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NEW APPROACHES IN SMART PACKAGING TECHNOLOGIES

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Abstract: *Customer expectations have changed due to the developing technology and changing and improving product variety. This has led the printing industry, the packaging sector in particular, to grow considerably. The food industry along with the increasing need to preserve food long periods of time have led to the need to develop methods that preserve the freshness and safety of food products during their shelf-life. For this reason, attention was paid to packaging systems to facilitate food processing, preserve food quality, extend shelf-life, and prevent the food from spoiling. Thanks to these systems, packaging went beyond being a simple barrier outside the food, and has also taken upon roles of releasing protective agents or removing unwanted matter. Microbial growth is one of the most important factors that cause food to spoil. Although the problem has previously been tried to be solved by heating, drying, fermentation, freezing and adding antimicrobial agents, there are limitations, especially when used with fresh food. Today, a new generation of technologies have been introduced to monitor the condition of products with a tiny sensor or label placed onto the packaging. Smart packaging is a packaging material that not only improves the basic functions of a product, but also responds to stimuli around this product. Smart packaging in general, has two main categories, namely intelligent packaging and active packaging. This study will examine the concept of smart packaging that has emerged due to increased competitiveness, digital interaction and consumer awareness, changes in consumer behaviour and expectations, and improved interest in product safety. As a result, it is obvious that state-of-the-art smart packaging, which can connect to the Internet and has many channels of interaction, will bring about new business models and create new customer experiences and will replace conventional packaging, which has no interactions, in the near future.*

Keywords: Packaging, smart packaging, active packaging, intelligent packaging

1. INTRODUCTION

The historical development of packaging began with the most basic need for preservation and today (Lydekaityte and Tambo, 2020), it has become an integral part of the business models of product-based companies (Chan et al, 2006). The main functions of packaging are to contain food, protect it from the adverse external affects and damage from shipping, facilitate storing and communicate with customers by offering information about its content (Robertson, 2016). Today, aside from being wrapped around a product, packaging plays a major role in attracting the interest of customers by differentiating a product from its alternatives and increasing its visibility by means of shape and design (Wells et al, 2007). Packaging makes it easier for consumers to prepare and store food at home.

The main function of food packaging is to ensure the quality and safety of food during storage and transportation and to extend shelf-life by preventing chemical contamination, contact with oxygen, humidity, light and physical force and spoilage caused by microorganisms (Caon et al, 2017). Convenience food is reliable only if it does not pose a danger or risk to consumer health throughout the process of "from field to fork". Food security is safeguarded by national and international regulations and standards. To ensure food security, related policies must prevent unfair competition by means of an effective control network encompassing the entire food chain and protect the health and interests of consumers (Aytekin et al, 2015).

Despite the enormous contribution conventional food packaging techniques have made to the development of food delivery systems until recently, it is no longer possible for these techniques to meet the growing demands of consumers. Conventional packaging systems have some limitations, especially in terms of extending shelf-life and ensuring food safety. Increasing industrial use and technology development have led to an increase in consumer demands and changed the trends of the food industry in the same direction (Priyanka and Parag, 2013). While manufacturers' aim is to make sure that the packaging material keep the food fresh for as long as possible, customers want to see the freshness of the food for themselves without opening the packaging (Sürengil and Kılınç, 2011). In parallel with the increasing product variety, consumers are more meticulous about what they want. They pay attention to whether the production process is sanitary and hygienic. Active and intelligent packaging systems have been developed to meet growing consumer demands and industrial production trends (Lagaron et al, 2004). In recent years, rapid industrialization, population growth and changing lifestyles have led to increased demand for processed and packaged food (Pal et al, 2019). This, in turn, has led the packaging sector to develop along with the food sector.

The developing food industry and growing demand for long-term storage and preservation of food are have generated the need to develop methods that can easily monitor and preserve the freshness and safety of the food throughout its shelf-life (production, storage, transportation and consumption). Smart sensors and labels that can be added onto the packaging represent the next generation of technology that will help monitor the condition of products (Mustafa and Andreescu, 2018). Smart packaging in general, has two main categories, namely intelligent packaging and active packaging (Loucanova et al, 2017; Schaefer and Cheung, 2018).

As mentioned above, this study will examine a new generation of packaging that has emerged due to increased competitiveness, digital interaction and consumer awareness, changes in consumer behaviour and expectations, and improved interest in product safety. It will also explore the need to develop more innovative and smart approaches to packaging and its environmental impact. The study will investigate the functions of "containment-preservation-communication-facilitation" of new-generation packaging systems that go beyond the basic functions of protection and transportation. As a result, it is obvious that state-of-the-art smart packaging, which can connect to the Internet and has many channels of interaction, will bring about new business models and create new customer experiences and will replace passive packaging, which has no interactions, in the near future (Kontominas, 2015).

