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Recent advances to increase the shelf life and safety of packaged foods [1]

Avances recientes para aumentar la vida útil y la seguridad de los alimentos envasados

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Abstract:

Introduction. Food packaging has played an important and varied role, accordance with the requirements and demands of the market. Currently, these needs are focused on the goal of having safe and innocuous food for as long as possible. To this end, the study and development of new technologies for food packaging has been expanded, which provides the conditions and characteristics necessary to achieve the proposed objective. **Objective.** To present the most recent advances in the field of food packaging (active and intelligent). **Development.** This work presents different techniques and criteria that are considered used to propose the concept of active packaging. Gathering the necessary conditions for the supply or suppression of beneficial or harmful substances, contributing to the conservation and deterioration of the contained foods. In some cases, various compounds, mostly of natural origin, are incorporated to counteract the deterioration of food, such as antioxidants, antimicrobials, oxygen absorbers, carbon dioxide, and ethylene. At the same time, the technology known as intelligent packaging is presented, equipped with the necessary resources to monitor and interpret the internal state of the container, and with the ability to communicate this condition visually to be identified by consumers, merchants, and manufacturers. In both cases, the aim is to eliminate or delay the undesirable modification of food and its implications for human health. **Conclusions.** The generation of active and intelligent packaging represents an important innovation, which manages to increase the shelf life of food, in conditions suitable for consumption. Reaching a considerable economic impact of the sectors involved. These new developments require an individual evaluation of each specific food against the components used. To know the concentrations, according to the characteristic that is required to be controlled, and in this way, understand the possible interactions that can occur between the content and the container that contains it.

Keywords: packaging, food additives, sensors, essential oils, antioxidants, antimicrobial agents.

Resumen:

Introducción. El envasado de alimentos ha jugado un papel importante y variado, de acuerdo con los requerimientos y demandas del mercado. Actualmente, estas necesidades se centran en el objetivo de tener alimentos seguros e inocuos durante el mayor tiempo posible. Para ello, se ha ampliado el estudio y desarrollo de nuevas tecnologías para el envasado de alimentos, que aportan las condiciones y características necesarias para conseguir el objetivo propuesto. **Objetivo.** Presentar los avances más recientes en el campo de los envases para alimentos (activos e inteligentes). **Desarrollo.** Este trabajo presenta diferentes técnicas y criterios que se consideran utilizados para proponer el concepto de envase activo. Reuniendo las condiciones necesarias para el suministro o supresión de sustancias benéficas o dañinas, contribuyendo a la conservación y deterioro de los alimentos contenidos. En algunos casos, se incorporan diversos compuestos, en su mayoría de origen natural, para contrarrestar el deterioro de los alimentos como es el caso de antioxidantes, antimicrobianos, absorbedores de oxígeno, dióxido de carbono y etileno. Además, se presenta la tecnología conocida como embalaje inteligente, dotado de los recursos necesarios para monitorizar e interpretar el estado interno del envase, y con la capacidad de comunicar esta condición de manera visual para ser identificado por los consumidores, comerciante y fabricantes. En ambos casos, se busca eliminar o retardar la modificación indeseada de los alimentos y sus implicaciones sobre la salud humana. **Conclusiones.** La generación de envases activos e inteligentes representa una importante innovación, que logra incrementar la vida útil de los alimentos, en condiciones aptas para su consumo. Alcanzando un considerable impacto económico de los sectores involucrados. Estos nuevos desarrollos requieren una evaluación individual de cada alimento específico frente a los componentes utilizados. Para conocer las concentraciones, según la característica que se requiera controlar, y de este modo, comprender las posibles interacciones que pueden ocurrir entre el contenido y el recipiente que lo contiene.

Palabras clave: envases, aditivos alimentarios, sensores, antioxidantes, agentes antimicrobianos.

Introduction

Food packaging has played varied roles, always in accordance with the requirements and demands of the market, from its simple and direct role, through its innumerable commercial tasks. Traditionally the food package has been conceived as a wrapper of various materials such as plastic, metal, glass, paper, etc. (Dong et al., 2008). It includes the development of designs, sizes, and characteristics that responds to the properties of the product it will contain, the transport and storage conditions, among others (Ait-Oubahou et al., 2019).

