labels, or prints, or it can be formulated by coating a polymer film. They are widely used and commercialized oxygen gas indicators for this purpose. When the oxygen gas level in the package in which this indicator is placed falls below 0.1%, the color of the indicator label turns pink, and when it rises above 0.5%, it turns blue (Kokangül and Fenercioğlu, 2012).

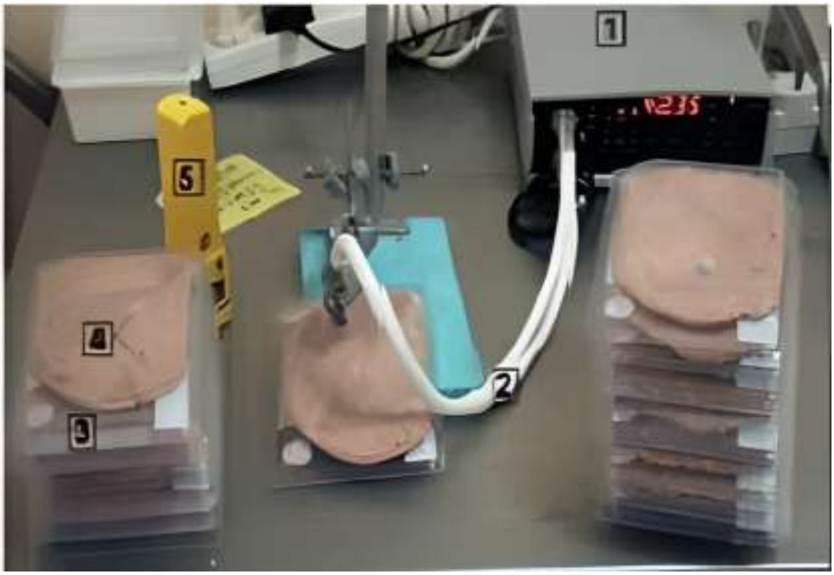

Figure 3. Gas sensor (Updated from Hepsag and Varol, 2018)

3.1.2. Fluorescent-Based gas sensors

Fluorescent-based gas sensors provide remote measurement of gases formed in the space at the top of the package. In fluorescent-based gas sensors, phosphorescent and fluorescent dyes are placed in polymer containers. When gas production begins to occur due to deterioration in the product, the packaging glows and gives information (Gök, 2007). The working principle is as follows; fluorescent or phosphorescent dyes are placed in polymer molds. The paint-polymer coating is applied as a thin film coating on a suitable solid support. The gas in the package penetrates the polymer with diffusion, reaches the fluorescent dye and makes the package glow. This process is reversible and has no by-products. Most oxygen sensors can operate over a wide temperature range. Figure 4 shows some optical oxygen sensors (Kokangül and Fenercioğlu, 2012).

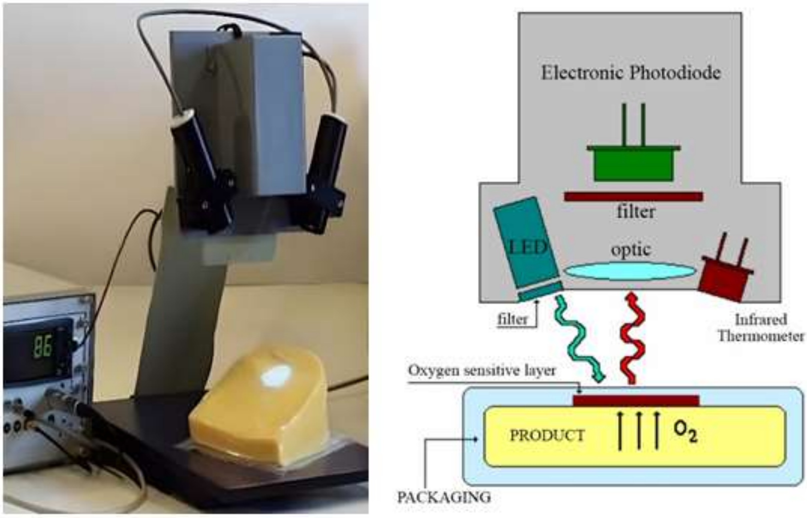

Figure 4. Fluorescent-based gas sensors (Kokangül and Fenercioğlu, 2012; Gök, 2007).