2. SMART PACKAGING CONCEPT

There are many definitions of smart packaging in literature. It can be defined as a packaging that is produced by adding new functions to passive packaging (Brockgreitens and Abbas, 2016) and a material that does not only improve basic functions but can also respond to external stimuli (Priyanka and Parag, 2013). Smart packaging is described as an active or intelligent technique that involves interactions between package and food (package content) or internal gas atmosphere and fulfils with consumer expectations for high quality, fresh, and safe products (Labuza and Breene, 1989). Active packaging prevents the growth of pathogens and destructive microorganisms, prevents the transport of pollutants, and extends the shelf-life while preserving the safety and quality of the product (Ozdemir and Floros, 2004). In other words, the produced packaging has interactive properties. Smart packaging has the ability to communicate with its environment in the supply chain or with the consumer. This is achieved through at least one of the electronic, mechanical, chemical, electrical or online technologies. These systems are focused on improving packaging functions to meet growing consumer demands, increasing regulatory requirements, and growing interest in safety. Smart packaging can have a variety of features or uses but overall, it has two categories, namely active packaging and intelligent packaging (Figure 1).

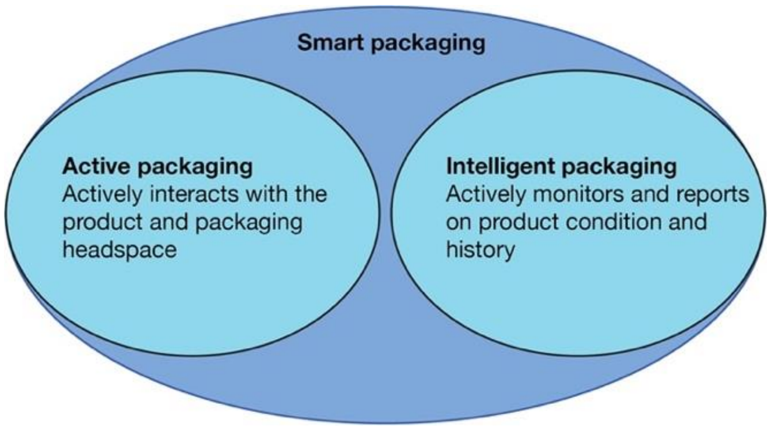

Figure 1: Smart packaging types (Young et al, 2020)

3. ACTIVE PACKAGING

Active packaging involves packaging systems that relate with food in a way that they deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food (European Commission, 2009). Active packaging offers innovative approaches to maintain or extend the shelf-life of a product, as well as to preserve the quality, safety and integrity of food products. Active packaging systems can be divided into active scavenging systems (absorbers) and active-releasing systems (emitters). Whereas the former remove undesired compounds from the food or its environment, for example, moisture, carbon dioxide, oxygen, ethylene, or odor, the latter add compounds to the packaged food or into the headspace, such as antioxidants, antimicrobial compounds, flavours, carbon dioxide, ethylene, or ethanol. Table 1 provides an overview of active packaging systems for food application and Figure 2 shows active agents for active packaging.

Table 1: Active packaging types for food applications (Yildirim et al, 2018)

Active packaging type	Food type	Expectation
Active scavenging systems (absorber)		
Oxygen scavenger	Cooked meat products	Prevention of discoloration
	Grated cheese, bakery products	Prevention of mold growth
	Fruit and vegetable juices	Retention of vitamin C content, prevention of browning
	Seeds, nuts and oils; fat-containing instant powders, fried snacks; dried meat products	Prevention of rancidity
Moisture scavenger	Mushrooms, tomatoes, strawberries, maize, grains, seeds, fresh fish and meat	Extension of shelf life through maintaining moisture content, decrease in moisture condensation in the packaging, positive impact on the appearance, reduction in browning or discoloratiion
Ethylene absorber	Climacteric fruits and vegetables	Reduction in ripening and senescence, theraby enhancing quality and prolonging shelf-life
Active releasing systems (emitter)		
Antioxidant releaser	Fresh fatty fish and meat; fat-containing instant powders; seeds, nuts and oils; fried products	Improvement of oxidative stability
Carbon dioxide emitter	Fresh fish and meat	Extension of microbiological shelf life, reduction in head space volume of modified atmosphere packaging
Antimicrobial packaging systems	Fresh and processed meat, fresh and smoked fish, fresh seafood, dairy products, fresh and processed fruits and vegetables, grain, cereals and bakery products, ready-to-eat meals	Inhibition or retardation of bacterial growth, extension of the shelf-life

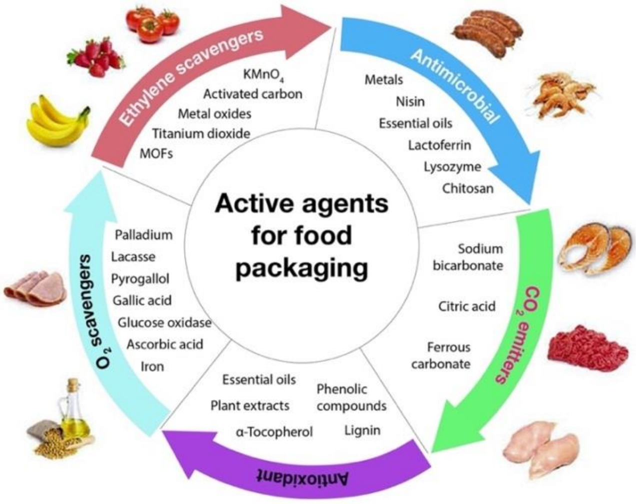

Figure 2: Active agents for active food packaging (Vilela et al, 2018)

3.1 Oxygen Scavengers

High levels of oxygen in food packaging can facilitate microbial growth, odor formation, colour change and nutrient loss, which considerably reduce shelf-life of products. Therefore, it is highly important to control the oxygen level in food products to limit food spoilage and degradation. Oxygen scavenging systems offer an alternative to vacuum or gas-flushing packaging and improve product quality and shelf-life. Moreover, they are more cost-effective as they reduce packaging costs and increase profitability.