Traditionally, it is considered that food package must fulfill four primary functions to be considered as such (Dong et al., 2008; Licciardello & Piergiovanni, 2020; Manalili et al., 2014; Risch, 2009; Watson et al., 2019; Wikström et al., 2019), these functions are: protection, containment, convenience, and communication. Nevertheless, the continuous process of innovation in the development of food container drives the generation of new features to maintain the quality and safety of food. Two specific properties stand out, active and intelligent. The use of these new techniques has mainly aimed at benefit and protect live products, such as fruits and vegetables. However, they have also been used for the protection of prepared foods.

Market studies have been conducted, which indicate that global sales of active and intelligent package grew from 4.95 to 6.0 billion dollars (USD) from 2015 to 2019, which represents an approximate annual growth of 5.1 %. This makes it possible to project that by 2025, total sales levels of approximately 8.6 billion dollars (USD) will be reached. Of this, the contribution of intelligent package is expected to be 2.5 billion dollars (USD) by 2025, compared to 6.1 billion dollars (USD) of active package. Which shows the crescent impact caused by the generation of these new developed container techniques (Cameron, 2020).

The innovation process is directly linked to research and development activities, in the academic field, they are reflected through the diversity of publications made over time. In this sense, in consultation in the ScienceDirect database, the significant increase in the number of articles published in multiples academics journals, in this thematic. By 2020, approximately 280 articles were published, which compared to a modest 25 in 2000, represents a growth of approximately 1200 percent. Within this classification, it is possible to mention the presence of publications dedicated to the container of meat products (chicken (*Gallus gallus domesticus*), pork (*Sus scrofa domesticus*), beef (*Bos primigenius taurus*) and seafoods), fruits, and vegetables (ScienceDirect, 2021).

This work has the aim to present the most recent advances in the field of food packaging (active and intelligent).

Types of containers

Active packaging

Active packaging is one capable of interacting with the product and the environment to extend the shelf life or improve safety or sensory properties, while maintaining the quality of the product (Vermeiren et al., 1999). It involves the incorporation of certain additives in the packaging systems, whether they are loose inside the container, fixed inside the material, or incorporated into the materials, with the aim of maintaining or extending the quality of the product and the shelf life (Montero-Prado et al., 2011; Nerín et al., 2017; Rodriguez-Lafuente et al., 2010; Yildirim & Röcker, 2018).

The active packaging work by removing compounds that can accelerate the food spoilage. Control the contribution of agents that help to maintain the proper conditions of food, thus extended its shelf life for consumption. The Figure 1 shows a graphical representation of this functionality of the active food package (Kuswandi & Jumina, 2020).

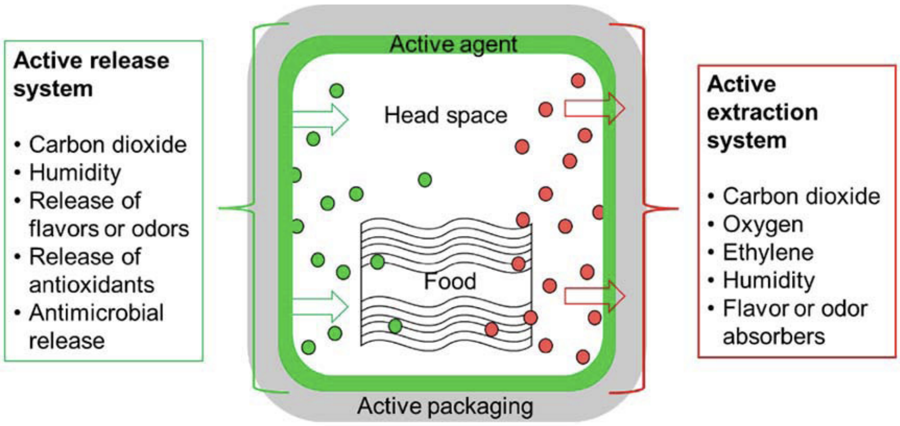

FIGURE 1
Graphic representation of the functionalities and characteristics of the active food package. Adapted from Kuswandi and Jumina (2020).
Figura 1. Representación gráfica de las funcionalidades y características del envase activo de alimentos. Adaptado de Kuswandi y Jumina (2020).