3.1.3. Biosensors

Biosensors are systems that have the capacity to detect, record and transmit information about biological reactions and are used to determine the quality of products (Yam et al., 2005). Many different types of biosensors are used to detect the reactive changes that occur as a result of spoilage in foods. The type of biosensor to be used is determined by the type of compound released into the environment when the deterioration of the food in it begins. Biosensors detect changes in cells and molecules used to measure and identify the substance to be tested. They are effective even at deficient concentrations of the material to be tested. Like other sensors, it consists of a receptor (bioreceptor) and transducer (Alocilja and Radke, 2003). It can be composed of organic or biological materials such as bioreceptors, enzymes, hormones, nucleic acids, antigens, and microbes. The transducer can be visual, auditory or electrochemical. For example, the “Food Sectional System” biosensor integrated into the barcode warns the target audience by making the barcode illegible in case of pathogen development in the product (Yam et al., 2005). The recognition system called Toxin Guard, developed by Toxin Alert (Canada), contains antibodies in polyethylene-based plastic package films and can detect microorganisms such as *Salmonella* sp, *Campylobacter* sp., *Escherichia coli* 0157 and Listeria sp. Packaging material visually signals when antibodies encounter a target pathogen (Fig. 5) (Kerry et al., 2006). When sensors are integrated into food packaging, they can detect chemicals, pathogens and toxins in food. Many biosensors, including integrated optics, immunoassays and surface chemistry, have been developed to detect deadly Salmonella bacteria in meat. For example, biosensors detect *Staphylococcus* enterotoxin B, *E. coli*, *Salmonella* spp. (Tiju and Morrison, 2006) and Listeria moncytogenes have been developed (Liu et al., 2007). When the material binds to the biological component, the transducer generates a signal proportional to the amount of material. In other words, if the concentration of bacteria in food is high, the biosensor generates a strong signal that the food is not safe (Demirbilek, 2015). Sensors can also detect protein allergens in foods, such as peanuts, and tree nuts, and prevent adverse reactions to gluten (Doyle, 2006). However, due to the many studies carried out in the field of sensors related to foodstuffs, progress in this field has gained significant momentum in recent years.

Figure 5. An example of a biosensor from the food sentinel system (SIRA Technologies, California, USA) resulting in an unreadable barcode in the event of a food safety risk (Yezza, 2008).

In smart packaging, biosensor technology is generally used as a toxin indicator. These indicators only work specific to the toxin of a microorganism. The application of toxin indicators is that harmful microorganisms are often found in foods or on the surface, even in low concentrations. For this reason, the sensor to be applied must be susceptible and entirely in contact with food (De Jong et al., 2005). To identify microorganisms that are harmful to health, SIRA Technology (USA) has developed a biosensor/barcode combination based on the principle of immunochemical reaction, also called the Food Watch System, in food packaging. The way the system works is quite simple. In this system, the antibodies of disease-causing microorganisms are added to the membrane part of the barcode. In case of contamination of microorganisms, it causes a localized dark bar to appear on the barcode, and the barcode cannot be read (Yam et al., 2005).

3.1.4. Nanosensors

Today, nanotechnology developments are trendy and are used in many fields such as scientific research, materials and manufacturing, electrical electronics and computer technology, space studies and aviation, medicine and health, and environment and energy. One of these areas is nanosensors used in packaging systems to detect whether foods are spoiled (Öksüztepe and Beyazgül, 2015). Nanosensors can quickly detect microorganisms that produce toxins or cause food poisoning with the color, mass and temperature changes they cause and molecular recognition systems. For example, when the oxygen concentration in the package increases as a result of microbial growth in packages with MAP applied, nano-TiO_2 and nano-SnO_2 oxygen sensors, these nanoparticles sensitize the redox dyes in the polymer environment to light and bleaching is observed in the sensor color in the package (De Azeredo, 2009; Mills and Hazafy, 2009; Yılmazer and Altay, 2014).