Typical oxygen absorption systems are based on the removal of oxygen through chemical oxidation of iron powder or the use of enzymes. In the first case, iron placed in a small sachet is oxidized to iron oxide. For the sake of effectiveness, the material used to make the sachet is highly permeable to oxygen and in some cases to water vapour. This system, known as Ageless and developed by Mitsubishi Gas Chemical Company, is very widespread and the first one to be used in food packaging. The type and amount of absorbent to be used is determined by the initial oxygen level in the package, the amount of dissolved oxygen in the food, the permeability of the packaging material, its size, shape, weight and the water activity of the food. Iron-based oxygen absorbing systems have the ability to scavenge oxygen in many foods, including high, medium or low-moist foods and lipid-containing foods (Smith, 1995). They can also work in chilled and frozen storage conditions and can be used as effective oxygen scavengers even in microwave-safe food products. In enzymatic oxygen scavenging systems, an enzyme reacts with a substrate to remove oxygen (Figure 3). These systems are more expensive than iron-based systems due to the cost of enzymes used for oxygen removal. Enzymatic oxidation systems are also very sensitive to temperature, pH, water activity, and solvents included in the sachet, which limit their widespread use (Ozdemir and Floros, 2004).

Figure 3: Enzymatic oxygen cleaning systems for food packaging

Oxygen scavenging sachets are not suitable for liquid foods as the direct contact of the liquid with the sachet may cause its contents to spill. Also, the sachets may accidentally be consumed along with the food or may be swallowed by children. For this reason, the U.S. Food and Drug Administration mandates that oxygen scavenging sachets sold in the United States must be labeled with “do not eat” (Figure 4).

Figure 4: Oxygen scavenger bag for food packaging

3.2 Moisture Scavengers

Controlling excess moisture in food packaging is important to suppress microbial growth and prevent foggy film formation. If the packaging has poor water vapour permeability, the accumulation of water inside the packaging will be more pronounced. Excess water formation inside a food packaging is usually caused by inhalation by fresh produce, temperature fluctuations, or dripping of tissue liquid from fresh-cut meat. Excess water accumulation inside the packaging promotes the formation of bacteria and mold, resulting in reduced quality and shelf-life. Moisture scavengers physically absorb and hold onto water molecules from the surrounding environment. Drying agents absorb the moisture in the environment through both physical and chemical adsorption, and thus reduce relative humidity in the headspace (Gaikwad et al, 2019). The most effective way to control excess water accumulation in food packaging with a high barrier against water vapour is to use moisture scavengers such as silica gel (Figure 5), molecular sieves, natural clay, calcium oxide, calcium chloride and modified starch. Silica gel is the most widely used moisture scavenger, as it is both non-toxic and non-corrosive. Moisture absorption by silica gel is an example of physical moisture adsorption, while moisture absorption by calcium chloride is an example of a chemical reaction. In general, moisture scavengers are most commonly used in food packaging applications (Wilson, 2017). Table 2 lists the moisture scavengers used in food packaging.

Figure 5: Silica gel for moisture scavenger

Table 2: Classification of moisture absorbing materials for food packaging applications (Gaikwad et al, 2019)

Classification	Moisture absorbing materials
Inorganic	Silica gel, natural clay (monotomorillonite, zeolite), calcium chloride, magnesium chloride, aluminium chloride, lithium chloride, potassium acetate, calcium bromide, calcium nitrate, zinc chloride, phosphorus pentoxide, activated alumina, calcium oxide, barium oxide, sodium chloride, potassium chloride, potassium carbonate, ammonium nitrate, bentonite, sodium hexametaphosphate
Organic	Sorbitol, xylitol, fructose, cellulose and their derivatives (sodium carboxymethyl cellulose, potassium carboxymethyl cellulose, ammonium carboxymethyl cellulose, monoethanolamine carboxymethylcellulose), diethanolamine or triethanolamine
Polymer-based	Starch copolymers, polyvinyl alcohol, absorbent resin
Other synthesized	Starch-grafted sodium polyacrylate, acrylamide synthesis attapulgite, diatomaceous earth

3.3 Ethylene Absorbers

Ethylene is a growth-stimulating hormone accelerating ripening and senescence through increasing the respiration rate of fruits and vegetables, thus shortening the shelf-life. Ethylene also accelerates chlorophyll degradation rates in leafy products. For these reasons, the removal of ethylene from the headspace slows senescence, thereby prolonging shelf-life.