The evolution of active packaging has led to advances in many areas, including oxidation retardation, respiration rate control, microbial growth, and moisture migration (Dey & Neogi, 2019; Qiu et al., 2019).

Antioxidant packaging

The main deterioration of food is mainly due to aging and senescence factors, these processes promote the proliferation of reactive oxygen species (Fellows, 2017; Jacob et al., 2020; Nerín et al., 2017; Rudra et al., 2020; Watson et al., 2019). These factors cause food spoilage, affecting their quality and safety, such as fat oxidation, enzymatic and non-enzymatic browning, component separation, dissociation of different components such as water, lipids, proteins, polysaccharides, etc. (Estévez, 2011; Gómez-Estaca et al., 2014; Jacob et al., 2020; Lorenzo et al., 2016; Nerín et al., 2017; Robertson, 2016; Sommano et al., 2020). The different types of antioxidant packaging, on different types of food, and using different functional agents are summarizes in Table 1.

TABLE 1
Functionalities of antioxidant packaging on several foods and agents used.

	Action	Food Applications	Component	Reference
Antioxidant	Control of the increase in reactive oxygen species	Cashew (*Anacardium occidentale*) fruits	Mango leaf (*Mangifera indica* L.) extract	(Rambabu et al., 2019)
	Enzymatic and non-enzymatic browning	Apples cut into quarters	Sodium metasulfite	(Jeong et al., 2020)
	Fat oxidation Lipid peroxidation	Fresh chicken (*G. gallus domesticus*) meat	Aloe vera (*Aloe barbadensis Miller*)	(Kanatt et al., 2020)
		Beef	Oregano (*Origanum vulgare*) and rosemary (*Salvia rosmarinus*) EO	(Pelaes-Vital et al., 2016)
		Fresh meat	Flaxseed, ginger (*Zingiber officinalis*), grape seed and rosemary EO	(Wrona et al., 2021)

EO: essential oil. / EO: aceite esencial.

Cuadro 1. Funcionalidades de los envases antioxidantes sobre diversos alimentos y agentes utilizados.

With the aim of minimizing and controlling the development of these oxidative processes, and extending the shelf life of food, various studies have been carried out to incorporate different components and antioxidant substances into food packaging (Bhargava et al., 2020; da Silva-Filipini et al., 2020; Lloyd et al., 2019; Yildirim & Röcker, 2018).

For the development of these active packaging, a wide variety of research has been required. The cashew fruits (*Anacardium occidentale*) stored for 28 days, with chitosan (Ch) films impregnated with mango leaf extract (MLE) (*Mangifera indica* L.), showed 56 % less oxidation than control seeds. In addition, the 3 % mango leaf extract films showed a 9 % moisture reduction, while the 5 % extract achieved a 18 % decrease, both compared to the control (Rambabu et al., 2019). MLE contains a wide variety of phenolic components, mangiferin, gallic acid, glycosides such as isoquercetins, among others, responsible for the antioxidant characteristics of the extract (Barreto et al., 2008).

The antioxidant capacity of sodium metabisulfite ($Na_2S_2O_5$, CAS Reg. No. 7681-57-4), was evaluated by means of the 2,2'–azino–bis–(3–ethylbenzothiazoline–6–sulphonic acid (ABTS) and 2,2-difenil-1-picrilhidracilo (DPPH). It was used in biodegradable polycaprolactone films for the packaging of apples cut into quarters and stored at room temperature. Colors variations were measured every 24 hours, to verify their browning. The results show that the films have an antioxidant capacity, managed to eliminate 99.9 % of radicals according to the ABTS method, compared to 2.34 % of the control. According to the DPPH method, 25.3 % of these radicals were eliminated against 1.82 % in the controls. In general, the results obtained indicate that there is a considerable ($p<0.05$) antioxidant capacity of biodegradable films (Jeong et al., 2020).