For this purpose, semiconductor systems containing nano-sized metal oxides are mostly preferred (Figure 6). While conductivity is low in the air, an increase in conductivity is observed with gases such as carbon dioxide. The sensor's electrical resistance is measured (Sozer and Kokini, 2009). The main problem in the food industry is the inability to identify and develop an effective packaging material. With smart packaging materials designed with nanotechnological methods, the continuity of the freshness and quality of the food can be ensured (Çelik and Tümer, 2016). Nanocomposite materials formed by integrating some nano metals or metal oxides into polymers show antimicrobial properties. The antimicrobial properties of nanoparticles are utilized. These materials slow down the growth of microorganisms in foods and ensure a long shelf life (Sürengil and Kılınç, 2011). Apart from these, the inclusion of foods produced with nanoparticles in the food chain and such uses of nanotechnology may cause food toxicity and the accumulation of this toxicity in the human body. What is important here is whether the foods produced with nanotechnology will be classified as new or unnatural materials. Due to their characteristic properties, nanoparticles can pass through the cell or enter the bloodstream directly through the lungs and reach all organs. Therefore, they can be much more dangerous than materials larger than themselves. In addition to the application of nanotechnological developments in food science, regulations regarding risky nanomaterials and toxicity should be carefully considered (Kokangül and Fenercioğlu, 2012; Demirbilek, 2015).

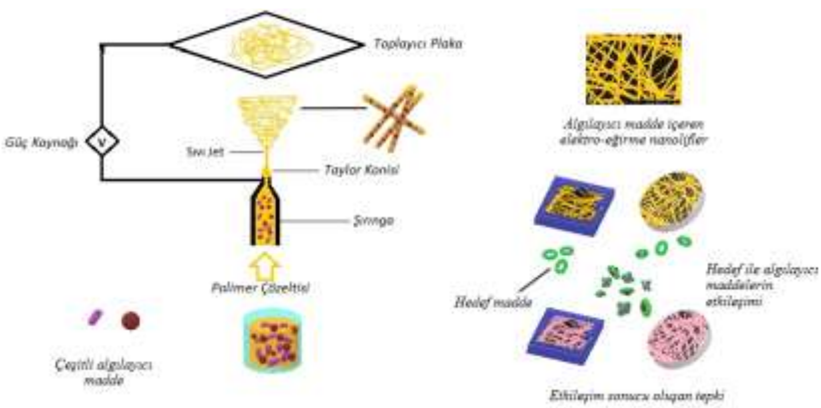

Figure 6. Schematic diagram of a simple nanosensor detection mechanism (Yılmaz and Altan, 2017).

3.1.5. Time-Temperature indicators

"Smart Labels," designed according to the shelf life and storage conditions of each product, work with a color-coded system for all temperature-sensitive foods. "Temperature-Time Labels," which are used to prevent the consumption of foods that are presented or stored under adverse conditions, convey information to the producer and the consumer with color change (Bal, 2019).

Time-temperature indicators (Time-Temperature Indicators/TTI); These are the labels prepared to ensure the continuity of food safety and quality and to monitor the temperature changes of the product throughout the entire supply chain (Shimoni et al., 2001; Gök et al., 2006).

The basis of this indicator; is the change of color depending on the pH decrease caused by the breakdown of fat components in foods as a result of enzymatic reactions. In systems where these indicators are used, the control of the entire distribution chain is carried out effectively. It is mainly used for perishable foods such as dairy products, meat, fish, poultry, frozen fruits and vegetables, and frozen meats (Riva et al., 2001; Giannakourou and Taoukis, 2002, Vainionpää et al., 2004).

It is reported that Time-Temperature Indicators can also be used as a "freshness indicator" when an appropriate selection is made for the type of food (Riva et al., 2001, Yam et al., 2005). It provides conveniences such as following the history of the temperature and confirming the accuracy of the shelf life (Bobelyn et al., 2006). Advantages over different tracking systems; It is reported as a low-cost and active specific placement possibility in packages. Another benefit is the new methods such as "giving the product on time or with the earliest shelf life" instead of the usual "first in, first out, last in, last out" in inventory tracking and management (Riva et al., 2001). Bobelyn et al. (2006) reported that the working life of time-temperature indicators should be the same as the shelf life of the food in their study conducted to detect the quality loss of mushrooms through this indicator. In this case, the application of product combinations with the relevant time-temperature indicators could be successful.