The best-known, inexpensive and widely used ethylene absorption system is potassium permanganate in silica. Silica absorbs ethylene and potassium permanganate oxidizes it to ethylene glycol. Silica is kept in a highly permeable sachet or can be incorporated into a packaging film. With that being said, potassium permanganate is not integrated into the surface of packaging films that contact food due to its toxicity. The surface area of the substrate and the amount of potassium permanganate affect the performance of these systems. Another system for ethylene adsorption is based on impregnating zeolite with potassium permanganate, followed by coating the impregnated zeolite with a quaternary ammonium cation. This system not only absorbs ethylene from the environment, but can also absorb other organic compounds such as benzene, toluene and xylene (Sacharow, 1998; Zagory, 1995). An example of an ethylene-scavenger used in food packaging is shown in Figure 6.

Ethylene released from fruits and vegetables directly affects growth and ripening processes (Dan et al, 2018; Sun et al, 2018). The role of ethylene in the growth of plants often varies based on the nature of fruits, the stage of ripeness and the degree of exposure to ethylene (Pathak et al, 2017). In addition to accelerating fruit ripening, ethylene often leads to over-ripening and even rotting, which shortens shelf-life and causes losses. There is also an increasing demand for long-term preservation of food quality and minimization of food spoilage for both health and economic reasons (Wei et al, 2020). Therefore, making use of ethylene synthesis inhibitors or scavengers to slow the ripening of fruits and vegetables is critically important in post-harvest preservation (Pathak, 2019).

Figure 6: Ethylene gas absorber for food packaging

3.4 Antioxidant releaser

Significant interest has also been placed on antioxidant agents because of their capability to increase the stability of oxidation-sensitive food products. Oxidative degradation is the major cause of food spoilage after microbial growth (Gómez-Estaca et al, 2014). Oxidative reactions are responsible for reducing the nutritional value of food affected by the degradation of essential fatty acids, proteins and lipid soluble vitamins, producing off-flavours and odors, and colour change due to pigment degradation (Bastarrachea et al, 2015; Sanches-Silva et al, 2014). There are studies focusing on the inclusion of antioxidant agents in packaging and on natural antioxidants currently applied in active food packaging. In addition, edible and active films and coatings (chitosan, cellulose derivatives, gelatin, galactomannans, alginate,) are used as carriers of natural antioxidants for lipid foods (Ganiari et al, 2017). The advantage of enclosing antioxidants within the packaging material surpasses the beneficial of their direct inclusion in food formulations. So, most of the antioxidant systems are manufactured in the form of sachets, pads or labels, or incorporated into the packaging monolayer or multilayer materials (Vilela et al, 2018). Classification of antioxidant compounds according to their mechanism of action is shown in Figure 7.

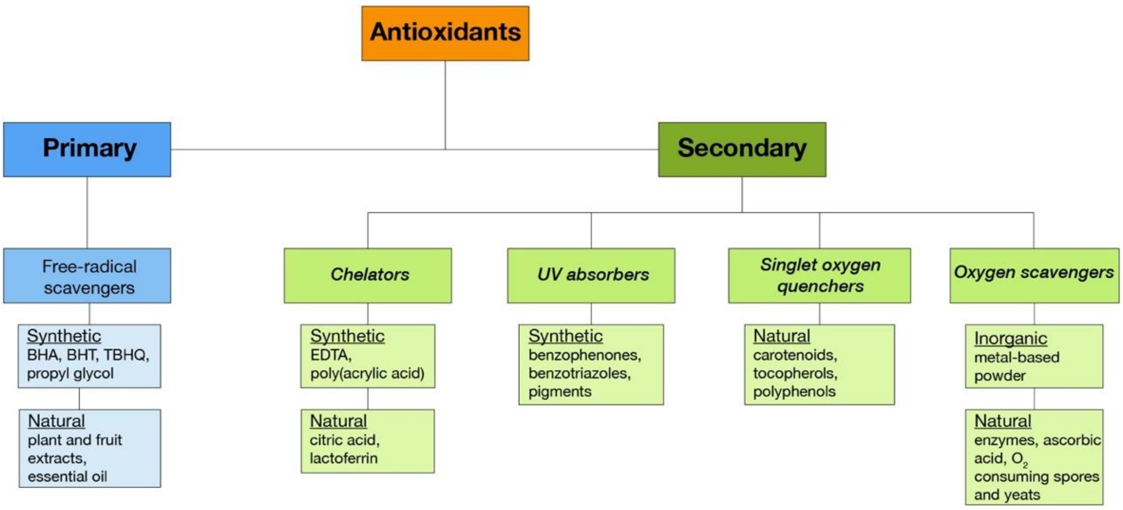

Figure 7: Listing of antioxidant compounds according to their mechanism of action (Tian et al, 2013).

3.5 Carbon dioxide emitter

Carbon dioxide (CO_2) is formed in some foods due to spoilage and respiratory reactions. This CO_2 must be removed from the packaging to prevent the product from spoiling and the packaging from damage. For example, roasted coffee can contain 15 atm of dissolved CO_2 due to the Strecker decomposition reaction taking place between sugars and amines. In such a case, CO_2 scavengers can be of use. O_2 and CO_2 scavenging bags are used to delay flavour changes due to oxidation and to absorb CO_2 (Floros et al, 1997). An example of carbon dioxide emitter in food packaging is seen in Figure 8.