Aloe vera (*Aloe barbadensis* Miller), it is made up of different components such as proteins, lipids, amino acids, vitamins, enzymes, inorganic compounds and small organic compounds in addition to different carbohydrates (Hamman, 2008). In a recent study, it was found that the use of aloe vera in fresh chicken (*G. gallus domesticus*) meat packaging films was able to reduce lipid peroxidation through the formation of malondialdehyde (MDA). Since, in the control containers, an increase in MDA from 0.78 to 2.85 mg kg^{-1}

was observed on day 3; compared to 2.42 mg kg^{-1} on day 13 of storage with films treated with aloe vera. In this case, carboxymethyl cellulose-poly vinyl alcohol, demonstrates considerable free radical scavenging activity. Reaching approximately 69 % uptake of these radicals after 24 hours (Kanatt & Makwana, 2020).

Essential oils (EO) of oregano (*Origanum vulgare*) and rosemary (*Salvia rosmarinus*) have been used as active agents, for the manufacture of coatings for the packaging of beef, stored at 2 °C. To verify the effectiveness of the antioxidant activity of both oils, Pelaes-Vital et al. (2016) evaluated the levels of oxidation of meat lipids, again measuring the MDA present, after 14 days of storage. MDA levels were found to decrease by 47 and 39 % for OE from oregano and rosemary, respectively, compared to control samples. Compounds of natural origin as active components can be incorporated into packaging (Pelaes-Vital et al. 2016).

It has been shown that it is possible to increase the shelf life of fresh meat by 22 %. For this, different concentrations of flaxseed, ginger (*Zingiber officinalis*), grape seed, and rosemary (*S. rosmarinus*) EO were tested on low-density polyethylene films. All applications were stored at 4 °C and in a modified atmosphere. The treatment that offered the best antioxidant activity was flaxseed EO (Wrona et al., 2021).

Antimicrobial packaging

Traditionally, packaged foods are subjected to different processes to ensure the elimination or reduction of the microbial load present, as an assurance of food safety and to achieve a longer duration of these in time, as is the case of pasteurization, cooking, dehydration, freezing, etc. (Fellows, 2017; Kilcast & Subramaniam, 2016).

The microbial load present is the main cause of food deterioration, which results in food of degraded quality and possible pathogenic problems (Gómez-Estaca et al., 2014; Kilcast & Subramaniam, 2016; Munekata et al., 2021; Otoni et al., 2016; Rudra et al., 2020; Sucheta et al., 2020; Sung et al., 2013; Yousuf & Qadri, 2020). Various yeasts, molds, and bacterias can cause the deterioration of the food, since these develop due to different causes such as variations in pH, water activity, partial pressures of oxygen and carbon dioxide (CO_2), temperature, etc. (Kilcast & Subramaniam, 2016). As a result, have been generated new possibilities for antimicrobial package, interact with food, delaying or inhibiting the growth of microorganisms (Nerín et al., 2017). The Table 2 shows a summary of the use of antimicrobial packaging for the preservation of different types of food.

TABLE 2
Compendium of different antimicrobial packaging options for the preservation of packaged foods.

Antimicrobial Function	Food Applications	Component	Reference
Antifungal and antibacterial activity	White shrimp (*Parapenaeus longirostris*)	Pomegranate skin extract (*Punica granatum*)	(Licciardello et al., 2018)
	Fresh shrimp (*Caridea*)	Mint (*Ziziphora clinopodioides*)	(Mohebi & Shahbazi, 2017)
	Sliced cooked ham	Green tea extract and oregano EO	(Pateiro et al., 2019)
	In vitro inhibition of Gram-positive bacteria and fungi	Chitosan and titanium dioxide nanocomposites	(Kaewklin et al., 2018)
	Largemouth bass (*Micropterus salmoides*)	anthocyanin extracts from Goyi blackberries (*Lycium ruthenicum*)	(Qin et al., 2021)
	Oyster mushroom (*Pleurotus ostreatus*)	pulverized pomegranate peel (*P. granatum L.*)	(Han-Lyn et al., 2020)
	Fresh strawberries	Ethyl formate	(Zaitoon et al., 2021)
	Apples (*Malus domestica* Borkh.)	Palmarosa (*Cymbopogon martinii*) and star anise (*Illicium verum*) EO	(da Rocha-Neto et al., 2019)
	In vitro gram-positive and gram-negative bacteria	Sodium metabisulfite	(Jeong et al., 2020)
	Kimchi	Calcium hydroxide with activated carbon and calcium hydroxide with zeolites	(Lee et al., 2019)
	Fresh meat packaged	Sodium carbonate and / or sodium glycinate	(Wang et al., 2015)

EO: essential oil. / EO: aceite esencial.

