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Review

A critical review on intelligent and active packaging in the food industry: Research and development

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ABSTRACT

The emergence of many new food products on the market with need of consumers to constantly monitor their quality until consuming, in addition to the necessity for reducing food corruption during preservation time, have led to the development of some modern packaging technologies such as intelligent packaging (IP) and active packaging (AP). The benefits of IP are detecting defects, quality monitoring and tracking the packaged food products to control the storage conditions from the production stage to the consumption stage by using various sensors and indicators such as time-temperature indicators (TTIs), gas indicators, humidity sensors, optical, calorimetric and electrochemical biosensors. While, AP helps to increase the shelf-life of products by using absorbing and diffusion systems for various materials like carbon dioxide, oxygen, and ethanol. However, there are some important issues over these emerging technologies including cost, marketability, consumer acceptance, safety and organoleptic quality of the food and emphatically environmental safety concerns. Therefore, future researches should be conducted to solve these problems and to prompt applications of IP and AP in the food industry. This paper reviews the latest innovations in these advanced packaging technologies and their applications in food industry. The IP systems namely indicators, barcoding techniques, radio frequency identification systems, sensors and biosensor are reviewed and then the latest innovations in AP methods including scavengers, diffusion systems and antimicrobial packaging are reviewed in detail.

1. Introduction

The field of food packaging is exponentially growing in both scientific and industrial sectors due to increasing world population to meet new food safety regulations which are constantly and strictly updated and upgraded. Packaging is one of the main processes of preserving and maintaining the quality of food products for export, storage, and final consumption. Changes in lifestyle of customers have increased the demand for clean, high quality, fresh, minimally-processed and ready-to-eat produces having an extended shelf life which subsequently create the urgency and need for a modernized packaging technology. Todays, the new technologies namely intelligent packaging (IP) and active packaging (AP) are progressively applied in the food industry, but in many cases, they are still under study and have not been commercialized. The IP systems are used to increase safety and display various warnings about potential problems inside the food packaging environment (Yam, Takhistov, & Miltz, 2005). The IP systems are designed to detect condition storage, expiration date, quality, safety diagnosis, monitor microbial growth and to determine freshness of food. Although the AP system changes the environmental conditions of the packaged food during preservation period, but this is very important for preserving the safety and sensory properties along with maintaining the quality of packaged foods (Ahvenainen, 2003). Grand view research company (San Francisco, California, the United States) in its market report declared that in 2024, packaging market revenue in the United States would reach to $6 billion for AP and almost $3.45 billion for IP (Nano-enabled Packaging Market report). There is no doubt that the development of packaging techniques is severely related to the researches that are carried out in these areas. Today, a large number of scientists work in this field. Monitoring the quality of food is necessary from two aspects: it is aimed to protect consumers from diseases resulting from the food spoilage, and it is used to increase the productivity of the food industry and reducing the losses caused by food corruption. These advanced packaging methods are not just for protecting food against external conditions but also, they have other benefits such as helping to continuous monitoring and control of surrounding

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conditions of packaged foods to increase the shelf-life of products.

Due to the increasing interest in AP and IP developments in the food industry, this paper aims to critically review recent advances in the fields of IP and AP technologies that are used to improve product integrity and to provide greater benefits to the final customers. This research focuses on the main categories of the IP systems, namely indicators, barcoding techniques, radio frequency identification systems, sensors and biosensor and then the latest innovations in the AP methods including scavengers, diffusion systems and antimicrobial packaging are described in detail. The knowledge gaps needed to optimize the use of the modern packaging technologies (AP and IP) in the food industry are examined.

2. Intelligent packaging technology

IP is an emerging technology within the food packaging field. It has a great potential to improve the traceability, safety and quality of food. IP is described as the science and technology that introduce the communication tools for a food packaging system to monitor changes in the internal and external environmental conditions of the system as well as the packaged food, in order to communicate the status of the system to the stakeholders of the supply chains including producer, retailers and consumers (Yam, 2012). IP facilitates decision making, enhances safety and helps to improve quality by providing information, and warning potential problems. Sensors, indicators and identification systems are main components of IP that are used to estimate and communicate the corresponding factors of a food product to users (Heising, Dekker, & Bartels, 2014). General working principle and applications of the most important IP devices used in the food industry are presented in Table 1.

2.1. Indicators

2.1.1. Time TEMPERATURE INDICATOR (TTI)

The quality of a food material is severely dependent to its temperature history from production to consumption. Therefore, temperature is a key factor in cold chain management systems (Tsironi, Ronnow, Giannoglou, & Taoukis, 2017). To monitor the temperature history of a food product, in the packaging to consumption chain, TTIs would be helpful. TTIs monitor the accumulative effect of temperature on food quality. They are attached on the surface of food packages and integrate the exposure of the packaged food to temperature by accumulating effects of such exposures along the entire cold chain. The working principle of these indicators is based on different reactions between two or more materials (enzymatic, mechanical, chemical, etc.), and as a result, the irreversible discoloration of indicator as an explicit response is happened. Diffusion-based TTI and microbial TTI are very common in food applications. To make TTIs more functional, a proper reaction to temperature alterations and a proper model to map temperature changes to the spoilage kinetics of the product seems to be crucial. While, laboratorial studies in this area are rare. Such models should be integrated in a user-friend tool to simultaneously deliver information about compensatory operations to temperature abuses. Below, the original composition of these two indicators along with offering some types of commercially available indicators are presented.

2.1.1.1. Diffusion-based TTI. This indicator consists of a layer, and inside of it contains thin layers from paper, film, glue, and so on. When the storage conditions of the food (i.e. temperature) reach to undesired limits, the appearance of the indicator changes to inform the customer that the product is corrupted. This indicator is made up of a wick porous with dyed fatty acid ester. With increases in temperature above a certain level, the ink goes to different layers and color of the indicator changes. It should be noted that the ink used for each food is different and it depends on the storage condition of food (TAOUKIS & LABUZA, 1989). 3M Company (Saint Paul, Minnesota, the United States) developed a TTI based on diffusion called MonitorMark^{TM}. When the food exposures to high temperatures, the indicator offers a contrast index with a blue color. This indicator provides a continuous and lasting record of exposing the product to undesirable temperatures during excessive storage times. The color converting in the indicator is irreversible even after storage conditions return to agreeable levels. These indicators are placed on the outside surface of heat-sensitive product packages or on the outside surface of export boxes in order to provide the required information to estimate storage and shipping conditions. Accordingly, these indicators are not in direct contact with the product itself, but they only monitor and display the conditions of storing. A range of MonitorMark™ TTIs (9860 A- 9860H, 9861 A and 9864C) commercially are available in different time-temperature thresholds. Topcryo TTIs (CRYOLOG company, France), Tempix TTIs (TEMPIX company, Sweden), and OnVu TTIs (Ciba Specialty Chemicals and FreshPoint company, Switzerland) are other kinds of commercial diffusion-based TTI. Biegańska, Gwiazdowska, Kozak, and Kluczyńska (2014) benefited from visible changes of the 3M MonitorMark® indicators (9860C model) for monitoring the quality of non-pasteurized fresh juices (apple, orange, carrot, and beetroot) stored in various conditions (Fig. 1). The results showed that the color changes in the indicators present the actual time that the juice is stored at temperatures above 10 °C.

The diffusible mediums for TTI indicators must specifically have an activation energy (E_a) value. It is crucial that the TTI response matches to the quality losses of food. Hence, it is essential that E_a of TTIs to be within the acceptable range of E_a of the related food during storage, and the TTI's endpoint should correspond to the shelf life of the product.

The reaction rate of indicators is the function of the indicator's viscosity. In order to have an indicator with low E_a, its viscosity should be decreased A potential solution for decreasing the viscosity of the TTI indicators is the blending oils having different viscosities (Kim, Kim, Lee, Yoo, & Lee, 2010). Researchers are trying to develop models to fit on the diffusion-based TTIs using Fick's second law. The problem is that each indicator has its individual diffusion reaction characteristics. Therefore, so many prediction models would be developed for this type of

Table 1
Working principle and food applications of some smart devices used in IP (Fang et al., 2017; Hurme, Malm, & Ahvenainen, 2002; Kerry et al., 2006).

Smart devices	Principle	Applications
TTI	Mechanical, chemical, enzymatic or microbiological.	Continuously monitors and reflects the temperature history along the entire cold chain of the stored food; Diagnosis storage conditions.
Gas indicator	Redox dyes, pH dyes or enzymes.	Dependent on the indoor atmosphere, indicates the quality condition of the food; Detecting changes in the atmosphere inside the packaging; Monitoring the quality and safety of packaged food regard to specific gas composition inside (modified atmosphere packaging)-Diagnosis package leak.
Barcode	Symbology	Product identification; The originality of product- Facilitating inventory control.
RFID tags	Radio waves	Product identification- tracking and anti-theft protection.
Sensors	Physical or chemical	Detecting the activity, concentration and composition of specified physical or chemical analytes.
Biosensor	Biological materials including antigens, enzymes and nucleic acids.	Detecting specific biological analytes in the purpose of diagnosis of food quality and its safety.

TTI, Time-Temperature Indicator; RFID, Radio frequency identification system.

Fig. 1. Visible changes on MonitorMark® indicator (Biegańska et al., 2014).

indicators. Also, more researches are needed to develop the TTIs and to study potential of these indicators to apply on a specific product (Khairunnisa, Suyatma, & Adawiyah, 2019).

2.1.1.2. Microbial TTI. The microbial TTI response is directly related to food microbial spoilage, a correlation is established between the bacterial growth in the food and the bacterial growth and the metabolism within the corresponding TTI. There is an increasing trend in developing and applying of microbial TTIs for monitoring shelf life of the perishable foods in a cold chain (Mataragas, Bikouli, Korre, Sterioti, & Skandamis, 2019).

One type of these indicators is formed from a label containing lactic acid bacteria (LAB) that is placed inside the food package. Generally, the indicator comes with a color index that commonly its initial color is green. Increasing of the temperature inside the food package above a specified value leads to absorb bacteria by the food. In this storage conditions, the food releases carbon and lactic acid compounds and bacteria use this composition to grow. According to the temperature and the length of time which food remains in these conditions, bacteria grows at different rate. As a result, the pH inside the environment of the package decreases. The decreasing rate of pH is proportional to the growth rate of the bacteria. Based on that, the color of the indicator changes gradually to red.

Wanihsuksombat, Hongtrakul, and Suppakul (2010) prepared the TTIs based on the propagation of lactic acid vapor to monitor quality of foodstuffs (Fig. 2). They used a mixture of bromothymol blue and methyl red as a mixed-dye-based indicator, which changes from bright light green to bright red when exposes to amounts of 0.01 M lactic acid from 0 to 5.5 μL. Mixing indicators is a good solution to expand the range of color change compared to the used single indicators.

The reason of color changes in the developed TTI is that the Lactic acid as a monoprotic material, has a hydrogen atom which dissociates from the parent molecule, forms hydrogen ions (H^+) and lactate ions ($CH_3CH(OH)COO^-$). The hydrogen ion combines with water molecule and forms hydronium ion (H_3O^+). Hydronium reacts with the mixed dye (In) in a gel matrix, which results the acid form (HIn) of the dye leading to color change of the gel matrix (Wanihsuksombat et al., 2010). The average E_a value of the developed TTIs was about 52 kJ mol^{-1}. While, the E_a values for enzymatic and nutrient losses and microbial growth have been reported as 41.84–62.76, 83.68–125.52, and 83.68–251.04 kJ mol^{-1}, respectively (Labuza, 1982). So, this TTI is not a proper indictor to monitor the whole range of food quality losses. Lim, Choe, Son, and Hong (2014) developed a microbial time-temperature integrator system utilizing LAB (Weissella koreensis). They also indicated that the developed microbial TTI system was useful in quality monitoring of such foods that the E_a values of the TTI system and the food are similar.

To have a proper chilled distribution of fish products at the optimized quality and safety conditions, continuous monitoring of temperature using TTI seems to be a good approach. Giannoglou et al. (2019) studied on response of different enzymatic TTIs applied for smoked European eel (Anguilla anguilla), smoked rainbow trout (Oncorhynchus mykiss) and smoked salmon (Salmo salar). The used TTIs worked as a time-temperature dependent hydrolysis leading to a gradual pH decrease and consequently color change from green to red. Quality control of the labels was conducted by measuring lipase activity using a spectrophotometric method with p-nitrophenyl as substrate. The TTI response was kinetically studied and modelled as a function of lipase enzyme concentration. Quality assessment of the products was based on lipid oxidation, color, microbial growth and etc. The existence of total aerobic bacteria, LAB, *Brochothrix thermosphacta* and *Pseudomonas* were investigated in the samples. The applied TTIs were based on the

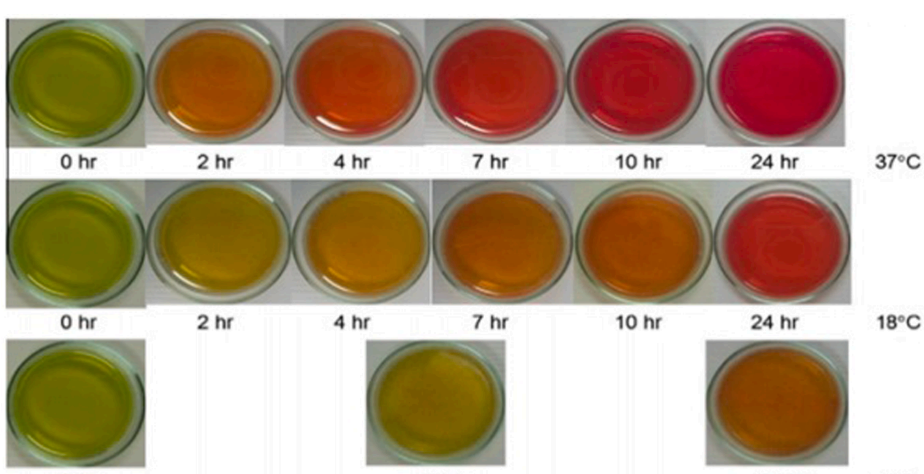


Fig. 2. Color changes of indicator based on the release of lactic acid under different temperatures and time passes (Wanihsuksombat et al., 2010).

enzymatic reaction i.e. color change correlated to the cumulative effects of the time-temperature variations during storage on the studied food product. They proposed M-17U, M-5U and LP-17U, as the optimum enzymatic TTIs for the monitoring of the cold chain distribution of the smoked salmon slices, the smoked eel fillets and the smoked trout fillets, respectively. The developed TTIs indicated that for each fillet type, an individual TTI must be developed. This proves that it is not possible to develop an individual TTI for several types of food products. In the meantime, they have not examined the effect of race and species on the selection of appropriate TTIs for the smoked products. Another thing to keep in mind is that the responses of the microbial TTIs are expressed as color changes that are visually inspected by consumers. This can lead to a misidentification in the view of consumer. Because, every consumer can have an individual interpretation of the TTI color he/she observes. Hsiao and Chang (2017) also designed and developed a microbial TTI for vacuum-packed grouper fish fillets. Among more than 150 species of grouper, they selected giant grouper (Epinephelus lanceolatus) and used *L. sakei* as major spoilage bacteria in vacuum fish fillet.