Figure 8: Carbon dioxide emitter in food packaging

In some plastic films, CO_2 permeability is 3 to 5 times higher than oxygen permeability. In such cases, CO_2 must be produced continuously to maintain the desired concentration in the packaging. For this purpose, CO_2 producing systems are used in the packaging of products such as fresh meat, poultry, fish and cheese. In some food products where the volume and appearance of the packaging is critical, O_2 scavengers and CO_2 emitters are used together to prevent the packaging to collapse due to O_2 absorption (Mane, 2016).

However, in some cases, high CO_2 levels are desirable for food such as meat and poultry as this prevents microbial growth on the surface and therefore extends shelf-life. Fresh meat, poultry, fish and cheese can benefit from packaging with a high concentration of CO_2. Commercially available CO_2-scavengers are listed in Table 3.

Table 3: CO_2-scavengers in commercial use (Vermeiren et al, 1999)

Trade name	Company	Substances and actions
Freshlock or Ageless E	Mitsubishi Gas Chemical (Japan)	CO_2-scavenging ($Ca(OH_2)$)/O_2-scavenging (iron powder)
Ageless G	Mitsubishi Gas Chemical (Japan)	CO_2-generating (ascorbic acid)/O_2-scavenging
Freshilizer CV	Toppan Printing Co (Japan)	CO_2-and O_2-scavenging (non-ferrous metal)
Freshilizer C and CW	Toppan Printing Co (Japan)	CO_2-generating/O_2-scavenging
Freshpax M	Multisorb technologies (USA)	CO_2-generating/O_2-scavenging
Verifrais	S.A.R.L. Codimer (France)	CO_2-generating
Vitalon G	Toagosei Chem. Ind. Co. (Japan)	CO_2-generating/O_2-scavenging

3.6 Antimicrobial packaging systems

There is increasing interest in the use of packaging materials containing antimicrobial substances due to increasing sensitivity towards health. Consumers demand minimally processed, preservative-free food products with longer shelf-life (Irkin and Esmer, 2015). Packaging materials, edible films and coatings can be reinforced with antimicrobials to form a protective barrier to prevent and delay such microbial growth. Packaging materials serve as carriers of antimicrobials that are effectively released into the food to extend the shelf-life, and improve the quality and safety of the food (Corrales et al, 2014). This allows packaging to provide an additional and final barrier to prevent the growth of foodborne pathogens (Guarda et al, 2011). In addition, most natural antimicrobial agents are biodegradable and easily decompose. Antimicrobial packaging can be produced by incorporating antimicrobial substances directly in packaging films, coating packaging films with these antimicrobial substances and producing packaging materials made from polymers. In general, antimicrobial packaging systems can either migrate or not migrate into the food based on their interaction with the antimicrobial substance used and with the packaging and food matrix (Muriel-Galet et al, 2012). Antimicrobial packaging has been proven to improve the shelf-life, safety and quality of many food products due to its potential to reduce or minimize microbial growth in food (Jung et al, 2018; Kandirmaz and Ozcan, 2019). Natural antimicrobial agents and biopolymers are listed in Table 4.

Table 4: Samples of potential natural antimicrobial agents and biopolymers for food packaging (Tang et al, 2012; Imran et al, 2010)

Classification	**Antimicrobial agents and biopolymers**
Plant volatiles and plant/spice extracts	Allyl-isothiocyanate, cinnamaldehyde, eugenol, linalool, terpienol, thymol, carvacrol, pinene, allicin
	Grapefruit seed extract, grape seed extract, hop beta acid, Brassica erucic acid oil, rosemary oil, oregano oil, basil oil, other essential oils
Polysaccharides and derivatives	Starch, chitosan, pullalan, natural gums
	Cellulose based paper, fatty acids, alginate, carrageenan, chitosan
Proteins/enzymes/ bacteriocins	Corn-zein, soy-protein isolate, whey-protein isolates, wheat-gluten, peanut-protein, milk-proteins, collagen/gelatin
	Lysozyme, glucose-oxidase, lactopeoxidase
	Nisin, pediocin, subtilin, lacticin (EDTA)
Lipid based coatings	Beeswax, carnauba wax, sugar cane wax, rice bran wax, bay berry wax
Chelating agents	Ethylenediaminetetraacetic acid

4. INTELLIGENT PACKAGING

Intelligent packaging is one type of smart packaging that’s normally used for food, beverage, and pharmaceutical products. Although intelligent packaging is related to the food industry, it has no direct effect on the product. The European Food Safety Authority (EFSA) defines intelligent packaging as “materials and items that monitor the state of packaged food or the environment around the food” (EFSA, 2009). They have the ability to communicate the conditions of the packaged product, but do not interact with the product. The goal is to monitor the product and offer information to the customer (Figure 9). This information can be about the contents of the packaging, as well as terms of use and storage (Müller and Schmid, 2019). Another definition for intelligent packaging is about the fact that they monitor the condition of packaged products or the environment surrounding the packaging to inform the customer about any changes to the product or about the current situation of the product (Biji et al, 2015). In more detail, intelligent packaging is a system that fulfills smart functions such as detecting, sensing, recording, tracing, communicating and applying scientific logic to prolong shelf-life, improve quality and safety, and facilitate decision-making, and alerts customers about possible problems (Loucanova et al, 2017).