Cuadro 2. Compendio de diferentes opciones de envases antimicrobianos para la conservacion de alimentos envasados.

Has been possible to use the pomegranate skin extract (PSE) (*Punica granatum*) incorporated into edible coatings of Ch and locust bean gum for cold storage (4 °C) of white shrimp (*Parapenaeus longirostris*). In the case of Ch and PSE, it was possible to reduce the *Pseudomonas* spp. in approximately 2 logarithmic units. They managed to keep the psychrotrophic microbial load below the limit of 7 CFU/g for 6 days. It was possible to minimize total volatile basic nitrogen levels in 20 % after 6 days of storage relative to controls. The efficacy of CH added with PSE was demonstrated to reduce microbial deterioration and the production of volatile bases in shrimp during storage (Licciardello et al., 2018).

The effects of CH and gelatin films containing mint (*Ziziphora clinopodioides*) EO and PSE, and cellulose nanoparticles for packaging fresh shrimp (*Caridea*), refrigerated at 4 ° C have been determined. For this, cultures of different microorganisms were carried out, such as: *Pseudomonas* spp., *P. fluorescens*, *Shewanella putrefaciens*, lactic acid bacteria, Enterobacteriaceae family, and *L. monocytogenes*. The results obtained showed that it was possible to delay the growth of spoilage microorganisms, maintaining quality, and extending the shelf life of the shrimp by at least 11 days (Mohebi & Shahbazi, 2017).

The active packaging with green tea extracts in the preservation of sliced cooked ham, showed effective antimicrobial activity against total viable counts and lactic acid bacteria. Additionally, by combining green tea extract and oregano EO, very low counts of *Brochothrix thermosphacta* were obtained. In all cases, it was found that packaged ham maintained lower levels of color variation and sensory acceptance (Pateiro et al., 2019).

Through the development of Ch and titanium dioxide nanocomposites (TiO2, CAS Reg. No. 13463-67-7), achieving *in vitro* inhibition of Gram-positive bacteria and fungi (*Staphylococus aureus*), and

Gram-negative (*Escherichia coli*, *Salmonella Typhimuriu | my Pseudomonas aeruginosa*) and fungi (*Aspergillus and Penicillium*) (Kaewklin et al., 2018).

It was possible to extend the shelf life of largemouth bass (*Micropterus salmoides*) fillets up to 7 days. For this, anthocyanin extracts from Goyi blackberries (*Lycium ruthenicum*) were used, in starch / polyvinyl alcohol films, added in free form and encapsulated in nanocomplexes thereof. Both films used yielded satisfactory conservation results for the fish packed under these conditions (Qin et al., 2021).

The development of antimicrobial packaging has also extended to the preservation of edible mushrooms, fruits, and vegetables. The combined use of a modified atmosphere (varying the oxygen concentration) and pulverized pomegranate peel, for the packaging of oyster mushroom (*Pleurotus ostreatus*), stored in dark conditions at 4 °C. Showns that the samples with low oxygen content and pulverized pomegranate (*P. granatum* L.) rind, maintained significantly lower counts of aerobic bacteria in all of them (Han-Lyn et al., 2020). This indicates that it is possible to consider the existence of a synergy between the manipulation of the modified atmosphere and the antimicrobial potential of the pomegranate peel, which contributes to reducing bacterial growth inside the container.

Ethyl formate ($C_3H_6O_2$, CAS Reg. No. 109-94-4) is a commonly used compound as insecticide and antimicrobial agent of natural origin (Coetzee et al., 2019; Lee et al., 2018). In this sense, Zaitoon et al. (2021), delayed the appearance and growth of microorganisms that could affect the quality and conditions of fresh strawberries for at least 10 days of storage at 5 °C, in polyethylene terephthalate (PET) containers with ethyl formate encapsulated in ethylcellulose / polyethylene oxide fabrics.