To date, the microbial TTIs that have been applied for monitoring the quality of chilled foods involve color change of an indicator due to either acidification or hydrolysis of the TTI medium during the growth of a selected microbe. Researchers try to develop flexible microbial TTI having the capability of applying in a wide range of refrigerated foods. To achieve this purpose, various factors of the microbial TTI system should be studied, the main factors are the activation energy and TTI's endpoint at a reference temperature. In literature, it has been suggested such TTI systems that $\Delta E_a \leq 20$ kJ/mol between the TTI and the food agent that causes food quality deterioration, represent reliable predictions of the shelf life (Taoukis, 2001). But, Mataragas et al. (2019) have found that $\Delta E_a \geq 10$ kJ/mol lead to unacceptably and predictions errors more than 20%.

Mataragas et al. (2019) aimed to develop a versatile microbial TTI system by the microorganism *Janthinobacterium* sp. which produces violet pigment by formation of violacein during early growth, depending on temperature and intrinsic properties of the growth medium. They used luminosity (L*) factor as a representative of color changes and the Baranyi model to fit the violacein kinetics data to estimate the TTI's endpoint. The TTI system was made of Tryptic Soy Agar enriched with 1% glycerol and spot-inoculated with the bacterium. The factors including the storage temperature, the initial concentration of the microorganism, the volume of the spot and the pH of the medium, were studied. They found a marked effect of the spot quantity, pH of the growth medium and initial *Janthinobacterium* sp. concentration and on the response of the microbial TTI that have led to different E_a and endpoint time of the TTIs contributing to the flexibility of the developed TTI. Nevertheless, to have a successful monitoring of the food quality degradation due to microbial activity, the selection of the most proper combination of the input parameters, is a key factor that needs implementation of time-consuming experiments. At pH = 5.5, they however observed high variability between the TTI's endpoint values and the inability of the microorganism to grow and subsequently produce violacein, the reliability of the TTI could jeopardize especially at low population levels (1–2 log CFU/spot). At a high pH equals to 9 and low temperature of 0 °C, *Janthinobacterium* sp. influenced violacein production leading to spots with higher luminosity values (lighter violet color) compared to the other cases. They validated the developed TTI under dynamic temperature conditions and found the TTI showed a proper ability to monitor the whole time-temperature history of a food product. The most important limitation of the TTI system was defining a threshold L^* value to clearly indicate the TTI's endpoint in an objective manner, regardless of the individual and the means of assessing the color. So, the developed TTI needs modifications in formulation of the solid growth supporting medium to achieve more distinct colorings to easily read.

Freshness TTI is also a kind of LAB TTIs. This label is made of gel-shaped and transparent material which comes with color indicators and places on the product barcode. In big supermarkets where loads of vegetables and fruits are stacked, tracking of all products is very time-consuming. Also, all purchasers may have not a proper skill to identify freshness of perishable food. The freshness code presents a modest solution to this issue that shows the freshness level of the food. The form of barcode continues receding during passing the time until it finally disappears or becomes sufficiently matte (Fig. 3), indicating that the quality of product is very bad and should not be sold. When this happens, scanner devices cannot read the barcode.

According to the increasing demand for food quality and safety, these smart barcodes are expected to significantly spread in the coming years. Many of these techniques have become commercially available. For example, Japanese TO-GENKYO company have developed a smart barcode for monitoring the quality of meat. When the meat becomes aged, the barcode becomes paler. Eventually, the barcode completely vanishes.

Chen, Wang, and Jan (2014) proposed a low-cost colorimetric sensor array for evaluating chicken freshness. To fabricate colorimetric sensor arrays, two crucial requirements should be considered: every dye must possess a center interacted strongly with analytes; and the interaction center must be strongly coupled to an intense chromophore (Chen et al., 2014; Huang, Xin, & Zhao, 2011). Three pH indicators including bromocresol purple, neutral red and bromocresol green and several metalloporphyrins materials were used for fabricating colorimetric sensor and eventually the colorimetric arrays of chemoresponsive dyes were made by printing the dyes on C2 reverse phase silica-gel plates by using the micro-capillary pipettes. They reported that selected metalloporphyrins dyes in the sensors array sensitively responded to most of volatile organic compounds (examples for tryptamine, cadaverine and putrescine) during chicken spoilage as well as pH indictors to hydrogen sulfide and the organic acids (examples for acetic acid and lactic acid). So, the sensors array had its unique colorific fingerprint corresponding to the freshness of the chicken samples. Nevertheless, the selected dyes

Fig. 3. A typical smart barcode based on freshness TTI (Lee, 2017).

had non-specific sensitivity and wide cross-sensitivity toward spoilage metabolites meaning that each dye was sensitive to numerous volatile compounds and different dyes were sensitive to one of volatile compounds. Therefore, for the proposed system it was difficult to assign specific colorific profile to a specific volatile material. and analyses the headspace component-by-component.

However, enzymatic TTIs are more sensitive to changes in environmental temperature and exhibit higher accuracy than to microbiological and physical diffusion TTIs. Nevertheless, the diffusion type systems currently dominate the TTI market, because some limitations of the enzymatic TTIs possessing high price and enzymatic instability remain unresolved (Kalpana, Priyadarshini, Maria Leena, Moses, & Anandharamakrishnan, 2019). Diffusion-based TTIs are designed for a wide range of temperatures and have a relatively uncomplicated production process. But the colored material exudation impacts on the accuracy and safety of such TTIs, adversely. For enzyme and biological systems, higher temperature does not mean a higher reaction rate of such TTI response. So, wrong information would be provided to consumers about the food, which actually may have already spoiled. As for the biological TTI, it should be noted that humidity, water activity, pH, temperature and the presence of antimicrobials and other microbes may affect dominant microbial growth to some extent, so the activity of microorganisms can fluctuate in practical applications (Wang et al., 2015b).

2.1.2. *Gas indicator*

It is an adhesive label placed on the package surface to show changes in the composition of the gas inside the package. Usually, this indicator shows the presence or the absence of CO_2, O_2 or C_2H_4 (De Jong et al., 2005). This kind of indicators should be in permanent contact with the food and the atmosphere inside the package. Recently, some researches had been conducted on the manufacture of CO_2-sensitive smart packaging films (Baek, Maruthupandy, Lee, Kim, & Seo, 2018; Lee, Baek, Kim, & Seo, 2019; Lyu et al., 2019). When the percentage of CO_2 gas inside the headspace of the package increases, the color of the films would change to give a visual index of the quality of the packed food. These indicators are able to accurately monitor quality changes of food which are not visible to the consumer, resulting in visible changes. Gas indicators can monitor alterations of metabolites such as CO_2, NH_3, H_2S and dimethylamine ($(CH_3)_2NH$) and trimethylamine (C_3H_9N) as quality indices (Lee et al., 2019). However, there is a gap in the research of these indicators which very few scientific papers have been published on their development for quality monitoring of foods. Food material, contrary to industrial matters, usually exhibit a particular behavior in the production process until consumed, and usually a gas sensor cannot be used for a wide range of foods, so scientific studies should be performed for each food product. So, configuration of gas indicators and selection of proper materials are important for developing the best indicator and enhancing the accuracy of information regarding food quality. Baek et al. (2018) aimed to prepare and characterize pH dyes containing a poly (ether-block-amide) (PEBA) film as a CO_2 indicator for displaying changes of CO_2 concentration in the headspace of the packaged kimchi to monitor its quality. They developed an indicator system made of PEBA film, bromothymol blue (BTB) and methyl red (MR) as the pH dependent indicators. The fabricating process of the indicator is described in Fig. 4. The color changes of the developed indicators as a function of CO_2 level inside the packaging container were correlated with the proportion of the materials used in their structure. Among the developed indicators, the PET/PEBA + dye (MR + BTB) (3:7) + PEI 5%/PEBA combination revealed the highest total color difference value. It should be noted that the developed indicator was also sensitive to acetic acid and its color changed by changing acetic acid concentration in the headspace of the packages. This may conflict performance of the indicator to accurately represent quality of the food. They have not validated their developed system with the real experiments using kimchi samples to determine if it can truly reflect the quality of kimchi for the consumer.

The main problem of using pH sensitive dyes in the packaging industry is that the dyes are strongly hydrophilic. This issue results in the migration of these dyes to the foods with high water content by only a simple contact. Mixing these dyes with the hydrophobic polymers of packaging materials is also an important issue. To overcome these problems, Lyu et al. (2019) developed a (BTB^-)/tetrabutylammonium (TBA^+) ion-paired dye and produced a CO_2 sensitive packaging film. The color of the developed film was changed from blue to yellow by decreasing pH (Fig. 5). They used the fabricated film in the kimchi packaging and monitored the CO_2 level in the headspace during the fermentation process. The hydrophilic BTB dye can be converted to hydrophobic using phase-transfer tetrabutylammonium cation (TBA^+). The ion-paired dye is adequately lipophilic and soluble in polyolefin-based film solutions. The advantages of this method are: the dye becomes more sensitive to pH than that of the original one, the ion-paired dye react with CO_2 gas without any water generation and finally it has relatively short response times to CO_2 (Behera, Pandey, Kadyan, & Pandey, 2015; Lyu et al., 2019). Fresh kimchi samples were cut into small pieces, were packaged by the fabricated film and then were stored

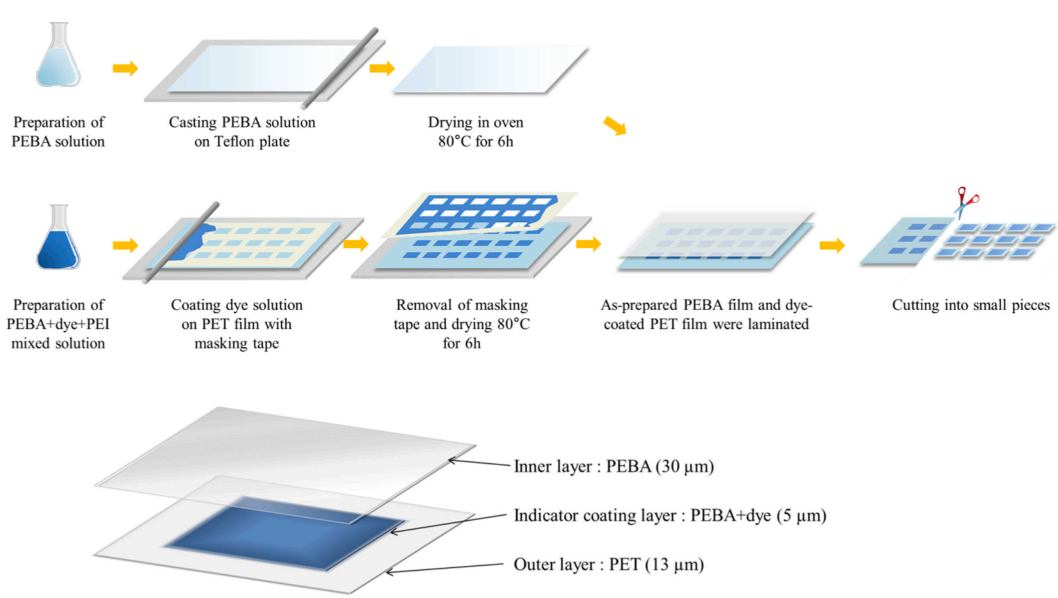


Fig. 4. The structure the CO_2 indicator and the corresponding fabrication process performed by Baek et al. (2018).

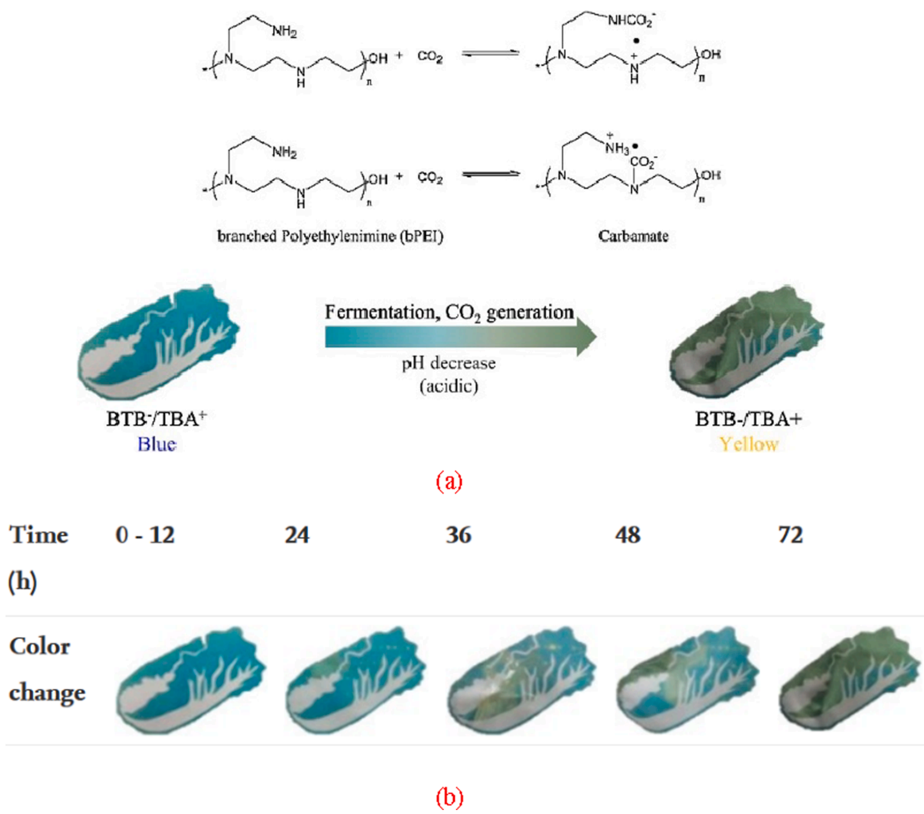


Fig. 5. An example of a CO_2 gas indicator: (a) a CO_2-sensitive packaging film prepared by BTB−/TBA+ ion-paired dye, and (b) the color changes in the CO_2 indicator at 20 °C through three days of storage (Lyu et al., 2019).

in an incubator at 20 °C. As shown in Fig. 5, the increased acidity due to the fermentation and consequently CO_2 generation in the headspace of the packages, was detectable by absorption changes of the BTB^-/TBA^+ ion-paired dye. The pH and titratable acidity (TA) factors of the kimchi specimens as well as CO_2 concentrations in the packaging during the fermentation process are presented in Fig. 6. However, to validate the developed CO_2 indicator, it was preferable to use a colorimetric system such as CIELAB color space for illustrating the color changes of the indicator numerically, as the performance comparison of the IP system would be better provided at different shelf-life period of the product and different concentrations of CO_2. Interference with pH change by other reactions, cost, stability and the release of substances harmful to human health are the important problems that indicate the need for further research in this field.