These indicators are sensitive to environmental factors; they indicate the chemical, enzymatic, microbial and mechanical changes that occur in the product due to external factors such as heat and humidity to which the product is exposed (Figure 9). Therefore, it has widespread use. It can be placed on the products one by one, or it can be placed in parcels or containers depending on the vehicle. According to the working principles of time-temperature indicators, there are three types “Polymer-based”, “Diffusion based,” and “Enzymatic based” (Riva et al., 2001; Taoukis and Labuza, 2003; Kokangül and Fenercioğlu, 2012).

The polymer-based time-temperature indicator provides information about the freshness of the product. In this indicator, there is a reference ring to enable the consumer to understand the freshness of the product easily. Riva et al., (2001) preferred "Fresh Check" labels, which are based on the polymerization reaction of diacetylenic monomers and cause color change in the center of the label. The sensitive areas of these labels, which can take the form of sticky labels and become part of the package, change color. The outer part is a non-polymer structure with a reference color ring. The colors of the inner ring and the outer ring are compared (Figure 7). By comparing the color inside this ring with the color of the ring, the consumer understands that the product is fresh and should be consumed as soon as possible or should not be consumed (Taoukis and Labuza, 2003). Since these indicators are activated by temperature, they are stored in deep-freezing cabinets before use. Since the indicator has a deterioration time of 9.36 days at 5ºC, it is recommended to be used in fresh foods such as ready-to-eat products that must be kept at refrigerator temperature for 7 days (Bal, 2019).

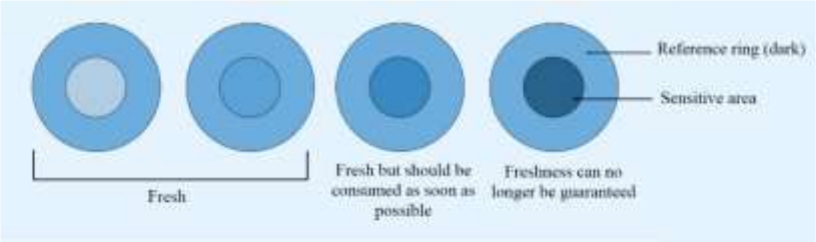

Figure 7. Example of polymer-based time-temperature indicator (Update from Öcal and Çakmak Karapınar, 2016; Riva et al., 2001).

Diffusion-based time-temperature indicators are used extensively in the monitoring of products that need to be stored at 10°C and below. This indicator, like the polymer-based indicator, informs the consumer with color change. Ester dye is used as an indicator, and it shows the temperature changes that the product is exposed to by adjusting the type and concentration of the ester dye (Robertson, 2006) (Figure 8).

Figure 8. Diffusion based time-temperature indicators (Öksüztepe and Beyazgül, 2015).

Time-temperature indicators show temperature changes during logistics and storage. Temperature indicators are usually labeled on the packaging and indicate the temperature exposed during shipment and transportation processes due to mechanical, chemical, electrochemical, enzymatic or microbial changes with the color changes on the indicator (Bal, 2019). It is an indicator of deviations from the reference temperature and temperature changes throughout the whole process (Taoukis and Labuza, 1989).

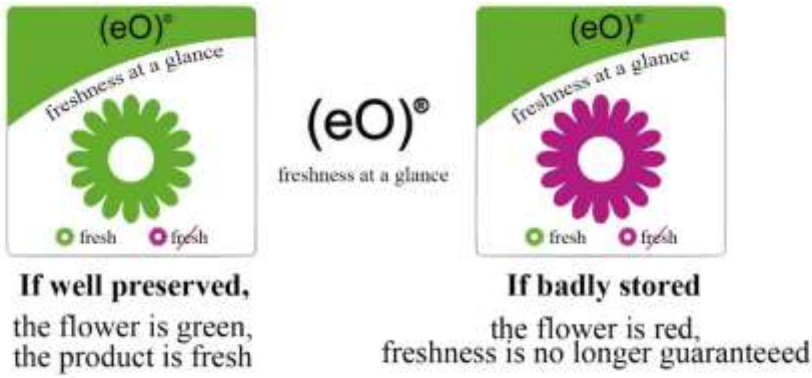

Figure 9. Time-temperature indicator based on microbial growth (Kokangül and Fenercioğlu, 2012).