A container has been developed to increase the shelf life of apples (*Malus domestica* Borkh.) by incorporating EO, palmarosa (*Cymbopogon martinii*), and star anise (*Illicium verum*) in b-cyclodextrin complexes. These were placed in the double bottom of PET containers, apples of the variety "Red Delicious" were placed, inoculated with *Penicillium expansum*, sealed and stored at 23 °C. After 12 days of storage, in both containers used, it was possible to reduce the growth level of the inoculated fungus by a third (da Rocha-Neto et al., 2019).

The use of sodium metabisulfite on biodegradable polycaprolactone films as a polymeric matrix has been proven. The antimicrobial capacity was evaluated by incubation of gram-positive and gram-negative bacteria, *Staphylococcus aureus* (ATCC 6538) and *Escherichia coli* (ATCC 8739). Incubated in a 90 % relative humidity (RH) and 38 ± 1 °C for 24 hours. Also, this film was used to determine its antifungal capacity using *Aspergillus brasiliensis* (ATCC 9642), *Penicillium funiculosum* (ATCC 11797), *Chaetomium globosum* (ATCC 6205), Trichoderma virens (ATCC 9645) and *Aureobasidium pullulans* (ATCC 15233), incubated at 30 °C and 85 % RH for 28 days. The results indicate the efficacy of sodium metasulfite on the control of gram-positive and gram-negative bacteria and the growth of fungi (Jeong et al., 2020).

Scavengers packaging

Active packaging has the ability to absorb different compounds, present in the head space generated inside the container, and that induce the deterioration of the food contained in said containers. The Table 3 shows a synthesis of different containers with characteristics of absorbent activity as a method of food preservation.

TABLE 3
Different types of absorbent active packaging used to improve the shelf life of foods.

Scavenger function	Action	Food applications	Component	Reference
Oxygen absorbers	Oxygen scavengers	Beef jerky	Polyisopropene	(Gaikwad et al., 2020)
		Ham cut into slices	Palladium	(Hutter et al., 2016)
		In vitro studies	Pyrogallol	(Gaikwad et al., 2017)
Carbon dioxide absorbers	Reactivity with CO_2	Fresh strawberries (*Fragaria × ananassa; cv. Camarosa*)	Commercial CO_2 absorbers (EMCO-A and EMCO-B)	(Aday et al., 2011)
		Kimchi	Calcium hydroxide with activated carbon and calcium hydroxide with zeolites	(Lee et al., 2019)
		Fresh meat packaged	Sodium carbonate and / or sodium glycinate	(Wang et al., 2015)
Ethylene absorbers	Reactivity with ethylene	Cherry tomatoes (*Solanum lycopersicum var. Cerasiforme*)	$KMnO_4$	(Aragüez et al., 2020)
		Fresh common mushroom (*Agaricus bisporus*)	1-MCP, $KMnO_4$ and cinnamon (Cinnamomum Zeylanicum) essential oil	(Ni et al., 2021)
		In vitro test	$KMnO_4$, 1-MCP, calcium chloride, salicylic acid and ultraviolet radiation	(Mansourbahmani et al., 2018)
		Tomato fruit	Chitosan and titanium dioxide nanocomposite	(Kaewklin et al., 2018)

1-MCP: 1-methylcyclopropene; $KMnO_4$: potassium permanganate. / 1.MCP: 1-metilciclopropano; KMn O_4: permanganato de potasio.

Cuadro 3. Diferentes tipos de envases activos absorbedores utilizados para mejorar el tiempo de vida útil de los alimentos.

Oxygen absorbers

The existence of oxygen in the headspace of food containers can cause the oxidation of various components of the food, such as fats and vitamins, especially in meat products. Thus promoting the sensory and nutritional deterioration of food, reducing its shelf life (Bolumar et al., 2016; Dey & Neogi, 2019; Kumar et al., 2015). Is an ideal promoter for the growth and proliferation of aerobic microorganisms such as yeasts and molds (Dey & Neogi, 2019). Hence the importance to monitor the oxygen levels inside the food package, to minimizes rancidity, retards lipid oxidation, without any damage to sensory or nutritional properties, resulting in maintaining the quality and shelf life of meat products (Fraqueza & Barreto, 2011).