The objective of Chen, Zhang, Bhandari, and Yang (2019) was to develop and assess a colorimetric label for monitoring shelf-life of cold storage packaged lean pork. They developed three types of indicators based on different components of pH-sensitive dyes using BTB, bromocresol purple and a mixture of MR and BTB. The freshness indicators were made by mixing a suspension of methylcellulose, polyethylene glycol-6000 and corresponding dye solutions in distilled water. Six types of indicators were simultaneously installed above each prepared lean pork, the samples were packaged and stored at 5 °C for 8 days. Microbial spoilage and biochemical reactions are two key reasons for freshness deterioration of pork. During storage, metabolites like amines, aldehydes, ketones and esters are produced as well as other low molecular weight substances responsible for off-flavors and sensory product rejection. Total volatile basic nitrogen (TVBN) is an essential reference index for evaluating pork freshness (Li, Chen, Zhao, & Wu, 2015). The TVBN content of the samples were changed from 4.23 to 28.96 mg/100 g during the storage period. The initial pH value of pork samples was the lowest (5.84) and gradually increased to 6.67 on day 8. There was an increase of aerobic plate counts from 3.1 $\log_{10}$ CFU/g on day 0 to 7.8 $\log_{10}$ CFU/g on day 8. Releasing volatile organic bases due to spoilage of pork, modifies gas composition in the headspace of the tray and pH increases when the basic spoilage volatile amines are

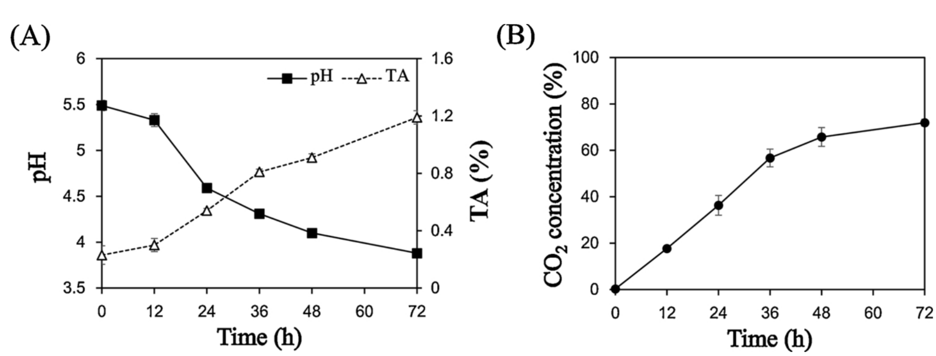


Fig. 6. Changes in: (A) quality factors of the packaged kimchi stored at 20 °C; (B) CO_2 concentrations in headspaces of the packages adopted by Lyu et al. (2019).

gradually produced into the package headspace. They found the indicator with initial pH of 5.0 composed of BTB:MR = 3:2 was the best one which was easily visible to the naked eye. The most important drawback of this indicator is that it cannot precisely identify the spoilage level of the product. They developed a system based on image analyzing technique and principal components analysis that was able to classify the pork samples into fresh, medium fresh and spoiled categories. While, the purpose of colorimetric indicators is to enable the consumer to directly detect the freshness level of the product, based on the observation of the corresponding color changes of the indictor, without the use of expensive and sophisticated techniques.

In the freshness indicator systems, permeability of the membrane polymer is a critical problem, it should allow the metabolites produced during aging of the food to permeate and should simultaneously prevent migration of dye in to the package. The method often used in construction of the freshness indicator is; applying white porous filter papers as backgrounds of color recognition, binding polymers for immobilizing the dyes by coating or impregnation and laminating the freshness indicator. Automation of this process for mass production of the indicator is very complicated. Freshness indicator is often used for high water content foods, which exposes the filter paper to moisture that can induce color change distortions, unexpectedly (Lee et al., 2019). To reliably visualize the shelf life status of the packaged foods, the freshness indicator should present an excellent performance with "zero false-positive" or "zero false-negative" results (De Jong et al., 2005). Other issues that would be limited performance of the freshness indicators is the effect of unrelated to quality metabolites on color of the used dyes, exitance of a complexity or ambiguity in the relationship among product type, target metabolites, safety and organoleptic quality of the food (Salinas et al., 2012).

Lee et al. (2019) developed a freshness indicator for detecting chicken-breast spoilage having a three-layered structure and a porous Tyvek® sheet for high permeation of vapor and gas. The indicator solutions containing bromocresol green 1.0%, 1.5% and 0.5% were coated on LDPE films, were dried and laminated on the Tyvek® sheet and were cut into 20 × 20 mm^2 squares. They examined the developed indicator on fresh chicken breast of normal pH (5.9–6.0) sealed with a sterilized polyethylene terephthalate/casting polypropylene (PET/CPP) film at two different storage temperatures of 4 °C and 10 °C. They used a smartphone camera to capture digital color images of the freshness indicators during storage and extracted the corresponding average RGB pixel intensities. The quality factor including CO_2 concentration, TVBN content, microbial growth and total plate count (TPC) were studied. According to Rukchon, Nopwinyuwong, Trevanich, Jinkarn, and Suppakul (2014), for human consumption, the acceptable limit of microorganisms in fresh poultry is in the range of 6.0–7.0 log CFU/mL. Accordingly, the minimum spoilage level was on day 7 at 4 °C and day 4 at 10 °C. Fig. 7 shows the quality factors of the stored product and the respective responses of the indicators.

As the TVBN content and CO_2 concentration increased due to the proteins breakdown by the proteolytic enzymes produced by microorganisms, the color change from yellow to green was suddenly occurred at day 7 and day 4 at storage temperatures of 4 °C and 10 °C, respectively, which is consistent with the minimum spoilage-level data at each storage temperature. Nevertheless, no significant distinctions were made among the color of the indicators until the product reached to the spoilage threshold. They proposed to analyze the relationship between the changes in the quality factors of the packaged product and the corresponding changes in RGB color of the indicator, and to develop mobile apps for real-time freshness determination. The problem is that despite the fact that the mobile apps make the freshness indicator systems more accurate, but it makes the system more sophisticated and more expensive. The advantage using Tyvek® as the inner layer of the freshness was the prevention of dye migration and thus ensured food safety. The CO_2 concentration in the headspace of the modified atmosphere (MA) packaged foods is a crucial problem. Because, an initial concentration of CO_2 gas may be injected in the headspace of the food packages that is not result of the food's spoilage. This issue should be considered in developing the freshness indictor for the MA packaged foods. Strong effect of CO_2 on the pH under humid conditions needs to be considered in commercialization of such freshness indicators.

Releasing of C_2H_4 from the climacteric fruits is an important phenomenon in post-harvest handle, ripeness and senescence of these fruits which are severely related to emission of the ethylene gas. Monitoring the ripening status in the distribution postharvest chain by a colorimetric sensor can help to human to be careful of quality losses due to mechanical damages or unfavorable storage and handling conditions. Colorimetric indicator is a good approach to monitor the ethylene concentration by color changes. Ripesense company (Auckland, New Zealand) developed a C_2H_4 gas indicator to recognize the degree of fruit ripeness. This indicator is commercially available as a ripening sensor®. The primary color of the C_2H_4 indicator or as it called ripening sensor label is red, which indicates the premature of the fruit. Gradually, the color of the indicator turns into orange and eventually turns to yellow (Fig. 8) which means that the fruit is fully ripped.

The reduction reaction of platinum or palladium compounds can be applied for monitoring of ethylene gas, which are very expensive. In such systems, molybdenum oxides are also used, the ions of molybdenum (VI) would be reduced fractionally and provoked than the formation of intensively colored molybdenum blue. This type of indicator is sensitive to UV light, other reducing materials, humidity and temperature that lead to unwanted coloration without the presence of ethylene and consequently low stability (Lang & Hübert, 2012). In addition to ethylene, apples emit various organic flavor compounds, including

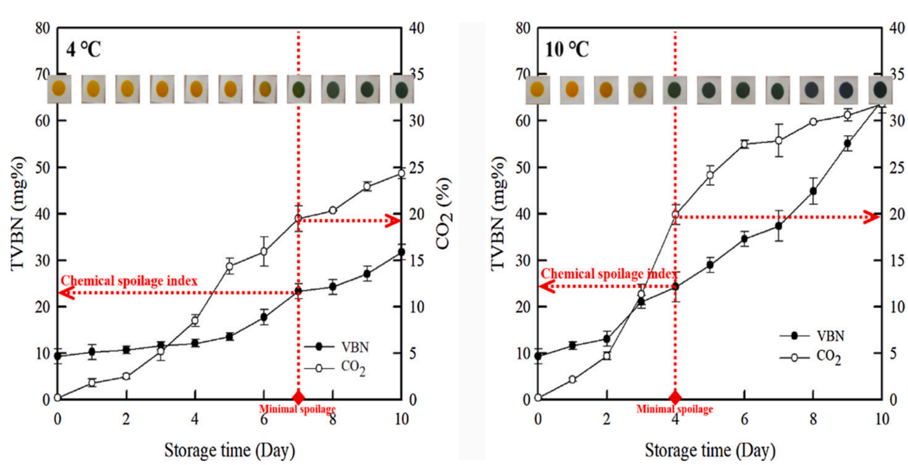


Fig. 7. Color changes in freshness indicators in response to changes in the TVBN and CO_2 content in chicken breasts stored at 4 °C and 10 °C (Rukchon et al., 2014).

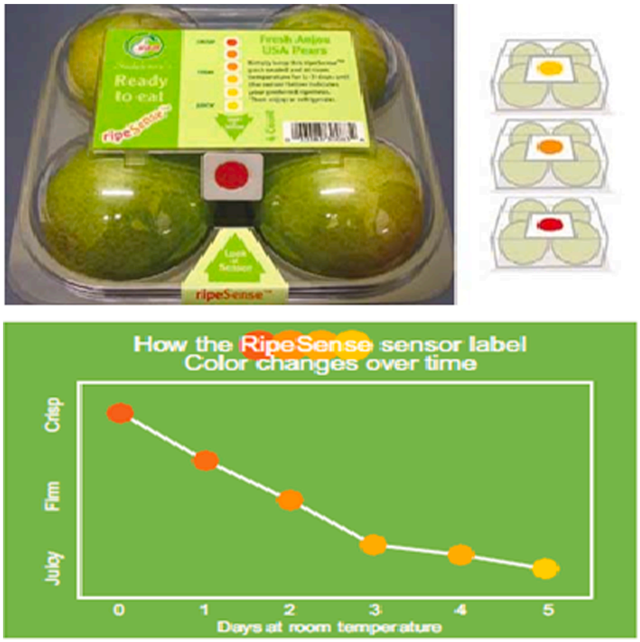


Fig. 8. Color changes in gas indicator from red to yellow during ripening (Giménez, 2009; Ripe sense company). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

aldehydes, alcohols, esters, and ketones. Aldehyde-sensitive colorimetric sensors have been developed using pH indicators that are good alternative material for on-packaging colorimetric indicators with regards to sensitivity, ease of preparation and cost. Kim et al. (2018) developed an on-packaging Methyl Red-based colorimetric indicator for detecting the aldehyde emission of apples. The system was relied on the change in basicity caused by the nucleophilic addition reaction between hydroxide and aldehyde through the Cannizzaro reaction (Fig. 9). The fabricated colorimetric sensors were attached onto the surface of the samples and were stored at ambient temperature of 18 °C. The colorimetric sensor responded to acetaldehyde (CH_3CHO), selectively. While, it did not respond to acetone, water and alcohol due to the absence of reactive site with an OH^-.

The aqueous hydroxide is a key factor in stability to humidity, selectivity, and controllable sensitivity of the sensor. The ripeness sensor was designed to operate in unsealed systems. So, color-change reversibility is an important issue due to evaporation of carboxyl acid formed on the surface of the sensor and the pressure dependency of acid dissociation constant. The usability of the sensor for different types of apple varieties is also a challenge.

2.2. Biological sensors (Biosensors)

Sensors are considered as the most promising technology for the development and improvement of future IP systems. Generally, sensors consist of three functional sections, the sensing part followed by the signal conditioning part (signal processing) and finally, interface part which displays the measured properties. The first part senses the physical or the chemical properties and commonly converts it to an electric signal. Signal conditioning unit processes the generated signal. In this unit, the signal amplifies, linearizes and scales. The final part can be in the form of an adapter, a simple mechanical connector, a wireless sensor and etc. In most cases, electronic tools are used in the last two parts (Korhonen & Ahola, 2018). For example, in the chemical sensors, the sensing part usually covered with a chemical layer. When on this layer a chemical change occurs due to dissolution with a substance or other agent, change in the properties of the sensing part happens. In other words, with a change in the pH, the signal processing part receives energy changes from the sensing part and turns it into a useful electric signal. Then, the last part displays these changes (Demas, DeGraff, & Coleman, 1999). The biological sensor was defined by Fracchiolla, Artuso, and Cortelezzi (2013) as follow: "Biosensors are devices that are capable of detecting specific biological analyses and converting their presence or concentration into some electrical, thermal, optical or other signals that can be easily analyzed". The main difference between chemical sensors and biological sensors lies in the first part or in the identification layer. The sensing part in the chemical sensor consists of chemical components. Whilst, this part in the biosensor is composed of

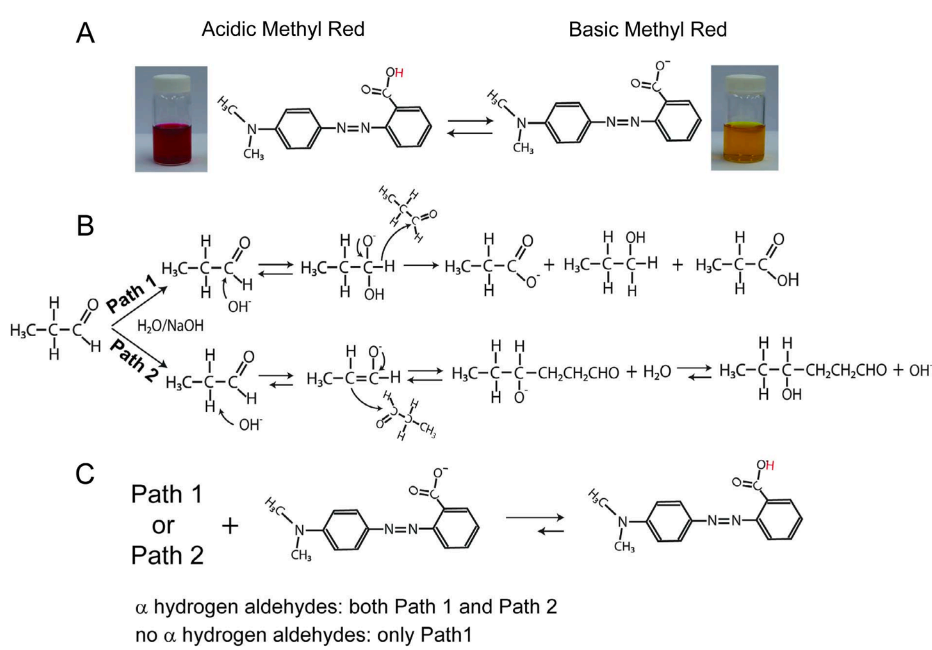


Fig. 9. The theory of the developed colorimetric sensor for aldehyde detection proposed by Kim et al. (2018); (A) The chemical structure of Methyl Red. (B) Chemical reactions with aldehyde and concentrated OH^-. (C) Proposed reaction mechanism between aldehyde and the sensor. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

biological materials called bioreceptor such as antibodies, enzymes, deoxyribonucleic acid (DNA) or cells. A typical biosensor consists of three basic components; bioreceptor, transducer and electronic system (Alocilja & Radke, 2003). Biosensors can be categorized based on the kind of transducer to four classes: optical biosensors (fluorescent, colorimetric, interferometric and luminescent), mass-based biosensors (acoustic wave and piezoelectric), calorimetric biosensors, and electrochemical biosensors (potentiometric, amperometric and conductometric) (Fracchiolla et al., 2013). A specific substance in a biological analyte (named bio-samples) is determined by a special bioreceptor and as a result, a signal is generated. All kinds of transducers are used to convert the signal into measurable responses. In the electronic part, the measured signal is amplified and processed to display the result. The working principle and components of a typical biological sensor is illustrated in Fig. 10.