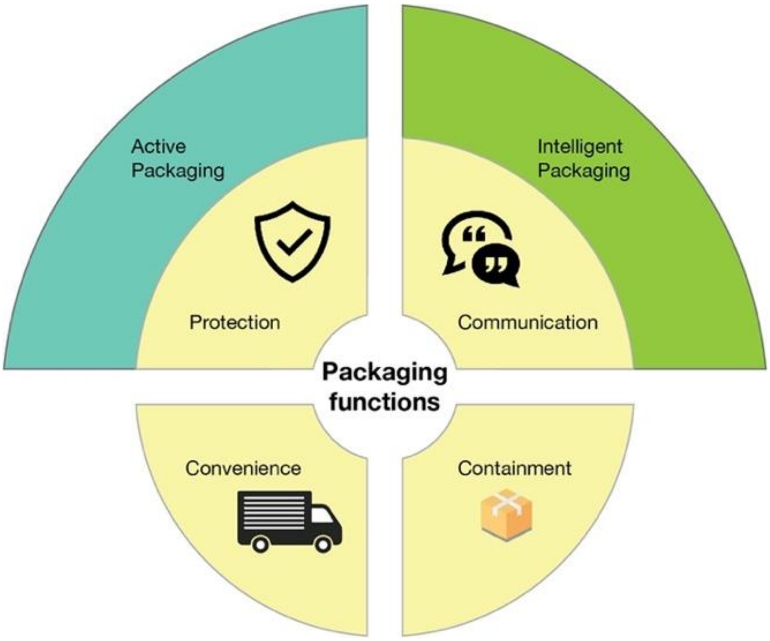

Figure 9: Packaging functions

As seen from the figure, smart packaging systems have added advanced features to two functions of packaging in particular. These are the improvement of protective properties thanks to active packaging and of information function thanks to intelligent packaging. There are three main intelligent packaging systems, which are indicators, sensors and radio frequency identification (RFID) tags (Ghaani et al, 2016). Time-temperature indicators, oxygen and carbon dioxide indicators, colour temperature indicators, pathogen indicators and refraction indicators are some of these systems.

4.1 Indicators

Indicators communicate the necessary information to the consumer. This information can be about presence or absence of a substance, as well as about the reaction between two or more substances. Usually, such information is indicated by instantaneous visual changes, such as, different colour densities or diffusion of the dye across the indicator geometry. A distinctive feature of indicators is the type of relevant information that is qualitative or semi-quantitative by nature. There is a wide variety of indicators, which can be reduced to three categories, namely, time-temperature indicators, freshness indicators and gas indicators. These indicators improve product quality and value (Hogan and Kerry, 2008; Robertson, 2016).

4.1.1 Time-temperature Indicators

Temperature indicators show whether a product is heated above or cooled below a threshold temperature and warn customers about the possible survival of microorganisms and protein denaturation when freezing or defrosting. It is also possible to monitor temperature throughout the supply chain. Temperature indicators are based on chemical, electrochemical, mechanical, enzymatic or microbiological change and they produce a visible reaction such as a mechanical deformation, colour formation or change of colour. Due to the role of both time and temperature in physical and chemical degradation, TTIs have taken on a crucial task in obtaining information about the history of temperature of a packaged food over a given time. TTIs are usually small self-adhesive labels and are also user-friendly thanks to being easy to understand (Taoukis and Labuza, 2003; Biegańska, 2017). Different time-temperature indicators are shown in Figure 10.