The commercially available 3M Monitor Mark indicator is preferred for foods stored below 0°C (Figure 10). This label reports temperature deviations by changing color in temperature changes. If the color of the shape in the circle is lighter than the color inside the circle, it has been maintained at the appropriate temperature-time (Taoukis and Labuza, 2003).

Figure 10. Example of 3M monitor mark indicator (Yezza, 2008).

Vaikousi et al. (2008) developed a microbial-based time-temperature indicator. This type, unlike other time-temperature indicators, shows the deterioration directly. The principle of changing the color of the chemical chromatic indicator depending on the decrease in pH as a result of the growth and metabolism of *Lactobacillus sakei* on the selected substrate is discussed.

It is stated that there are more than 200 patented time-temperature indicators with different mechanization (polymerization, diffusion and enzymatic reactions) commercially in many countries (Kerry et al., 2006). Enzymatic-based time-temperature indicators work based on the logic of the pH indicator changing color with the destruction of the barrier between it and the other sac as a result of the enzyme in one sac being activated with an increase in temperature (Taoukis and Labuza, 2003) (Figure 11). These indicators are preferred in the packaging of foods such as UHT milk, pasteurized milk, cold fruit juices, frozen hamburgers, frozen raspberries, and frozen fish products (Singh and Wells, 1987).

Figure 11. Enzymatic based time-temperature indicators (Öcal and Çakmak Karapınar, 2016).

3.1.6. Leakage and freshness indicators

Freshness indicators work with the principle of changing the color of the indicator with the effect of metabolites produced by microorganisms in contaminated food. It can be used both as a package label and on the packaging film. It allows us to easily observe the gas changes occurring in the packaging (Gök et al., 2006). These metabolites are glucose, ethanol, volatile nitrogen compounds, organic acids, biogenic amines, sulfur compounds and carbon dioxide (Lechuga, 2006, Zeuthen and Bogh-Sorensen, 2003; Gök et al., 2006). While freshness indicators are product specific, they are susceptible. A robust relationship is required between target metabolite, product type, organoleptic quality and trust. For this reason, it is positioned in the package. However, it is necessary to test their usability for each product (De Jong et al., 2005). Randell et al. (1995) determined that the ethanol level increased depending on the storage time in marinated chickens packaged in a modified atmosphere, while Okuma et al. (2000) determined that the diamine concentration increased with the increase in the total bacterial count in chicken meat. An example of a freshness indicator is given in Figure 12. These indicators give an idea about the freshness of the products by using the effects such as pH changes, formation of toxic compounds, formation of foul odor, formation of gas and lubricity as a result of microbial development, together with the color change of the markers (Figure 13). Metabolite residues such as glucose, biogenic amines, organic acids, volatile nitrogen compounds, CO_2, ATP degradation products, sulfur compounds, and ethanol are considered degradation factors (Dainty, 1996; Kruijf et al., 2002). Organic acids such as lactic acid and acetic acid are the most essential compounds produced by lactic acid bacteria fermenting glucose.

Figure 12. The Fresh-Check® TTI label (Fresh-check is a registered brand of the TEMPTIME Corporation, Morris Plains, NJ, USA) of which the color of the inner circle changes (depending on time and temperature) and needs to be compared to the outer circle to establish use-by status.

Figure 13. A sensor that monitors carbon dioxide as an indication for the freshness of the desert golden drop (Nopwinyuwong et al., 2010).

The expiry dates on the food packages are determined by assuming that the food is stored under normal conditions. However, there are many times and places that cannot be kept under control, from the production to the consumption of the product. Production and distribution processes are held under the control of companies. However, when the product from the companies reaches the retailers, the product's shelf life may vary depending on the way it is kept in the warehouse or on the shelf, the way of sale, and the way the consumers store the product. These indicators (Table 2), which have a wide application area, are sensitive to environmental factors and inform consumers of color changes that occur on the label as a result of mechanical, chemical, enzymatic or microbial deterioration due to incorrect temperatures.