A sensor that measures a change in the environment should mediate a reversible reaction so that it can continuously monitor changes, especially when it is deployed at a remote location. While the developed biosensor should be economical, price is always an important factor. The precise biosensors however accurately measure the corresponding factors, but their expensive manufacturing process would lead to a decrease their competitiveness in the market that would not be viable, commercially. Nontoxicity of the constituent materials is another factor that should be considered in manufacturing biosensors. So, integration of materials in food biosensors should be done with full consideration of safety regulations because of the migration potential and contact with food. (Mustafa & Andreescu, 2018). Some biosensors must be in contact with the whole surface of the product to detect spoilage point, otherwise, they would make an error. Electrochemical biosensor is one of the most promising tools for continuously quality monitoring of food in IP that can produce an electrical signal proportional to the analyte concentration (Park, Kim, Lee, & Jang, 2015). The use of enzymes is the most simplistic approach among the different types of electrochemical biosensors. The enzymes-based sensors are inexpensive, small in size and easy to use. They do not need additional instrumentation and so can be adapted to packaging mediums, easily (Ronkainen, Halsall, & Heineman, 2010). This type of biosensors is selective and highly specific to the substrate, due to the innate nature of the enzymes so that pretreatment and separation steps are not necessary. Most of the biosensors cannot display the full history of freshness and quality factors, but can only show the current status (Park et al., 2015). In most cases, the food sample must be destructively treated to make an appropriate condition for the sample to be suitable for biosensor-based measurements. Such biosensors are not commercially suitable for IP that aim to nondestructively exhibit real-time quality changes in the packaged food. However, the demands of packaged foods with a high safety grade, have prompted many researchers and companies to develop biosensors in the IP sector, in recent years. Nevertheless, current applications of biosensor systems in IP are limited to a few cases and require further research to integrate them in food packaging. The possible hazardous effects of the used biological components in structure of biosensors on the packaged food is a fundamental issue that needs special attention (Vanderroost, Ragaert, Devlieghere, & De Meulenaer, 2014). The main challenges in applying biosensors in IP are the difficulty to directly measure degradation markers in closed packaging without prior treatment of food sample and the complexity of food structures. The volatile compounds detection including ethylene (Esser, Schnorr, & Swager, 2012; Vong et al., 2019; Weber, Luzi, Karlsson, & Fussenegger, 2009), volatile alcohols (Bekmezci et al., 2020; Schlangen, Hämmerle, & Moos, 2012) and amines (Verma, Hooda, Gahlaut, Gothwal, & Hooda, 2020) are the most successful examples of applying biosensors in IP. Biosensors have also recently been developed for detection of food contamination such as pathogens and toxins (Gaudin, 2019; Sabet, Hosseini, Khabbaz, Dadmehr, & Ganjali, 2017; Singh, Poshtiban, & Evoy, 2013; Younis, Wang, Younis, & Xia, 2020). In the biosensing-based methods, more research is needed to miniaturize the sensor and to simplify detecting systems to avoid the use of reagents and multiple steps. Validation of the biosensing systems on large amounts of food samples should be implemented before any commercialization of the biosensors. Stabilization of the biological elements especially for the biosensing systems that incorporate sensitive enzymes and antibodies is a critical issue to ensure that the biosensor has a long operability time to be appropriate for the stored packaged food. The biosensors are in the initial design/proof of concept stage and significant efforts must be considered to further develop them into the marketable products to meet health concerns and regulations. (Mustafa & Andreescu, 2018).

2.3. Humidity indicator/sensor

Generally, humidity sensors are manufactured by using electronic hygrometers based on the measurement of capacitive and/or resistance parameters that changes as a function of humidity. Wheat gluten is recently used for monitoring of relative humidity in the packed food products. Bibi, Guillaume, Vena, Gontard, and Sorli (2016) studied on the thin wheat gluten protein film as a relative humidity monitoring polymer deposited on the interdigital capacitor (IDC) systems. They characterized ability of wheat gluten to interact with water molecules and examined its electrical and dielectric properties with the IDC method. They found when relative humidity increased, the dielectric permittivity and loss also increased indicating that dielectric

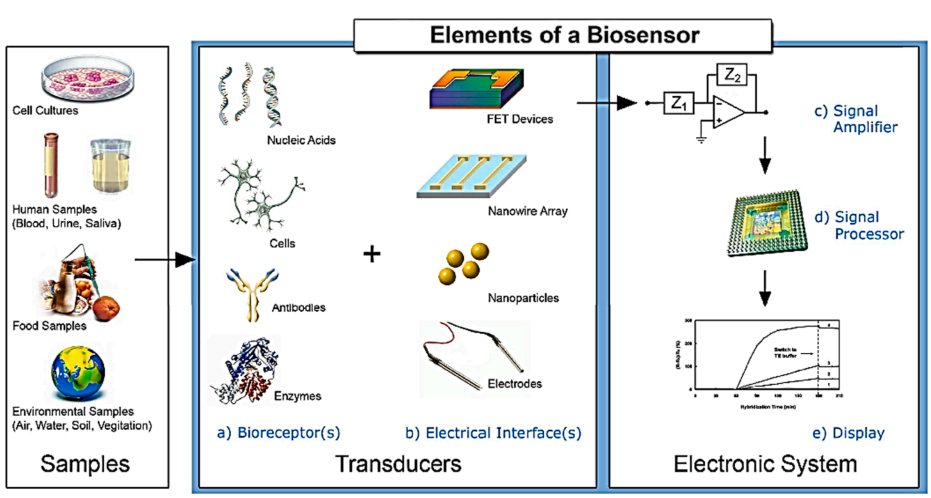


Fig. 10. Working principle and components of a typical biological sensor (Grieshaber, MacKenzie, Vörös, & Reimhult, 2008).

permittivity and loss of the developed system were sensitive to relative humidity. By observing the dependence of both dielectric permittivity and dielectric loss of wheat gluten on relative humidity, they confirmed the possibility of applying this protein for monitoring relative humidity in the headspace of packaged foods. The developed relative humidity sensor has a potential to be coupled with RFID systems for traceability and monitoring of the packaged products.

The colorimetric humidity indicators are mostly based on the inorganic salts. Cobalt (II) chloride is commonly used in the structure of such indicators, but it is inappropriate for such purposes that irreversibility is required, toxicity is a serious concern that needs to be addressed (Lauwerys & Lison, 1994). Other metal chloride-based humidity indicators have been developed and produced; however, they are more expensive than cobalt (II) chloride and are somewhat toxic. Environmental pollution is also a concern for these sensors when disposing of (Bridgeman, Corral, Quach, Xian, & Forzani, 2014). Due to these reasons, researchers are focusing on cobalt chloride-free humidity indicators to safely use them in food packaging systems. For example, Bridgeman et al. (2014) developed a humidity indicator using supported ionic-liquid membrane (SILM)-inspired methodologies, by coating a liquid composite material (consisted of sodium borohydride, sodium hydroxide, water, Denimblu30, and ethanol) onto a hygroscopic, porous substrate (GENETIX polypropylene 384-well plates and silica gel with gypsum). The liquid composite material responded to the relative humidity changes and DenimBlu30 converted the chemical changes into a visual change from yellow to blue. They found that the developed indicator could irreversibly detect relative humidity in the range of 5–100% that made it suitable for food packaging applications. However, the developed indicator is much safer than cobalt (II) chloride-based sensors, but it still is composed of the components having a low level of toxicity.

2.4. Barcoding technique

The barcoding technique or automatic identification (Auto-ID) technique was invented in the seventh decade of the last century to help the large retail and the grocery stores to manage their goods. The barcode is placed on products in characters and numbers forms. The data stored in barcodes are read by the optical barcode scanner and then it is sent to a central system. Today, the barcode technique is very common because it is very simple and it has very little cost. Conventional barcodes (one-dimensional) are ordinarily created as wide or narrow black color vertical bars printed on white color background. The distance between those bars is also either wide or narrow. Barcodes are measured by recording the width of lines by mile. The blank distance to the right and the left of the barcode character, are also measured to ensure the authenticity of the barcode reading. One-dimensional format of universal product code (UPC), European article numbering (EAN), code 128, and code 39 are very famous on all supermarket products (American barcode and RFID report). One-dimensional food barcodes usually consist of 13 digits. The first three numbers represent the country in which the barcode was made (Manthou & Vlachopoulou, 2001). The information stored on this barcode is only about 2953 bytes or 10–13 characters. The need to store more information on the barcode led to the emergence of a two-dimensional barcode format (Hadjila, Merzougui, & Hadj Irid, 2018). In 1988, Intermec company (Everett, Washington, USA) introduced the first format of two-dimensional barcode. The structure of this code consists of squares collection in white and black color. Two-dimensional code can store about 4296 alphanumeric characters and 7089 numeric characters. Today, the format of QR code, Data Matrix and PDF 417 are the most utilized popular 2-dimensional codes. In 2006, Content idea of Asia company (Kuwana-shi, Mie-ken, Japan) introduced a three-dimensional code called PM code. Actually, it is a colorful QR code, which its third dimension is color. Some models of common barcodes are illustrated in Fig. 11.

Fig. 11. Some models of common barcodes. All codes were generated by authors, https://barcode.tec-it.com/en.

Chen et al. (2017) proposed to incorporate colorimetric dye sensing arrays into the QR code to simultaneously obtain food UPC code and quality condition, (Fig. 12). Applying colorimetric dyes in the structure of the QR code would be useful for tracking and qualifying of food. Smartphones and developing mobile applications would be beneficial for consumers to determine the quality, freshness level or spoilage of the food. Combining machine learning methods with image processing technique would provide accurate assessment of food. However, they did not implement the proposed system on a mobile application. They only made a polymer mold with circle, square and triangle grooves, theses shapes were selected as a geometric substitute for QR code to show the system's capability to pattern complex geometry. Three types of dye-contained micro-beads were drop-casted on to the patterns of the stamp using a micro-pipette. Finally, the micro-beads-attached tape was attached to filter paper (as protective covering and a barrier). However, the use of this technology is difficult for some consumers, which creates a doubt about its popularity.

2.5. Radio frequency identification system (RFID)

RFID technology presents an advanced data carrier system which has the capability of data storage up to 1 MB, non-contact and non-line-of-sight ability to collect real time data. RFID tags in comparison with barcodes, are more expensive and need a more powerful electronic information network. Traceability and promotion of quality and safety are some advantages of RFID. However, the barcodes are inexpensive than the RFIDs, but they need a clear line of sight between the barcode reader and the barcode tag. In comparison to barcodes, the operation range of RFID is larger. Also, readers can communicate with multiple RFID tags, simultaneously. Automation of product handle from warehouses to retail markets can be facilitated by the RFID technology. The RFID system uses electronic and electromagnetic signals to remotely read and write data (Wilkins, 2017). The frequency ranges that are used by RFID technology are low frequency in the range of 9–135 kHz, high frequency in the range of 13.553–15.567 MHz, amateur radio band in the range of 430–440 MHz, ultra-high frequency in the range of 860–930 MHz, and microwave frequency in the range of 2.45 and 5.8 GHz (Brown, 2007). The RFID systems with operating frequencies of 100 kHz- 30 MHz use magnetic induction for communicating. While, the RFID systems with microwave frequencies (2.45 and 5.8 GHz) work using electromagnetic wave capture (Finkenzeller, 2010). The RFID technology can be applied in the food industry in the fields of supply chain management,

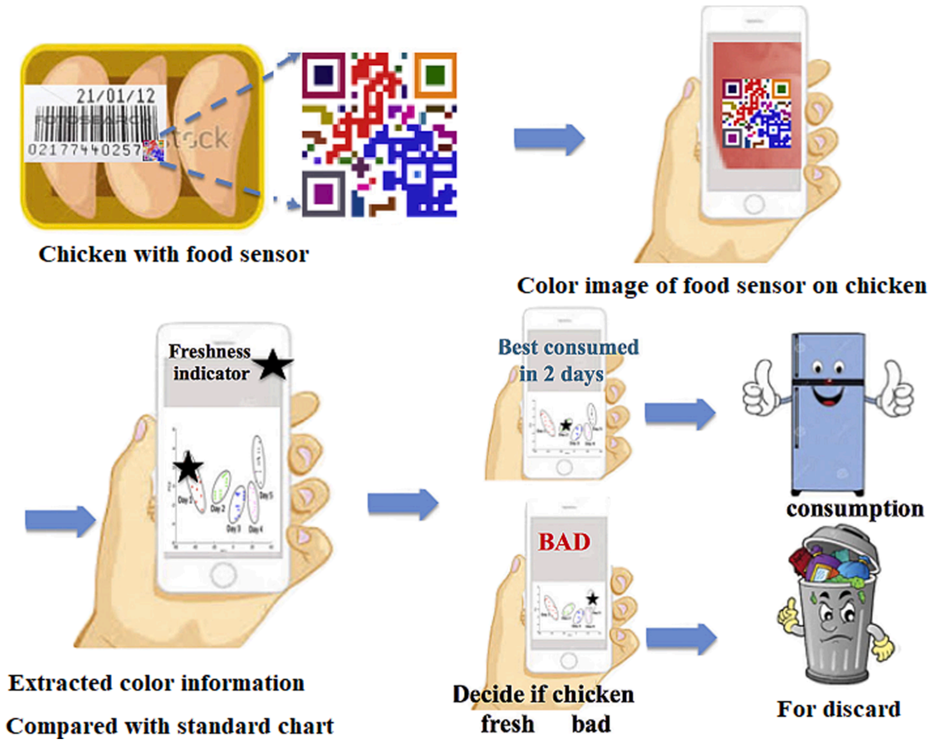


Fig. 12. Schematic of the proposed device application by Chen et al. (2017) as a food qualifying system.

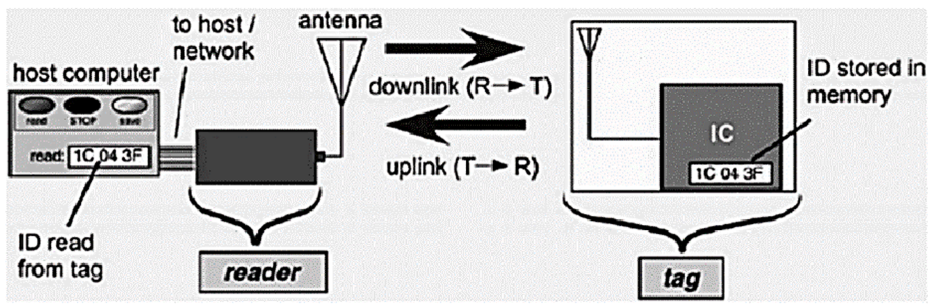
monitoring conditions of foods, and ensuring food safety. The small dimensions of these tags can be considered as an advantage, because they occupy very little space of food packaging's headspace. The smallest tags available commercially have surface of 0.4 × 0.4 mm^2 and are thinner than a paper sheet (Kumar, Reinitz, Simunovic, Sandeep, & Franzon, 2009).