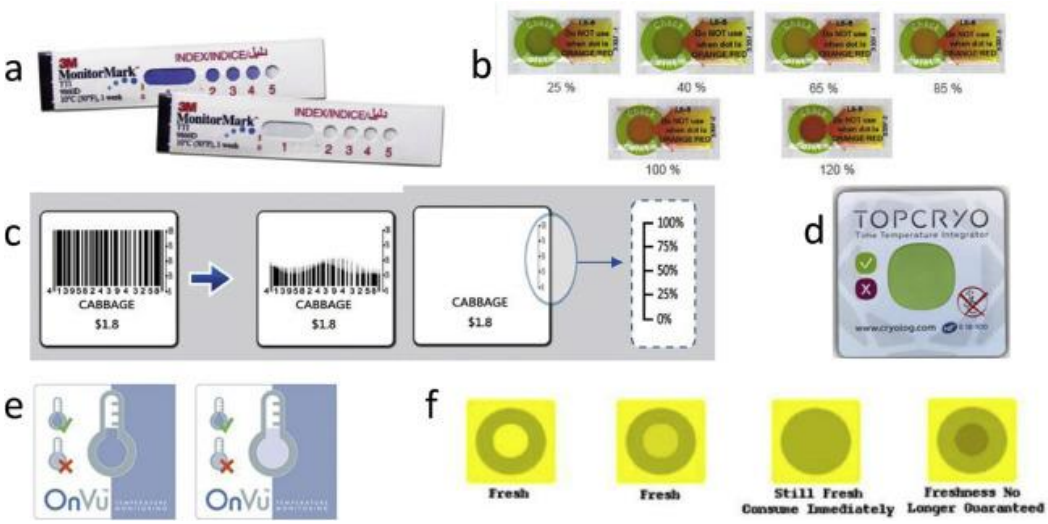

Figure 10: Time-temperature indicators (a) 3M Monitor Mark, b) VITSAB, c) FreshCode, d) TopCryo, e) OnVu, f) Fresh-Check) (Poyatos-Racionero et al, 2018)

4.1.2 Freshness Indicators

These indicators allow the quality of food products to be monitored during storage and transportation. Loss of freshness may be due to exposure to harmful conditions or exceeding shelf-life. Freshness indicators offer direct information about a product's quality based on microbial growth or chemical changes. It does so by detecting volatile amines, which are produced when a food product spoils, by conductometric or pH change or similar methods. Freshness indicators work on the principle that the organic acid, carbon dioxide and volatile nitrogen compounds that occur as a result of the microbial growth in the structure of the food that loses its freshness, change the chemical structure of the dye in the indicator. The dye usually changes colour as a result of the reaction between the dye and its degradation metabolites. In this way, visible, easily detectable freshness measuring systems can be created. Hydrogen sulfide, ethanol, diacetyl and carbon dioxide are some examples of freshness indicators. Freshness indicator sample can be seen in Figure 11.

Figure 11: Freshness indicator (Fresh-Check, 2018)

4.1.3 Gas Indicators

These label-shaped indicators are placed in the package and monitor changes in the inner atmosphere due to microorganism metabolism and enzymatic or chemical reactions on the food matrix. It can also be used to monitor the situation of active packaging such as O_2 and CO_2 scavengers. Since they are placed inside the packaging, they must be non-water-soluble and must have a certificate of food contact compliance (Fuertes et al, 2016). A gas indicator sample can be seen Figure 12.

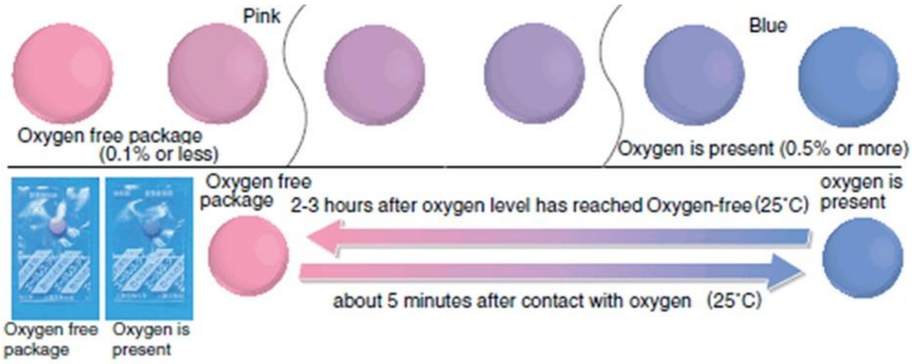

Figure 12: Gas indicator — Ageless Eye (MITSUBISHI GAS CHEMICAL, n.d.)

4.2 Barcodes and RFID Tags

These devices, which perform automatic identification, not only provide information flow within the food supply chain, but also increase efficiency in terms of food quality and safety. The task of these labels, which are also called data carriers, is to provide automation, traceability, protection from theft or counterfeiting, rather than providing information about the condition of the food. They are usually placed on an outer packaging (box, parcel, pallet, etc.) other than the product's packaging. The most commonly used systems are barcode labels and RFID labels.

Barcodes are widely used in retailers and stores for inventory check and stock tracking due to their low cost and ease of use. A barcode is made up of parallel spaces and bars arranged to represent a 12-digit data. The encoded information is read by an optical barcode scanner, which sends the information to a system where it is stored and processed. RFID tags are an advanced example of a data carrier tag. An RFID system has three main elements: a) a tag consisting of a microchip connected to a small antenna, b) a reader emitting radio waves and receiving responses from the tag in return, and c) a middleware communicating with the RFID through a local network or web server. Sample RFID tag can be seen Figure 13.

Figure 13: RFID tag (The Silicon Review, 2018)

4.3 Sensors

Sensors are electronic devices that detect one form of signal and convert it to another. Depending on the type of converter, sensors can be active or passive. Biosensors and gas sensors are used as intelligent packaging tools for common analytes such as pH, humidity, colour and biological species.

The pectin-based edible sensor was developed by the combination of the calorimetric exchange principle of anthocyanins and variations in total volatile basic nitrogen that cause the degradation of meat-based products. Similarly, membrane film sensors have been developed for maintaining the freshness of pomfret fish. Edible sensors are a new approach to food packaging as they are a harmless method for detecting deterioration (Mahalik and Nambiar, 2010; Dudnyk et al, 2018).