Table 2. Various freshness indicators and their mechanism of action (Gök, 2007)

Metabolic Product Method	**Indicator**
CO_2	Color change in bromothymol compound
CO_2, SO_2, NH_4	Color change in packaging material of indicators such as xylene blue, bromcresol blue, cresol, and phenolphthalein.
CO_2, NH_4, amines, H_2S	Color changes in CO_2, NH_4 amine sensitive dyes and due to H_2S.
Acetic acid, lactic acid, acetaldehyde, ammonia	Color changes in pH dyes and labels
E. coli O157 enterotoxin changes	Color in polydiacetylene-based polymers
Diacetyl	Optical changes in aromatic orthodiamines
Microbial enzymes	Color changes on chromogenic substrates of microbial enzymes

Shu et al. (1993) reported that L-lactic acid concentration decreased, but D-lactate increased during storage in meat and fish and showed that D-lactate could be used instead as freshness indicator. Kaniou et al. (2001), on the other hand, found that there was an increase in acetate density in fish during the preservation of fresh fish.

Along with lactic acid and acetic acid, ethanol is the compound that emerges after the fermentation of lactic acid bacteria. Rehbein (1993) pointed out that the increasing ethanol concentration during storage in fish and meat parallels the increase in microorganisms. Ethanol and volatile nitrogenous compounds (TVB-N) such as ammonia, dimethylamine and trimethylamine are the most important compounds that cause deterioration in fish. First of all, trimethylamine compounds are known as quality marks in fish. Along with the compounds above, biogenic amines, ATP degradation products, CO_2, and sulfurous compounds are reference compounds for freshness indicators, such as in Figure 14 and Figure 15 (Rodríguez et al., 1999).

Leakage indicators are systems that show the presence or absence of some gases used in modified atmosphere packaging and provide information about packaging integrity and leaks. As a result of the leakage, the protective atmosphere is destroyed, and the microorganism is transmitted from the outside to the inside. For these reasons, microbial growth accelerates, and the product deteriorates in a shorter time. Leakage indicators change color as a result of chemical and enzymatic reactions. Two leak indicators are used, namely oxygen and carbon dioxide (Özçandır and Yetim, 2010). Indicators; It can be in the form of tablets, labels, or prints or formulated by coating a polymer film. A widely used and commercialized example for this purpose is AgelessEye® branded oxygen gas indicators. When the oxygen gas level in the package in which this indicator is placed falls below 0.1%, the color of the indicator label turns pink, and when it exceeds 0.5%, it turns blue (Purma and Serdaroğlu, 2006).

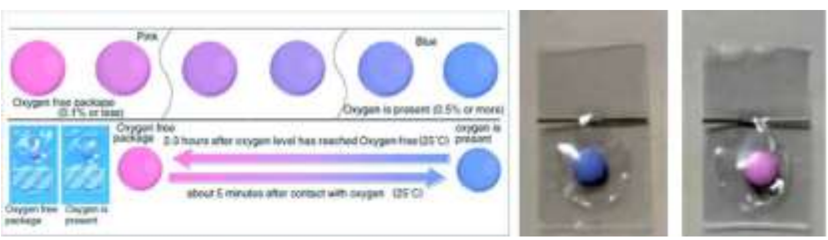

Figure 14. The color of the ageless eye oxygen indicator changes from pink to blue in the presence of oxygen (Wang and Wolfbeis, 2014).

Figure 15. Disposable freshness indicator, a commercial product of the TIMESTRIP® Brand (Gök, 2007)

3.2. RFID tags

RFID (Radio Frequency Identification Systems) is a system that uses radio frequency waves to identify and track objects (Turhan, 2009). There are three important components of the RFID system. These are a chip with an antenna, a reader with an antenna, and computer software that receives and analyzes data transmitted by radio waves (Özçandır and Yetim, 2010). RFID, which is used to track the product during the transportation and storage process, can keep simple information such as the barcode number of the product, as well as more complex data such as temperature changes, nutritional values or usage information (Figure 16). When choosing RFID technology to be used in products, the 13.56 MHz band is preferred because it adapts to flexible tags and is not easily affected by ambient humidity (Kokangül and Fenercioğlu, 2012).