The RFID tags are produced in three different modes; active, passive and semi-passive ones. The active tags are equipped with battery, they have longer range of operation and higher operating frequency. The drawbacks of these tags are; high price of 20 $ to 100$, large size due to battery, and short life of the batteries. The operating frequencies of active tags are 433 MHz, 2.45 GHz or 5.8 GHz and their operating distance is 20–100 m. The passive tags operate without power source. The signal received from the reader is used as a derive power. So, the reader must send a strong signal and the tag must transmit a weak signal to the reader. They transmit only when they are in the field of the reader. These tags are cheaper (10 cents), smaller and have a much longer operational life than active ones. The passive tags are used in supply chain for tracking different items. However, the passive tags are more expensive than a barcode label with 1 cent. The communicating distance of passive tags is in the range of few centimeters to 10 m. Semi-passive tags transmit the signal using same as passive ones, but they only use power of battery for running the circuit of its microchip. From another perspective, the RFID tags are categorized as read-only, write-once read-many (WORM), electronically erasable programmable read-only memory (EEPROM), and read-write tags based on their read–write capabilities (Brown, 2007; Kumar et al., 2009). Constantly, an RFID system consists of two basic ingredients; the transponder (tag or contactless card) and the reader, the reader, which rely on the type of technology used, perhaps a write and read device or just a read device (Finkenzeller, 2010). In food industry and retail sector applications, a simple device (RFID tag or RFID label) is attached to the food product. This device communicates with the RFID reader using wireless signals. The information from various tags located nearby can be received by the reader. In more detail, a query signal generated by the reader is radiated by its antenna to the surrounding area. This signal hits the tag that contains another antenna connected to a special electronic circuit, which contains the information about the product in a special memory. As an answer to the reader signal, the tag produces a response signal containing the product information, which is sent back and received by the reader. For processing and sharing the data radiated between the reader and the tag (Fig. 13a), the reader is generally connected to a host computer, a computer network or a microcontroller. A typical RFID system is illustrated in Fig. 13b (Zuffanelli, 2017)

Sen, Hyun, Kim, Shin, and Eom (2013) developed a system to detect and show the quality and freshness of meat using RFID technology. This system was composed of RFID tag, gas sensor, temperature sensor, reader and server. The system was able to classify meat quality into four categories (great, medium, low and corrupt). In that research, they used an intelligent tag that contains an antenna, battery, and processor. The processor converts the collected data from the sensor to digital data. They used MQ136 gas sensor which has a high sensitivity to hydrogen sulfide (H_2S). In that experiment, the concentration of H_2S released from meat was measured at different temperatures and its relationship with meat corruption was obtained. Accordingly, H_2S concentration is received by the reader and by sending this data to the screen, the consumer or the seller can be directly understood the degree of the meat quality, then decides to buy or not. In general, the MQ sensors are slow and their response time is long. In addition, they require an electronic system to derive and collect data, and their large size is a challenge that should be addressed, when to be placed in the headspace of the food packaging.

Some manufacturers in the packaging industry have integrated the RFID systems into the food box. Mondi plus is the name of an intelligent box containing the RFID tag on its surface that tracks the box throughout the production chain (Writer, 2010). In addition, NXP semiconductors company (Eindhoven, Netherlands) developed a system of wireless sensors based on the RFID technology for monitoring the packaged food products. In this system, environmental parameters such as O_2, CO_2 and C_2H_4 inside packaged fruit and vegetables are measured and the recorded information is sent to the central system (Vanderroost et al., 2014). Todorovic, Neag, and Lazarevic (2014) presented an idea to show the

(a)



(b)

Fig. 13. RFID system parts (Zuffanelli, 2017).

status of the content of a sealed container prepared for export without opening it. Their study was to utilize the RFID technology coupling with integrated sensors for tracking and monitoring of shipped perishable products. Grunow and Piramuthu (2013) studied and modeled usefulness of the RFID systems in a highly perishable product from different opinions including the distributor, retailer, and consumer. In their study, they focused on the expiry date and residual shelf-life of the product. Alfian et al. (2020) proposed a RFID-based traceability system equipped with IoT sensors to monitor and acquire environmental conditions such as temperature and humidity for perishable food distribution during transportation and storage, which was able to address counterfeiting and low-quality food product throughout the supply chain. They improved the efficiency of the RFID-based traceability by developing a machine learning model into RFID gate to automatically identify the direction of tagged products.

The main technical challenge of RFID technology is unreliability in retail markets. Due to the interference from the high-water content of human's body, it is very difficult to read ultra-high frequency tags near customers (Roberts, 2006). Reading the tags installed on the food materials with large amount of liquid or packaged in metal containers is not easily possible, metals reflect the signals. The lack of global standardized frequency prevents applying the RFID technology for various applications. The RFID tags are much more expensive than to the barcode labels, this issue makes that implementation of this technology would be uneconomical in many retail items. With the emersion of new manufacturing technologies in future, the final cost of tags would be reduced which helps widespread adoption of RFID technology (Roberts, 2006). Recycling and environmental pollution problems and security concerns are other challenges in implementation of this technology. For example, private information theft such as details of inventory and shipments may be happened by an unauthorized operator by scanning tags to access.

In summary, the interest in developing innovative packaging systems due to the safety and quality concerns along the food supply chain has accelerated researches on the IP systems and the commercialization of such innovations. Compared to traditional methods, IP has the ability to provide safer and higher quality food products to consumers. Applying the IP systems such as TTIs, RFID tags, gas indicators, etc. can provide solutions to the food producers to protect food products in more convenient and secure manners. Nevertheless, the prices of the commercialized TTIs are relatively expensive. The accuracy of TTIs is another problem that needs more research to solve. The TTIs containing organic or inorganic materials as well as biosensors may raise toxicity concerns due to the migration into food. For this reason, the toxicological studies should be established for such systems to reduce safety concerns of consumers. The main problem affecting the performance of the freshness indicators is reacting to unrelated metabolites. The biosensors are novel concepts that were recently introduced in IP and further studies should be considered to overcome the challenges in commercialization. The RFID systems are also expensive making this technology uneconomical for many food products. Increasing the security of these systems against data theft and counterfeiting is also essential. Further studies on the IP developments will lead to further improvement of the existing food packaging technologies and introducing new and safe mass production methods of the IP systems, will allay concerns about the widespread use of IP in the food industry.

3. Active packaging technology

Active packaging (AP) is defined as "packaging in which subsidiary constituents have been deliberately included in or on either the packaging material or the package headspace to enhance the performance of the package system" (Janjarasskul & Suppakul, 2018; Robertson, 2012). The major AP systems are oxygen scavengers, ethylene absorbers, carbon dioxide absorbers/emitters, flavor releasing/absorbing systems, antioxidants, antimicrobials and moisture controllers. Moisture can affectively change the quality of food materials by changing the texture, appearance and microbial activity. Scavengers (gas absorbers (and diffusion systems (emitters) which contain preservatives, flavors, antimicrobials and so on, are among the widest technologies applied currently in the AP sector. Recently, essential oils were incorporated into edible films to introduce active edible films which have antimicrobial and antioxidant properties (Al-Hashimi, Ammar, Lakshmanan, Cacciola, & Lakhssassi, 2020; Cai, Wang, & Cao, 2020; Li, Pei, Xiong, & Xue, 2020; Venkatachalam & Lekjing, 2020). Recent researches carried out in the field of AP are summarized in Table 2.

Table 2
List of recent works on AP systems conducted for food applications.

Objectives/Applications	Active materials	Reference
A multilayer film based on PET films combined with chitosan and alginate layers was fabricated and its performance on the shelf-life extension and the quality of chicken breast meat was evaluated.	Black cumin oil	Konuk Takma and Korel (2019)
The different properties including the release rate of active antimicrobial agents from a developed active packaging film were studied and its performance on extending the shelf life of beef was investigated.	Bioactive compounds encapsulated in β-cyclodextrin inclusion complex of citral (β-CD-CI) and *trans*-cinnamaldehyde (β-CD-TC)	Chen, Li, Ma, Mcdonald, and Wang (2019)
Active polypropylene-based packaging films for food applications were prepared and its antibacterial and antifungal effects were studied.	Sorbic acid	Fasihnia, Peighambardoust, Peighambardoust, and Oromiehie (2018)
Edible chitosan-based antioxidative and antimicrobial films with improved specifications were produced to be applied as alternative food packaging material.	Methanol extracts gained from pistacia terebinthus plant	Kaya et al. (2018)
Active packages consist of CO_2 and moisture absorbing pad were designed and their effectiveness in quality preservation of shiitake mushrooms was tested.	Sodium carbonate, calcium hydroxide, super absorbent polymer, and polyacrylate	Wang, An, Rhim, and Lee (2017)
High-quality polymer nanocomposites including a synergistic antimicrobial composition as an AP films were generated and their effect on *Escherichia coli* growth in inoculated hummus was demonstrated.	Carvacrol and thymol	Krepker et al. (2017)
The effect of O_2 scavenger and antimicrobial film in extending the shelf life of fish steaks stored in plastic pouches were investigated.	Ginger essential oil	Remya, Mohan, Venkateshwarlu, Sivaraman, and Ravishankar (2017)
Different packaging methods including rosemary-based AP, oxygen scavenger packaging, and vacuum packaging were applied and their effects on reducing the lipid oxidation in pork patties stored after high pressure processing were compared.	Rosemary extract and carnosic acid	Bolumar, LaPeña, Skibsted, and Orlien (2016)
Active antimicrobial packaging films based on polyamide 6 for various fresh produce (cherry tomato, lychee and grape) were developed and their antifungal efficacy against a wide range of fungal molds (i.e. A. alternata, B. cinerea, P. digitatum, P. expansum and A. niger) were studied.	Carvacrol	Shemesh, Krepker, Nitzan, Vaxman, and Segal (2016)
The impact of different initial oxygen concentrations (1% and 3%) in oxygen scavengers integrated into a PET matrix on methionol oxidation in wine solutions was evaluated.	Oxygen scavengers incorporated in a PET matrix named 1osPET and 3osPET	Dombre, Guillard, and Chalier (2015)
Different AP systems including various packaging films (clear PVC box and stretch PVC) and four levels of moisture absorber at different storage time levels were investigated to determine their effects on the quality properties of button mushroom	Silica gel and spongy foam	Karimi and Mosharraf (2015)
Different AP systems including various packaging films (stretch polyvinyl chloride and biaxially oriented polypropylene) and four levels of moisture absorber were investigated to determine their effects on optimum shelf life condition of button mushroom	Silica gel, sodium chloride and foam	Karimi, Mosharraf, and Ghazvini (2014)
Active starch-clay nanocomposite films were prepared and their physical and mechanical properties were evaluated along with study their performance against Aspergillus Niger which is one of the important fungi caused the spoilage of bread.	Cinnamon oil and potassium sorbate	Barzegar, Azizi, Barzegar, and Hamidi (2013)
Antimicrobial AP films consisting of polypropylene thylene-vinyl alcohol copolymer bags were developed and their antimicrobial properties in the packaging of salad were studied.	Oregano essential oil and citral ($C_{10}H_{16}O$).	Muriel-Galet et al. (2012)
Plum seed protein isolate and gum acacia conjugates (through Maillard reaction) as well as encapsulation of grapefruit essential oil were applied to prepare emulsion-based antibacterial edible films. The mechanical properties, water vapor barrier property, surface hydrophobicity, thermal stability and inhibitory effect against *E. coli* of the films were studied.	Grapefruit Essential Oil	Li et al. (2020)

(continued on next page)

Table 2 (*continued*)

Objectives/Applications	Active materials	Reference
The active LDPE films were fabricated using both the essential oils and the vegetable oils. The heat-sealing attributes, antioxidant capacity and aroma of the fabricated active films were investigated.	Avocado pulp virgin oil, milk thistle seed organic extra virgin oil, grape seed organic extra virgin oil, pomegranate seed organic extra virgin oil, starflower seed organic extra virgin oil, flaxseed organic extra virgin oil, rose (Rosa eglanteria) seed essential oil and ginger root essential oil.	Wrona et al. (2021)

AP, Active Packaging; PET, Polyethylene Terephthalate; PVC, Polyvinyl Chloride; LDPE, Low Density Polyethylene.

In developing and manufacturing active systems, the requirements and standards of different regulatory agencies for instance the European Food Safety Authority (European Union), Food and Drug Administration (USA) must be followed that set the legal basis for their accurate use, safety and marketing (Restuccia et al., 2010). The most AP types commercially available are listed in Table 3.

3.1. Scavengers

3.1.1. Ethylene scavenger

Ethylene significantly effects on physiological properties, growth, ripening and senescence of fruits and vegetables (Gaikwad, Singh, & Negi, 2020). Increasing in production rate of C_2H_4 during ripening stage specially in the packed crops would lead to senescence. In this case, C_2H_4 gas has a negative impact on the marketing of the product (Mansourbahmani, Ghareyazie, Zarinnia, Kalatejari, & Mohammadi, 2018). To control the C_2H_4 gas in the package and extend the shelf-life of product, C_2H_4 scavengers were developed which absorb ethylene produced by the fresh produce. The double bond that exists in the molecular structure of ethylene, gives it a high level of reactivity which provides many opportunities for commercial methodologies to eliminate this hormone.

Table 3
Some AP techniques available commercially (Bolumar et al., 2016; COMA, 2008; Fang et al., 2017; Realini & Marcos, 2014; Sung et al., 2013).

Commercial name	Characterization	Manufactured state
Moisture Absorbers		
Nor®Absorbit	Microwavable film	Germany
Fresh-R-Pax®	Absorbent tray	USA
MeatGuard	Absorbent pad	USA
MoistCatch	Absorbent pad	Japan
Oxygen scavengers		
Ageless®	sachet	USA
ATCO®	Label	France
OxyCatch®	Sachet	Japan
Cryovac® OS2000	Film	USA
Freshcare®	sachet	Japan
OMAC®	Film suitable for high temperature	Japan
Carbon dioxide emitters		
UltraZap® Xtenda Pak pads	CO_2 emitter and antimicrobial pad	USA
CO_2® Fresh Pads	CO_2 emitter pad	USA
Antimicrobial AP		
Wasapower™	Coated PET film and tablets	Japan
Zeomic™	Films	Japan
WasaOuro	Sheets	Japan
Uvasy™	Laminated sheets and pads	South Africa
Microgarde™	Sachets, films, wraps	USA
Bactiblock®	Masterbatch	Spain
Bioka	Sachets	Finland

Potassium permanganate ($KMnO_4$) based ethylene scavenging systems are the most, commonly used that scavenges C_2H_4 by the oxidation process. In some scavenging systems, immobilized potassium permanganate ($KMnO_4$) on alumina or silica gel is used. Alumina acts as an absorptive surface and traps the ethylene molecules and is also as a carrier of permanganate. As can be seen in Fig. 14, $KMnO_4$ oxidizes ethylene (C_2H_4) to carbon dioxide (CO_2) and water (H_2O), releasing manganese dioxide (MnO_2) and potassium hydroxide (KOH) (Álvarez-Hernández et al., 2018). In the research of Gaikwad et al. (2020) the list of commercially available ethylene scavengers can be found that have been developed for packaging of fresh products.

Clays, zeolites, vermiculite, silica gel and activated carbon are also used as the porous inert materials with a high surface area for ethylene adsorption (Pathak et al., 2017). Ethylene scavenging systems are developed in the form of sachet containing the scavenger materials in the headspace of packaging. The ethylene scavenger materials can also be incorporated in construction of packaging film and containers. The ethylene scavenging materials classified by Gaikwad et al. (2020) are presented in Table 4. Recently, the demands have progressively increased for novel ethylene scavenging materials to use in construction of plastic film for packaging fresh products.