4.3.1 Biosensors

Biosensors are sensors with biological analyte in which the change in the product is detected and then converted into an electrical signal using a transducer. Biological analyte-interactive biosensors for monitoring quality and see changes in colour during deterioration for beef and chicken fillet and electrochemical biosensors based on nylon-6 nano fiber membrane operationalized by glucose oxidase to detect glucose in various beverages are some examples for biosensors (Fang et al, 2017; Scampicchio et al, 2010). Schematic diagram of biosensor is shown in Figure 14.

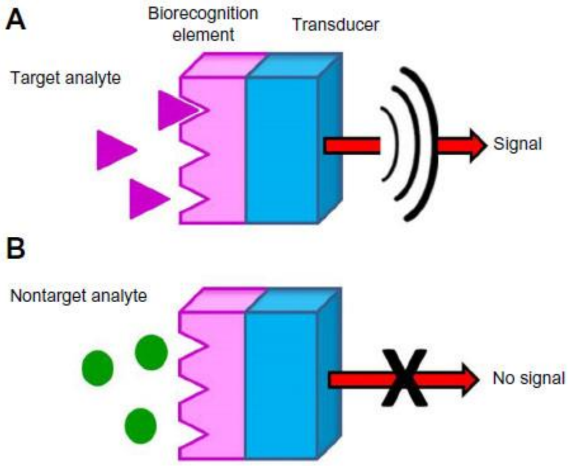

Figure 14: Schematic diagram of biosensor with target analyte (A) and nontarget analyte (B) (Krejcova et al, 2015)

4.3.2 Gas sensors

Gas sensors are designed to detect gaseous or volatile compounds such as carbon dioxide, oxygen, volatile amines and certain other gases. For example, a carbon dioxide sensor is used to detect accurate carbon dioxide levels using indicator paint and α-naphtholphthalein. These sensors are also characterized by toxicity caused by the displacement of dyes (Pereira et al, 2015; Kalpana et al, 2019). Gas Sensor-optochemical sensor, gas sensor-based on sol gel, gas sensor-based on colorimetric sensing, gas sensor-based on photoluminescence and gas sensor-based on colorimetric sensing are common gas sensors. A schematic of gas sensor is shown in Figure 15.

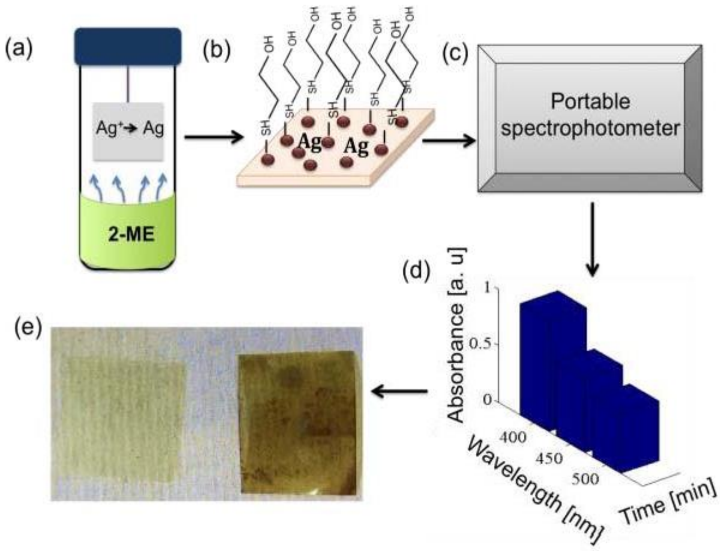

Figure 15: A schematic of the sensor set up showing (a) a flask tube with PEI/Ag film exposed to 2-ME vapours, (b) chemisorption of thiols to Ag+ prepared on PEI film, (c) a portable spectrophotometer, (d) expected absorbance results; € a photograph of the colour change of PEI/Ag film from transparent to yellow-brown after 2-ME exposure (Rvspayeva et al, 2018)

5. CONCLUSIONS

In a changing and developing world, demand for food has been increasing due to growing population, which has also attached great importance to issues such as food security, freshness, shelf-life, traceability and supply chain. For these functions to be fulfilled, packaging has to offer more than conventional packaging. Packaging has now undertaken intelligent tasks far beyond its conventional functions. Protecting the product from external conditions, transporting and storing it are not enough for today's demands. Smart packaging can be used in a wide range of applications, from meat products to liquids and fruits and vegetables.

With an active packaging, type of which is chosen based on the product's features, conditions preferred and reactions to stimuli, the product quality will be preserved and the growing of pathogens and microorganisms will be prevented, which will be directly reflected onto the shelf-life of that product. Smart packaging has the ability to communicate with its environment in the supply chain or with the consumer.

In addition to the improvements made on the food itself, intelligent packaging systems, which are applied only on the outer surface or on the packaging, both improve product traceability and safety and inform the customer. These can be smart devices in the form of labels. Or they may contain points or ink that perform various functions. Although the potential advantages of smart packaging technologies have been widely studied and proven, there is still not enough application in the market. Studies need to be conducted on their cost so that these systems can be commercially applicable.

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