Depending on the power source, they are divided into active and passive tags (Tajima, 2007). Passive tags; do not have a battery; the reader activates them. Active tags, on the other hand, have their battery, generate their energy and send signals to the reader (Vanderroost et al., 2014). In addition, semi-passive tags use waves from both the battery and the reader (Angeles, 2005).

With the establishment of the RFID system in the markets, information such as how many pieces of a product are left on the shelf, how much stock is in the warehouse, which products are about to complete their shelf life, and whether they are kept at the right temperature can be accessed automatically. Unlike barcode reading systems, it is unnecessary to read all the products in the shopping cart one by one, and the system automatically calculates when the products approach the cashier. This provides gain from both time and workforce (Kavas, 2007). RFID technology can be used for all commercial goods, including fresh fruit and vegetables (Ruiz-Garcia and Lunadei, 2011). With RFID, values such as temperature, relative humidity, light intensity, pressure and pH can be recorded perfectly.

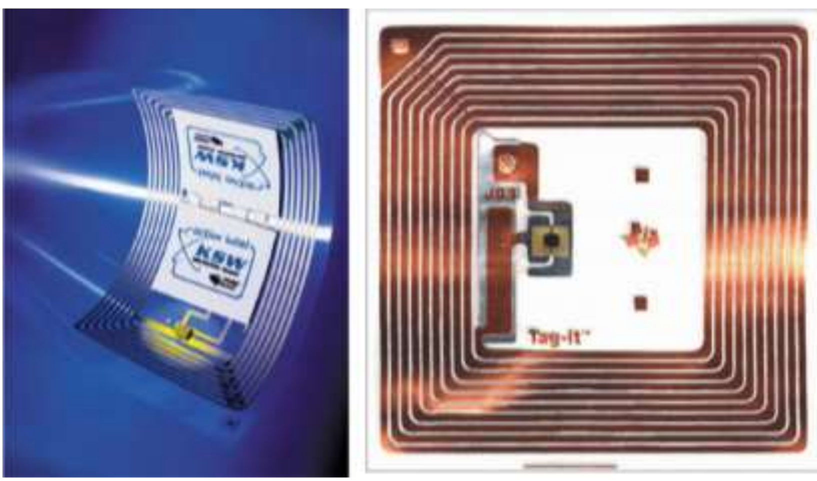

Figure 16. RFID tags (Yezza, 2008).

4. Conclusion

It is not always possible to control foods' freshness and other quality characteristics at all stages, from production to consumption. Therefore, in the smart packaging technology, indicators developed based on detecting various metabolite residues formed during storage are integrated both into the package and into the packaging material. At all stages of distribution and storage, information can be obtained about the freshness of foods and whether appropriate temperature time is applied in storage. By using smart packaging technology, both the health of the consumer is protected, and economic losses can be prevented. At the same time, since the changes in the products are noticed beforehand, there is no loss of prestige and trust in the eyes of the consumer. The risk of insufficient agricultural products produced in the face of the increasing world population in the future makes it even more severe that the products are spoiled and thrown away. Another advantage of smart packaging is that waste will be reduced as people will be warned thanks to smart packaging techniques. On the other hand, the disadvantages of smart packaging are that they are specific to certain foods or metabolites and their costs are high. With the new technologies developed, it aims to ensure food safety by adding smartness to labels and packaging, making traceability efficient and continuously improving food quality.

Although smart packaging systems have become available for processed food products, they have only recently been used for fresh fruits and vegetables. The purpose of using advanced packaging technology in fresh fruits and vegetables is to protect the quality, safety and product integrity by using natural active ingredients when necessary. The primary purpose is to extend the shelf life. There is a need to investigate whether packaging systems developed for other food products are also suitable for fresh fruits and vegetables. Development and improvement studies for suitable ones are needed. Traditional packaging methods are insufficient, especially in packaging freshly chopped or freshly prepared (fresh-cut) fruits and vegetables. In this context, with innovative systems such as active/intelligent packaging and nanotechnology, the functions of food packaging, which is an important factor in preserving food, have been increased, and the consumer has been allowed to have information about the condition of the food in the package. In addition, with some features added to the packaging, the shelf life of the food has been extended, and the food has been kept fresh for a longer time. Considering all these factors, the importance of packaging is understood, and it is expected that the properties of food packaging will be increased in parallel with the developing technology daily.

5. References

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