The ethylene scavenger based on zeolite is a worthy one that can be used as scavenging agent integrated into polymers for industrially producing packaging film due to its three-dimensional structure with a porosity and adsorption properties. Halloysite nanotubes are appropriate materials to use in food packaging applications, due to safety, ability to integrate in polymers as a nanocomposite material and encapsulation capability. Activated carbons are prepared in the forms of powder, granular and fiber ones. However, the granular activated carbon-based scavengers are preferred due to its versatility and easier regeneration. Martínez-Romero et al. (2007) have conducted a comparative study about the ethylene adsorption capacity of the activated carbons and reported that the best was the granular form (over 80%) followed by power (over 70%) and fiber activated carbon (over 40%). Palladium in integration with activated carbon is highly efficient in adsorbing ethylene in modified atmosphere packaging (MAP) system (Martínez-Romero et al., 2007). Palladium and Titanium dioxide (TiO_2) are the most used catalysts fixed on the activated carbons. Nanotitanium dioxide-based photocatalytic system is a good solution to eliminate ethylene gaseous. At the surface of the catalyst, UV illumination

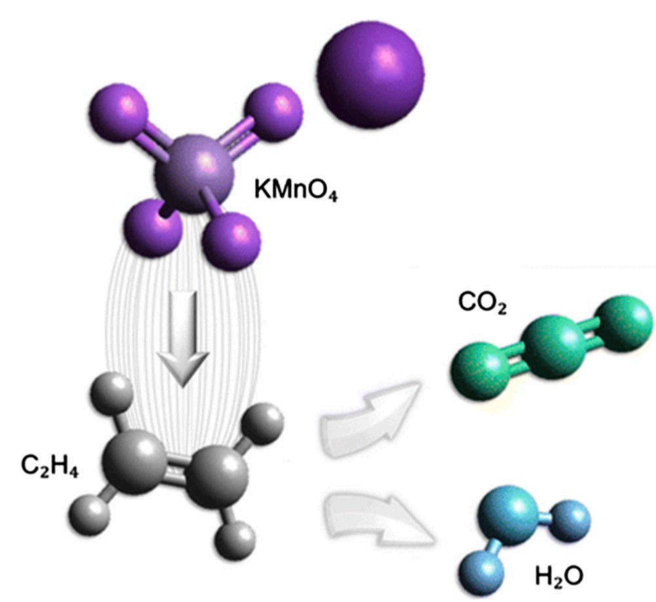


Fig. 14. Ethylene oxidation reaction by $KMnO_4$ adopted by Álvarez-Hernández et al. (2018).

Table 4
Some scavenging materials used for food packaging applications (Gaikwad et al., 2020).

Type	Ethylene scavenging materials
Natural clays	Zeolite, halloysite nanotube, Japanese Oya stone, cristobalite, bentonite, coral, ceramics
Regenerable sorbents	Propylene glycol, hexylene glycol, squalene, phenymethylsilicone, polyethylene, polystyrene
Catalytic oxidizers	Potassium permanganate, potassium dichromate, iodine pentoxide and silver nitrate, palladium
Electron-deficient dienes or trienes	Benzene, pyridines, diazines triazines, tetrazines (Having electron-withdrawing substitutes)
Other	Activated charcoal, crystalline aluminosilicates, kieselguhr, silica gel, aluminium oxide

generates reactive oxygen species, which further oxidize ethylene into water and carbon dioxide (Gaikwad et al., 2020). In the selection of ethylene scavenging materials, capacity, stability, safety and price should be considered for fresh products packaging systems. Some applications of ethylene scavengers for fresh products packaging were extensively presented by Gaikwad et al. (2020). There are concerns including the migration of packaging material to the food product, tearing of sachet and removal or leakage of scavenging materials from the sachet and subsequently contamination of food. Consumer acceptance, environmental safety concerns and marketability are other issues that challenge the use of these systems. In applying innovative packaging systems in the fresh produce industry, appropriate cost–benefit consideration is of particular importance (Gaikwad, Singh, & Lee, 2018). More research is needed to address the mentioned concerns and issues in the field of ethylene scavenging packaging materials to represent a lower final cost and safe packaging systems without affecting enhancements in food shelf life.

3.1.2. Oxygen scavenger

The presence of O_2 in food packages accelerates products spoilage, oxidation of fats and vitamins of food by promoting the growth of microorganisms like moulds, aerobic bacteria and yeasts. Its effects on food appear as a bad aroma, unpleasant taste, color changes and nutrient damage. To solve this problem, the O_2 scavenges were expanded. Although, vacuum packaging and MAP can reduce the oxygen level in the headspace of the packages up to 0.5–2% v/v, this range of oxygen level may be destructive (Gibis & Rieblinger, 2011). While, oxygen scavengers have a proper ability to reduce oxygen level to less than 0.1% v/v which leads to more acceptable shelf life extension (Mills, Doyle, Peiro, & Durrant, 2006). But in another study, Marangoni Júnior, Ito, Ribeiro, Silva, and Alves (2018) used different MA packaging systems including BOPP (biaxially oriented polypropylene)/metBOPP (metallized biaxially oriented polypropylene) with nitrogen and with and without an oxygen scavenger on the sweet potato chips and reported that the MAP system with oxygen scavenger presented a higher O_2 content in the period of storage as a result of the small fault found in the hermetic seal. This type of failure is a critical point because, through this small hole in the package, the O_2 content of the head space can increase as a result of enhancing oxygen transmission rate by the oxygen absorber.

The main oxygen scavenging systems are based iron, platinum and palladium metals, unsaturated hydrocarbon, tocopherol, ascorbic acid, enzyme and microorganisms-based scavengers. Nano-iron can be used both in hydrous or anhydrous environment and reduces oxygen level to 9.45% v/v. The roll of palladium is as a catalyst which produces water from oxygen in presence of hydrogen representing high scavenging rate. This system must be used in a modified atmosphere environment with the presence of hydrogen (Dey & Neogi, 2019). An oxygen scavenging film based on a catalytic system with palladium (CSP) has recently been developed by Yildirim, Röcker, Rüegg, and Lohwasser (2015) to reduce the residual oxygen in the headspace to $<0.01\%$ v/v. Faas, Röcker, Smrke, Yeretzian, and Yildirim (2020) developed a palladium-based oxygen scavenging film to prevent oxidation of lipid in linseed oil. They found the developed scavenging film in combination with MAP significantly reduced lipid oxidation in linseed oil compared to the conventional MA packaging (2 vol% O_2). The important point is whether the use of this type of scavenger system is economically viable for foods that are usually not very expensive.

Unsaturated hydrocarbon scavengers are appropriate for dry foods but leads to the generation of by-products including ketones and aldehydes which probably are effective on the sensory quality of food. Tocopherol, ascorbic acid, microorganism and enzyme are other scavenging systems that have slow scavenging rates. α-tocopherol and ascorbic acid are the natural form of vitamin *E* and vitamin *C* that make these scavengers compatible for food packaging options. But, these scavengers must be triggered using UV, light and/or transition metals and recurs higher cost compared to nano-iron based systems. Enzyme based scavengers usually generate hydrogen peroxide that should be converted it into water by enzyme catalase. The main drawback of these scavengers is that they are severely prone to denaturation due to temperature changes. The scavengers based on microorganism are also labile to temperature changes. Another problem in applying this type of scavengers that they may lead to uncontrolled growth of the microorganisms that affect the sensory properties of food. A proper immobilization of the microorganisms is a good solution to prevent their migration (Dey & Neogi, 2019). One of the most important uses of O_2 scavenger is controlling mold growth. Ageless O_2 scavenger is commercially available and is commonly used for many food products to absorb the O_2 overload. Different types of ageless absorbers each created with a specific task in mind as summarized in Table 5.

3.1.3. Moisture absorber

Humidity/moisture/water is usually one of the most disturbing factors in the food industry, which can have harmful and destructive effects in all stages, including storage of raw materials and products in warehouses and during transportation. Excessive relative humidity (RH) accumulation inside the headspace of the packaged food with a high-water activity such as meat products and fresh fruits and vegetables leads to an acceleration in the growth of mold and bacteria subsequently leads to food degradation and lose in nutritional and quality factors of the food (Ščetar, Kurek, & Galić, 2010). A good solution is the use of moisture absorber inside the package to control the presence and level of water in the package. Moisture absorbers are usually manufactured in the forms of pads, sachets, films and trays and treat with moisture via physical adsorption of a moisture absorbing material. However, RH levels in the food packages are controlled by the packaging materials having a proper barrier against water vapor. Moisture absorbers in the forms of RH controllers (such as desiccants) are used to absorb humidity in the headspace of package and moisture removers (such as pads and sheets) are used to absorb exuded liquids from food products or the

Table 5
Some types of Ageless absorbers available commercially (Brody, Strupinsky, & Kline, 2001; De Fátima, 2001; Ščetar et al., 2010; Mitsubishi Gas Chemical America Company).

Type	Feature	Applications
E	O_2 and CO_2 absorbing type.	Coffee
ZPT	Standard iron type.	Wide variety like beef, baked goods, pet food, and snacks.
SS	Fast reacting type.	Baked goods, frozen food.
GT	Absorbs O_2/Discharges same amount of CO_2.	Products that are sensitive to the shrinking of a package
Z	O_2 absorbing type.	Museum applications and Wide Variety of food like bread and beef
FX	O_2 absorbing type.	Pasta
S	O_2 absorbing type.	Cakes and bakeries
G	O_2 absorbing type with CO_2 diffusion.	Nuts

condensed water due to the humidity saturation in packages (Yildirim et al., 2018).

The moisture absorbers based on organic materials have good potentials to apply in packaging systems in the form of tray and film. The use of natural moisture absorbers such as sorbitol and fructose entrapped in a polymer matrix will be the focus of future researches (Gaikwad, Singh, & Ajji, 2019). Fructose as a hygroscopic monosaccharide absorbs moisture from surrounding at about 55% RH. Sorbitol is available in the form of white powder that can be placed in sachets to use in the packaged food. Cellulose is studied as moisture absorber by various researchers for food packaging systems (Maboonchuay, Chalapat, & Siraleartmukul, 2016). The most important drawbacks of the organic materials are their higher price and lower capacity in moisture absorption compared to the absorbers made by inorganic materials which leads to making larger sachets than the traditional silica gel desiccants. More research is needed to increase absorbance efficiency and commercialization possibility and prolong stability of organic-based moisture absorbers (Gaikwad et al., 2019). Cellulose as an organic polymer and hygroscopic material is plentifully available in nature. This polymer and its derivatives are used in production of moisture absorbing film for food packaging applications (Abral et al., 2020; Ghanbarzadeh, Almasi, & Entezami, 2010; Wang et al., 2018). Cellulose absorbs moisture either on its surface or in the bulk of amorphous regions (Boruvkova & Wiener, 2011). Recently, the use of derivatives of cellulose especially sodium carboxymethylcellulose (CMC) in the AP material is getting attention due to their excellent film forming properties. CMC is a polar macromolecule compound and its degree of moisture absorption subjects to the relative humidity, and the presence of some polarity groups. The higher the number of polarity group, the degree of moisture absorbing is high. Although the moisture absorption by cellulose causes deformation of macromolecular structure and ends the advantage of the dimensional stability of cellulose, it produces a unique pathway for their use as a moisture absorbing material, which has recently been used in an increasing number of AP areas. Inorganic materials are widely used in industrially production of moisture absorbers. Calcium oxide (CaO) and silica gel are mainly used in sachets to maintain the headspace of packaging at a very low level of relative humidity. Such mineral materials including potassium chloride (KCl), potassium carbonate (K_2CO_3), calcium chloride ($CaCl_2$) and bentonite are used in food packaging applications as moisture absorbers (Yildirim et al., 2018). Moisture absorbers applied in the food packaging sector act by physical (such as silica gel) and chemical (such as calcium chloride) adsorption and decrease the relative humidity in the headspace of the package or collect exuded liquid from the bottom of the container.

Some commercial sachets developed for food applications are Desi View, Desi Pak, Sorb-It and 2-in-1 (United Desiccants, USA), MiniPax, FreshPax® StripPax, Natrasorb (Multisorb Technologies, USA), Chunwang (Shenzhen Chunwang, China), and Ageless (Swiss Pac Pvt. Ltd, India) (Gaikwad et al., 2019). The main parameters that should be studied in designing the moisture absorbing sachets are: storage temperatures, equilibrium adsorptive capacity and the permissible range of relative humidity for the packaged product to minimize the activity of microorganisms. The packaging materials for sachet should be semi-permeable to water and should have proper physicomechanical properties to be resistant to rupture and leakage of the absorbing material inside the sachet during handling and distribution. However, in some cases moisture absorbing sachets can change the sensory properties of the packaged food and it is unlikely that their absorbing ingredients would be unconsciously consumed by the customer (Gaikwad et al., 2018). Introducing new materials for manufacturing sachet bags that meet the mentioned requirements, needs further research.

The moisture absorbent pads are great options for absorbing the exuded fluids from food collected at the bottom of polymeric trays due to temperature fluctuation during transportation and storage. The exuded liquid from the packaged food adversely changes its sensorial properties and leads to microbial spoilage, proliferation of pathogens as a rich source of macronutrients including carbohydrates, fats and proteins and micronutrients including vitamins and micro minerals (De Azeredo, 2013). The powder or granular forms of the superabsorbent polymers such as graft copolymers of starch are used in the structure of pads. In some cases, the absorber pads comprise of moisture absorbent paper located in between two microporous or nonwoven polymer sheets. Depending on the salinity, the moisture absorbing polymer are able to absorb 100–500 times its weight of liquid water (Gaikwad et al., 2019). A typical application of the moisture absorbent pad in food packaging systems and its structure are presented in Fig. 15. The multipurpose water absorber pads were also introduced possessing the active functions including pH decreasing, antimicrobial properties and odor absorption (Yildirim et al., 2018). In some cases, reverse migration of exudates would happen due to the compression load generated by weight of the food. The perforation of outer layers in the structure of the pad is another limitation that should be provided in a proper distance to prevent film tearing and releasing the absorbent material (Otoni, Espitia, Avena-Bustillos, & McHugh, 2016).

Applying moisture absorbing materials in manufacturing of polymeric packaging tray is a new approach for humidity control in the headspace of the packaged food products. Fresh-R-Pax® (CSP Technologies, USA), UltraFreshSystem (Paper Pak Industries, USA) and Tenderpac® (SEALPAC, Germany) are some examples of commercialized humidity-regulating trays (Gaikwad et al., 2019).

The packaging materials possessing certain substances such as sorbitol ($C_6H_{14}O_6$), glycerin ($C_3H_8O_3$), sodium chloride (NaCl) and magnesium chloride ($MgCl_2$) have the ability to regulate the humidity in the packaged foods. These packaging materials based on the uniform dispersion of such substances in polymers, increase the shelf life of the packaged foods due to the reduction in condensed water and/or stabilization of the relative humidity inside the headspace of such packaging systems. The issue that must be considered in manufacturing of these packaging materials is that a salt solution has a higher volume compared to its dry crystal form. So, the polymeric film should have a proper porous structure to be able to store the salt solution that performs inside the film due to water vapor absorption (Sängerlaub, Lehmann, Müller, & Wani, 2020). Sängerlaub et al. (2018) found that stretching of foamed polypropylene polymer film with dispersed NaCl salt increases the porosity and the effective diffusion coefficient of the film which results in higher absorption rates of water vapor. Sängerlaub et al. (2020) investigated effect of thermoforming on the vapor sorption capacity and rate of foamed monolayer polypropylene films with dispersed NaCl. They found thermoforming increased the porosity of the packaging material from 0.28 up to 0.63. Their results proved that thermoforming is a proper method to modify the water vapor absorption rate of polypropylene film with dispersed salt for humidity regulation. They recommended further investigations on multilayer film structures having a

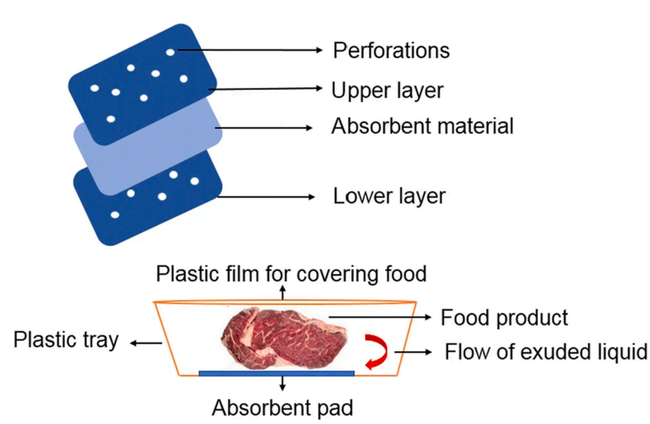


Fig. 15. The structure of the multi-layered moisture absorbent pad used in the food packaging system (Gaikwad et al., 2019; Otoni et al., 2016).

foamed polymer layer with dispersed salt. The moisture absorber salts can be incorporated into the polymeric matrix through hot melt extrusion. Although, the humidity-regulating films are successfully commercialized, but their capacity and rate of moisture absorbing are considerably lower than moisture absorbing sachets (Choi & Lee, 2013). Migration of moisture absorbing material from the film into the packaged foods is an important issue. The need for high quantities of the absorbing materials to uniformly disperse them all over the packaging films is another challenge that should be considered (Gaikwad et al., 2019). In selecting the appropriate materials among the wide range of candidate substances for moisture absorption systems, the activation mechanisms, moisture absorption capacity and safety should be taken into account. Other important and influential factors are: price, regulation and consumer acceptance.

3.2. Diffusion systems

The principle of diffusion systems or emitters is based on emitting the desired gases in to the headspace of package to positively impact on the packaged food, retard adverse processes and ensure extension of the shelf life. The most commonly used gas emitters are based on releasing ethanol (C_2H_5OH), sulfur dioxide (SO_2), and CO_2 (Wyrwa & Barska, 2017).

3.2.1. Carbon dioxide emitter

CO_2 has a positive impact on preservation of initial freshness of food produces and inhibits the formation of odor associated spoilage (Hansen, Moen, Rødbotten, Berget, & Pettersen, 2016). So, due to its useful antimicrobial properties, CO_2 is extensively applied in the food industry for shelf life extension and quality preservation. In general, high concentrations of CO_2 would be preferred for fresh meat, fish, poultry and nonclimacteric fruits to effectively reduce growth of microorganisms which increases lag phase and time during the logarithmic microorganisms phase through a complex set of mechanisms (Kuswandi, 2020), hypothetically includes an interplay between e.g. cytoplasmic pH changes, inhibition of bacterial enzymes and alteration of the bacterial cell membrane (Vilela et al., 2018; Yildirim et al., 2018). Hansen et al. (2016) used a combination of MAP technology and CO_2 emitter to increase the shelf life and preserve the quality attributes of cod loins. The emitters were prepared by adding 0.237 g citric acid and 0.304 g $NaHCO_3$ to a liquid absorber pad and then were used for both vacuum and MA packages. The applied ingredients and the absorber pad were approved for food contact. The reason for utilizing CO_2 emitter in MA packages was absorbing CO_2 gas by that the fish tissue, subsequently reducing the partial pressure of CO_2 in the headspace of the MA packages. During storage, the CO_2 emitter compensated for reduced headspace and ensured a higher partial pressure of the CO_2 gas in comparison with the packages without the CO_2 emitter. They proved that by using CO_2 emitter in the vacuum and MA packages, microbial and sensory properties of cod loins were better preserved.

Sodium bicarbonate ($NaHCO_3$) and citric are commonly used as two active materials in CO_2 releasing systems (Yildirim et al., 2018). The releasing system is triggered when comes into contact with liquid from the food product. The system acts according to Le Chatelier's principle which is based on that that when liquid is introduced into the system, the pH would drop and the production of carbon dioxide starts. Such systems are flexible to give a pH compatible with the pH of the food product, which have the capability of changing the ratio between the active materials. The capacity of such systems can be optimized according to the variable requirements of the food product including size, packaging volume, g/p ratios, gas compositions and physicochemical properties. The carbon dioxide releasing systems possessing ferrous carbonate ($FeCO_3$) are also used in AP. The solubility of $FeCO_3$ in acidic environments and subsequently CO_2 releasing is the basis of these emitters (Vilela et al., 2018).

3.2.2. Ethanol emitter

Ethanol emitters are used to release ethanol vapor into the headspace of the packaged foods to inhibit the growth of yeasts, bacteria and molds. Ethanol as an antimicrobial material reduces spoilage and prolongs the shelf-life of fruits and vegetables during handling, storage and retail. Ethanol vapor can prevent decay, prolong shelf-life and maintain the original textural quality of mango (Plotto, Bai, Narciso, Brecht, & Baldwin, 2006), sliced wheat bread (Latou, Mexis, Badeka, & Kontominas, 2010) and bayberry (Mu, Gao, Chen, Fang, & Han, 2017). However, a few commercial ethanol releasing systems are available, which are produced by the direct adsorption of ethanol on adsorbents such as silica. In these emitters, ethanol is conventionally used in liquid form having a high and uncontrolled volatilization rate. However, some other difficulties in applying ethanol emitters such as off-flavors and consumer resistance were reported. Some manufacturers including Oitech™ (Nippon Kayaku Co. Ltd), Anti-mold 102™, EthiCap™, Negamold™ (Freund Industrial Co. Ltd) and Ageless™ type SE (Mitsubishi Gas Chemical Co. Ltd) present ethanol emitting films and sachets. The packaging film should have high barrier properties to ethanol lower than 2 $g{\cdot}m^{-2}{\cdot}day$ to have its accumulation in the headspace. (Bodbodak & Rafiee, 2016).

Mu et al. (2017) developed a controlled release ethanol emitter to overcome such disadvantages of the conventional ethanol emitters. Ethanol was mixed with different concentrations of sodium stearate ($C_{18}H_{35}NaO_2$) and heated at 70 °C to obtain translucent ethanol gel product and then was added to diatomite of an equal amount to increase the mechanical strength of the gel and enhance its practical applicability. By cooling the final product, white powder ethanol emitters were produced. By increasing the sodium stearate content, the intermolecular bonding between ethanol and sodium stearate was strengthened. While by decreasing the sodium stearate content the internal liquid mobile phase increased. This is because of that the sodium stearate molecule is polar with a long carbon chain that dissolved in hot ethanol solution. So, the release rate of ethanol in the gels was controlled by the concentration of sodium stearate. Applying of the developed emitter in packaging of Chinese bayberry fruit confirmed its ability in reducing the decay rate, maintaining firmness and inhibiting increased malondialdehyde content. But more research is needed to explain the preservation mechanisms of the proposed technology and its impact on other fruits and vegetables and different environmental conditions.

3.2.3. Sulfur dioxide emitter

Addition of sulfur dioxide (SO_2) has been found to be helpful in preventing coloration during the storage period of a large number of agricultural products such as coconuts, walnuts, peppers, tomatoes, cabbage, gourd, beans, peas, potatoes, and carrots (Schroeter, 1966). In general, SO_2 emitters act according to the mechanism of metabisulfite hydrolysis and the reaction of calcium sulfite with moisture (Kuswandi, 2020). Sulfites including sulfur dioxide, sodium sulfite, sodium bisulfite, sodium metabisulfite, potassium metabisulfite and potassium sulfite can be used to inhibit the enzymatic and nonenzymatic browning during processing and storage. Codex Alimentarius classifies sulfites as one of major allergens. They act against the oxidative decay, fungi and the bacteria responsible for malo-lactic fermentation and can directly initiate polyphenol oxidase inhibition. The incorporation doses of SO_2 in foodstuffs are strictly reglemented by Codex Alimentarius and the concentration more than 10 mg L^{-1} is considered as an allergen, hence the presence of SO_2 should be marked on the label of the product (Pisoschi et al., 2020). Given the implications of its use on human health such as dermatitis, urticaria, flushing, hypotension, abdominal pain, diarrhea or anaphylactic reactions (Pisoschi et al., 2020), few researches have been published for use of sulfites in preservation and extending the shelf life of foods.

3.2.4. Antioxidant release

Antioxidants can be integrated into the polymeric packaging films or can be applied as a coating material on the surface of foods to limit oxidation of the fatty components. Gemili, Yemenicioğlu, and Altınkaya (2010) developed cellulose acetate-based films with different morphological features to control the rate of L-ascorbic acid and L-tyrosine release as natural antioxidants (Gemili et al., 2010). By increasing cellulose acetate content in the casting solution, the average pore size and porosity of the films decreased and subsequently the diffusion rates of the antioxidants reduced through the films. Butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) are also common synthetic antioxidants used in the AP sector. However, the US Department of Health and Human Services (HSS) reported that BHA is carcinogenic and should be replaced by other safe antioxidants (Kuswandi, 2020). On the other hand, consumers nowadays prefer to use the foods free of any synthetic additives due to possible adverse effects on human health. Therefore, natural antioxidants would be viable alternative for synthetic antioxidants since they are biodegradable and are safe materials (Marangoni Júnior, Vieira, Jamróz, & Anjos, 2021; Menzel, González-Martínez, Chiralt, & Vilaplana, 2019). Todays, researchers focus on incorporating natural antioxidants into polymer biopolymer-based films for food applications (Domínguez et al., 2018; Negm, Kana, Abubshait, & Betiha, 2020; Rodríguez, Sibaja, Espitia, & Otoni, 2020; Wrona et al., 2021). However, many of these natural antioxidant materials at the present stage of research, have problems to the incorporation in packaging systems due to their light oxidation, low thermal stability, high volatility, etc., and need further research to overcome these challenges. Some of these natural antioxidant components are aromatic materials and therefore due to their specific odors limit their application to many food systems (Negm et al., 2020).

3.2.5. Antimicrobial packaging

Utilization of antimicrobial agents in food packaging is beneficial to prevent the growth of microbes and bacteria that can be found in a packaged food or packaging materials and thus increases the shelf life of the food products. Researches carried out in this field show that antimicrobial films are more effective as compared to the direct addition of antimicrobial agents to foods because the combination of antimicrobial agents is slowly released from the packaging film surface to food products with the required concentration to prevent microbial growth. The direct addition of antimicrobials may cause some loss of activities due to leaching into the food matrix. Reaction of some antimicrobials with the components of food such as lipids and proteins would be inevitable. Considering this issue, the efficiency of multi-layer films, especially three layers are suggested. In these films, the propagation speed of the active compound is controlled by the inner layer, while the middle layer contains antimicrobial agents and the outer layers prevent transitions of the antimicrobials to outside of the packaging film (Appendini & Hotchkiss, 2002). The antimicrobial film should be effective against a wide range of microbes and bacteria and do not cause any changes in the sensory properties (Kerry, O'Grady, & Hogan, 2006). Muriel-Galet, López-Carballo, Gavara, and Hernández-Muñoz (2012) developed two types of active films made by lauramide arginine ethylester (LAE). LAE is a cationic layer derived from natural antimicrobials materials (Lauric acid, arginine, and ethanol) which is one of the most important and most effective materials used in food packaging that has a wide range of antimicrobial activity. The activity of these films was evaluated for the packaging of infants' milk in the presence of *Listeria* and *Salmonella* bacteria at 4 °C for six days. They concluded that these films had more activity to control *Listeria* bacteria from *Salmonella* bacteria.

Silver, silver zeolite, triclosan, glucose oxidase, chlorine dioxide, natamycin, and allyl isothiocyanate are widely used as active compounds in commercially available antimicrobial AP systems (Fang, Zhao, Warner, & Johnson, 2017). Gold, copper, titanium dioxide and zinc oxide are other metal based materials that represent antimicrobial activity.

Compared to the organic antimicrobials, metallic-based nanoparticles represent a superior antimicrobial performance. Zhang et al. (2017) developed a ZnO- Polylactic acid (PLA) nanocomposite coated paper as antimicrobial packaging material. To have proper antibacterial properties, uniform dispersion of nanoparticles within the host polymer is essential, while nanoparticles have a great tendency to agglomerate, so the de-agglomeration treatment should be accurately performed. They examined the coated paper on *Staphylococcus aureus* and found the susceptibility of *Staphylococcus aureus* follows the nanoparticle concentration. The antimicrobial material was tested on *Escherichia coli* which stronger inhibitory effect was observed than to *Staphylococcus aureus* (Gram-positive). In preparing the antimicrobial films different factors such as proper leaching medium and light irradiation significantly impact on the antimicrobial performance. In addition to the technical performance, other factors such as economical aspects and the regulatory issues regarding using nanomaterials for food contact application need to be considered important. The industrialization of the production process of such packaging materials, as well as the study of their direct effects on the food product, should be explained.

Essential oils extracted from such plants for instance coriander, clove, rosemary, oregano, lemongrass, tea tree, basil and fennel have a great impact on inhibiting the growth of microorganisms. This creates a good potential in their use as antimicrobial additives for food packaging applications (Maisanaba et al., 2017). Felix de Andrade et al. (2020) used orange essential oil (can be extracted from peel of the orange fruit) against the bacterium *Escherichia coli* in poly butylene adipate-co-terephthalate (PBAT) film fabricated by solvent casting method. They reported migration of the orange oil to the inoculum led to reduce in growth rate of *Escherichia coli.* The main issue in utilizing essential oils for antimicrobial applications is that they must be used in high concentrations to achieve the significant impact on microorganism, which could undesirably affect the organoleptic properties of the packaged food (Vilela et al., 2018). Also, a safe range of essential oils concentrations for applying in active food packaging should be determined and the corresponding antimicrobial films having the proper characteristics should be developed for food applications. Although, there are some difficulties to analyze antimicrobial activities of the developed films due to influences of various factors, such as the type of film and the exact composition of extracts, etc., which need to be taken into account (Maisanaba et al., 2017). Essential oils are volatile materials and easily evaporate under ambient conditions, this would reduce the antimicrobial ability of the essential oils-based active films. Changing flavor and odor of foods by the essential oils used in the structure of food packaging materials is an important issue that should be considered. Therefore, additional researches can be useful for producing and applying the ideal antimicrobial essential oils that are resistant to high temperatures, odorless and colorless. Maisanaba et al. (2017) extensively reviewed the potential of essential oils in developing AP systems for food preservation. Besides to metal-based antimicrobials and essential oils, proteins and peptides such as lactoferrin and nisin, enzymes such as lysozyme and polysaccharides such as chitosan have a considerable potential to be studied as antimicrobial materials and to be applied in AP applications in the food industry (Vilela et al., 2018; Wang et al., 2015a). Many research groups have developed antimicrobial films containing a polypeptide antibacterial substance for meat packaging in order to delay the growth of micro-organisms causing corruption and disease. Recent reports have found that using nisin substance with other preservatives is very effective for food packaging (Basch, Jagus, & Flores, 2013). McArdle, Marcos, Mullen, and Kerry (2013) reported that AP is able to delay oxidation caused by high-pressure processing and consequently extend the shelf life of chicken meat. Chitosan as a non-toxic and biodegradable material has excellent film-forming properties which make it suitable for food packaging applications. Nevertheless, the applications of chitosan film are limited in the food industry due to its low mechanical, antimicrobial and antioxidant properties. To solve these problems, scientists have focused on the incorporation of natural active materials including ascorbic acid, essential oils and polyphenols, etc., into the chitosan matrix. Bi et al. (2019) developed an antioxidant and antimicrobial packaging film based on chitosan and proanthocyanidins (PA). PA are suitable to be applied in the structure of AP films, owing to their antimicrobial and antioxidant properties. PA enhanced the antioxidant capacity of the fabricated film mainly attributed to the presence of polyhydroxyl groups in its structure (Sobeh et al., 2018). The antimicrobial ability of the developed film was examined against *Salmonella*, *Escherichia coli*, *Listeria monocytogenes* and *Staphylococcus aureus* which presented and improved antimicrobial ability due to the presence of O-heterocyclic in the structure of PA, which creates a capacity to bind with polymers of bacterial cell wall and subsequently inhibit cell wall synthesis. The CS-PA film with 20 wt% of PA showed the highest antimicrobial ability. However, in addition to the antioxidant and microbial properties, PA have enhanced mechanical properties of the film attributed to the intermolecular interactions between phenolic materials and chitosan. Also, the oxygen barrier property of the chitosan film improved by PA which filled into the void volume in the matrix of chitosan film and established intermolecular interactions (for example hydrogen bonds) with chitosan chains. Similar study was conducted by Wang et al. (2015a) on preparing nisin-loaded chitosan/poly (L-lactic acid) (nisinCS/PLLA) antimicrobial films by coating method and reported a well-controlled release and good antimicrobial activity against *Staphylococcus. aureus*, which may have a good potential as a novel active food packaging film, but they did not really evaluate the developed film on foods. Youssef, El-Naggar, Fouda, and Youssef (2019) developed an antimicrobial packaging film based on caroxymethyl cellulose (CMC) and polyvinyl alcohol (PVA). The developed films contained zeolite doped with silver or gold cations. The fabrication process is presented in Fig. 16.

They found that the composite film composed of less than 3% concentrations of Ag did not present any noticeable antimicrobial activity. Instead, the films incorporated with Ag or Au cations in the zeolite framework represented an acceptable antibacterial activity against microbes, that is due to the behavior of the cations, the Ag or Au cations can reach the nuclear content of microbes and present the greatest surface area. Two mechanisms of Ag and Au nanoparticles have been described in killing the microbes, the first one was based on the high oxidation state of Ag and Au that can produce atomic oxygen around it. The formed atomic oxygen reacts with lipids of cell wall and penetrates into the microbe and then interact with proteins and lipopolysaccharides leading to bacterial death. The second mechanism was direct contact of the nanoparticles to the cell membrane and disturbing the cell wall of microbes via electrostatic interaction. Water vapor transmission rate of the developed antimicrobial films (616 g/m^2 day) were lower than that of CMC/PVA films (2014 g/m^2 day), but gas transmission rates were increased. These two phenomena can be problematic in applying this packaging film to the foods such as fruits and vegetables that have high levels of transpiration and respiration rates. However, it is necessary that the developed packaging film to be actually tested on different food products with different respiratory and transpiration characteristics and different types of microbial contamination.

Achieving an adequate controlled release of agents in AP is critical to keep active substance concentration above the minimum inhibitory concentration against pathogenic or spoilage microorganisms during product shelf-life (Franssen, Rumsey, & Krochta, 2004). From this point of view, different strategies have been suggested based on: multilayer films (Buonocore, Conte, Corbo, Sinigaglia, & Del Nobile, 2005; Lopez-Rubio, Gavara, & Lagaron, 2006), smart bio-polymer blending (LaCoste, Schaich, Zumbrunnen, & Yam, 2005), matrix cross-linking (Buonocore et al., 2004), encapsulation technology (Parris, Cooke, & Hicks, 2005; Silva-Weiss et al., 2018; Tampau, González-Martínez, & Chiralt, 2018), and incorporation of various type of fatty acids (Arcan & Yemenicioğlu, 2014). Fatty acids have been also incorporated in zein films as plasticizers to overcome brittleness, poor process ability, low elongation, and to improve water barrier properties and visual appearance (Padua & Wang, 2002). Depending on the composition and structure of film matrix (Loeffler, Beiser, Suriyarak, Gibis, & Weiss, 2014), the addition of oleic acid into a complex active system might create molecular interactions which modify film antimicrobial properties (Weiss, Loeffler, & Terjung, 2015). Kashiri, López-Carballo, Hernández-Muñoz, and Gavara (2019) developed a Lauroyl-L-arginine ethyl ester monohydrochloride (LAE)-zein based antimicrobial coating and applied it to control foodborne pathogens in chicken soup. Zein as a biodegradable material

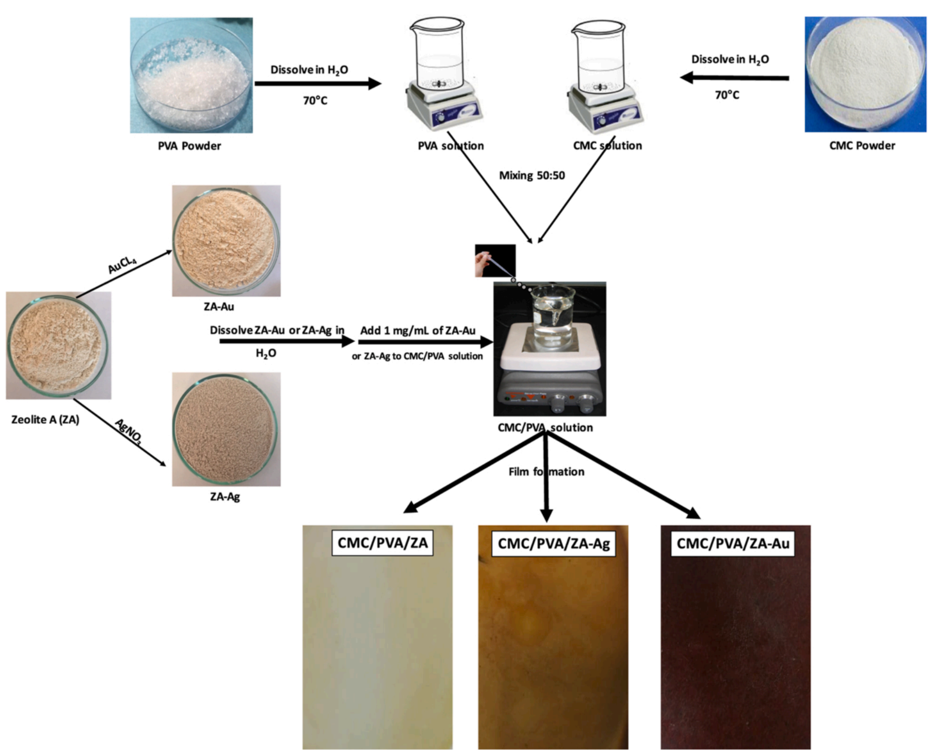


Fig. 16. Fabrication procedure of CMC/PVA film mixed with Ag or Au cations.

represents a good film-forming ability that makes it a proper candidate for food packaging applications (Kashiri et al., 2016). LAE at concentrations of 5 or 10% (w/w) was added to the zein film forming solution and glycerol or oleic acid were used as the plasticizers. Polypropylene/active zein bags were prepared by spreading the zein solution onto a corona-treated polypropylene film. Due to their relevance in food infections, *Listeria monocytogenes* and *Escherichia coli* were used for assessment of the proposed antibacterial film and the film without antibacterial agent was used as control. The chicken soup was packaged in the bags and antimicrobial activity of the packages were evaluated after 10 days of storage at 4 ± 1 °C. They found a reduction in plasticizing effect of oleic acid that would be due to interactions between LAE molecules and oleic acid and interactions between LAE and the biopolymer. While, the incorporation of LAE in films containing glycerol led to an improvement in plasticization. Concentration of LAE hardly affected the water vapor permeability of films, this issue makes some problems in applying of this film in packaging of fruit and vegetables as well as the foods with high levels of water activities. In addition to the microbial properties, color and transparency properties of the packaging films have important impact on food appearance and customer acceptance. They reported the developed films were partially transparent to UV irradiation that might impact on food quality owing to vitamin loss, discoloration, lipid oxidation and etc. The glycerol-based plasticized films revealed faster and more extended release than the films plasticized by oleic acid which could be due to electrostatic interaction of LAE (cationic charge) and oleic acid (negative charge). They reported an inactivity in the released LAE molecules which bonded to oleic acid ones limiting them to interact with the microorganisms. The real tests on chicken soup inoculated with *Escherichia coli* and *Listeria monocytogenes* confirmed a better action of PP/LAE glycerol-plasticized zein bags against *Escherichia coli* and *Listeria monocytogenes* compared to the PP/LAE oleic acid-plasticized zein bags which showed no antimicrobial effect.

4. Future trends

IP is an innovation in food packaging which has the capability to monitor the quality of food products to the consumer. The IP system are still in the development stage for many applications, due to the extensive varieties of food and agricultural products. There is a gap between the developed IP systems in the research stage and commercialization phase. Future research needs to consider some hurdles to make the IP systems commercially viable. Many physical and chemical factors in wide ranges of variability make the food systems complex and reduce the capability of the commercialization of the IP systems which are developed in vitro/lab scale and in the simplified experimental conditions. Single IP systems are expected to be integrated into a low-cost compact unit with small dimensions to provide more information about the quality factors of the food product. The collaborative research in the fields of electronics, mechanical and food engineering is very helpful for further successful IP developments. Combination of multiple sensors can improve the functionality of the IP systems which makes it possible to monitor the complex deterioration of product. In this case, the functionality interference of the sensors must be carefully studied. More advanced systems should be invented to replace the existing IP devices. Todays, IP methods are expensive due to the high price of raw materials or complex production processes and inventing lower cost IP systems seems to be necessary. So, there is a need to improve the economic and technical feasibility of such new systems. Electronic chip-based systems coupled with artificial intelligence will be able to communicate with the consumer in a more desirable manner which declare alarms to the consumer more conveniently during storage and consuming times. The advancement of nano-sensors, has a kay role in future development of IP. Currently, these systems are in the early stages of research and development and commercialization of these devices is expected to reduce the cost of the IP systems. However, focusing on systems development is not enough and the development of standards and legal issues for proper IP management needs to be considered. Another challenge is the possibility of counterfeiting in IP systems, increasing IP security could be the subject of further researches.

The major hurdle of the AP systems is the capability of the active materials to preserve their original properties. The invention of new production processes as well as introduction of new active materials having more stability with improved physico-chemical properties will be the subject of further research. Consumer demand for safe antimicrobial materials moves the research trend toward natural antimicrobials and biopolymers. Nonetheless, a few antimicrobial packaging systems have been commercialized due to adverse subsequent effects on food quality, consumer acceptance, scale up and technological problems, economic issues, etc. Further research in order to solve these problems as well as regulatory and economic challenges is necessary. Generally, due to the low molecular weight, the release rate of active materials is rapid which leads to loss of the performance of AP during the shelf-life of food. The development of the controlled release packaging (CRP) technology would be helpful for AP that aims to extend the delivery time of the active compounds and to improve the reproducibility and predictability of release rates. Research focuses only on the active properties of the packaging systems, rather than studying their behavior in the presence of real food materials, which leads to the failure of the active packaging system in commercialization. In the commercialization step, there are the technical and economic limitations. Therefore, multidisciplinary researches are needed to develop these novel packaging technologies in a low-cost manner having more capabilities to scale up and to commercialize. Determining the optimum concentration of active compounds for each type of food and acquiring releasing kinetic data for real food systems, safety concerns and the regulatory challenges such as permissible migration limits of active compounds and other packaging additives into food in addition to their toxicity are the main research gaps in the AP systems that should be scientifically addressed in the future. Nanotechnology as an emerging approach can be extensively applied in the AP systems to overcome challenges. One of the most important problems is migration of active materials that is still the main restrictive factor in further AP development. Nanomaterials and encapsulated microfibers can slowly and steadily release bioactive molecules representing good potential to be developed in future researches.

IP can be integrated into AP systems to monitor their performance and to determine the corresponding corrective actions. However, researchers generally focus on individual AP or IP, and a combination of these packaging technologies is rarely studied to introduce a system with simultaneous active and intelligent functionalities. Therefore, further research could focus on marriage between AP and IP to introduce a full smart packaging system for applying on real food materials during storage, distribution and consumption. If IP is combined with AP, further improvements for maintaining high quality of perishable foods could be realized. IP devices could monitor the quality or the conditions of the food and take decisions for corrective actions of the AP device. The combined IP-AP technique is also executable to many foods, which further researches are needed to provide models and find individual optimal design of IP-AP for each product. Investigating effect of AP and IP technologies on the sensory properties of the packaged food helps to assess whether the product is acceptable to the consumer. Synergistic AP-IP approaches have a significant potential in food packaging, but, the final costs need to be considered for the commercially viable systems. Studies on AP-IP developments could create further improvement of the existing food packaging systems, especially for fresh-cut fruits and vegetables, meat and seafood products to provide for consumer benefits and convenience having active and intelligent functions to improve food quality and safety, real-time monitoring and to reduce food loss.

5. Conclusion

Increasing demands for continuous monitoring of the food quality and extending the shelf-life of food products had led to emergence of developed types of packaging methods as IP and AP technologies. Based on the research carried out and the current applications of IP in the food industry, it can be seen that RFID and sensor systems are the most promising technologies to use commercially. However, the high costs and the technical challenges related the IP-based methods create major constraints for prevalence of using these methods in the field of food industry. For these reasons, the applications of IP techniques are still limited in the food industry. Undoubtedly, continuous progress in materials knowledge and microelectronics science would effectively contribute in finding solutions for these challenges. The trade implementations of the AP methods will grow to excess safety and expand the storage life of the food products. In this regard, AP-based technologies protect the food's quality and improve the safety of foods. The major problem for scavenging and absorbing systems is to design functional materials capable of maintaining their original properties during distribution and storage. Some other difficulties are the complexity and cost of the manufacturing process for mass production, lack of legislation for these technologies in food packaging and consumer acceptance. Therefore, more researchers should be focused on the technological problems, which are the key factors in commercialization of these methods in the food packaging applications. Specially, researchers are more concerned about antimicrobial-based systems and their effect on the sensory properties of food. The residuals antimicrobial materials on the packaged food and within packaging headspace should be studied which would be useful in improving safety and acceptability of these systems. In conclusion, it can be said that continuous researches and serious development aiming to reduce the cost and complicity of these technologies will play an important role to extend the applications of these techniques in the food industry.

6. Disclaimer

The commercial products and manufacturers' names listed in this review are not the only ones that have been commercialized and developed in the world. The authors are not related to any of the commercial products/manufacturers that are referenced in this review.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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