Oxygen scavenging films has been developed by the incorporation of polyisoprene (C5H8) on a low-density polyethylene polymer matrix. Polyisopropene is a renewable gummy polymer that oxidizes when exposed to atmospheric oxygen at room temperature (Geng et al., 2016). These films were used to make packaging to store beef jerky, then they were placed in multilayer coextruded high barrier bags. Subsequently, all packages were stored at controlled room temperature (25 ± 1 °C). The results indicated that the polyisopropene bags presented a considerable oxygen elimination capacity in the headspace, decreasing from 21.1 to 15.53 % after 8 days of storage (Gaikwad et al., 2020).

It has been reported that it was possible to decrease the oxygen concentration in the headspace with the use of palladium (Pd) as an absorbing agent. The Pd was incorporated on PET / SiOx (silicon oxide) films in labels placed inside the containers that were stored at 4 °C with the ham cut into slices. This technique achieved that the oxygen concentration decreased from 2 to 0.47 % in 24 hours, and after 21 days of storage, the levels remained below 0.05 % (Hutter et al., 2016).

Pyrogallol ($C_6H_6O_3$, CAS Reg. No. 87-66-1) is a phenolic compound of natural origin, present in different crops and fruits (Gaikwad & Lee, 2016). Under alkaline conditions, has a high oxygen uptake capacity (Gaikwad et al., 2017). This was checked by incorporating pyrogallol into low-density polyethylene films by extrusion at different concentrations and at three different temperatures (5, 23 and 60 °C). For this, a hermetically sealed glass absorption cell was used, with a fixed volume of 125 mL, with an initial headspace oxygen concentration of 20.9 %. The results indicate that the pyrogallol films are effective for the absorption of oxygen present in the atmosphere of the container, varying this capacity according to the concentration of the added component. After 8 days of treatment at 5 °C, a decrease of approximately 2.5 % was achieved; at 23 °C, oxygen decreased approximately 11.5 %, and in storage at 60 °C, the concentration reached the minimum on the fifth day. These results reaffirmed the potential use of pyrogallol as an oxygen absorbing agent in food packaging (Gaikwad et al., 2017).

Carbon dioxide absorbers

Adequate levels of CO_2 affect the delay of microbial growth and delay the respiration rates of fresh products (Lee, 2016; Nerín et al., 2017). At the same time, the presence of CO_2 eliminates or minimizes the concentration of oxygen available in the headspace of the active container (Lee, 2016). However, excess of this concentration can affect the flavor of the products and the development of undesirable anaerobic glycosis in fruits (Suppakul et al., 2003).

It has been shown that it is possible to maintain the quality of fresh strawberries for longer using commercial CO_2 absorbers. Specifically, EMCO-A (46 % sodium carbonate peroxyhydrate, 24 % sodium carbonate, 14 % sodium chloride, 16 % bentonite clay) and EMCO-B (50 % sodium carbonate peroxyhydrate, 20 % sodium carbonate, 14 % sodium chloride, 16 % bentonite clay). These were placed inside polylactic acid containers ([$C_3H_4O_2$] n, CAS Reg. No. 26100-51-6) to evaluate the preservation of fresh strawberries (*Fragaria × ananassa*; cv. Camarosa) stored at 4 °C for 4 weeks. The headspace of the containers with absorbers was found to contain lower levels of this compound than in the controls. Strawberries packaged in lower CO_2 conditions were found to have a higher concentration of total solids, which indicates a decrease in carbohydrate metabolism. In addition, they showed less color variation with respect to the initial point of the tests. At the end of storage, it was observed that the electrical conductivity was lower for the fruits packed with the CO_2 extractors, which indicates better levels of conservation and integrity of the cell membranes, a natural condition of the senescence of fruits and vegetables (Aday et al., 2011).

Kimchi is a traditional Korean food dating from the 3rd or 4th century AD, it consists of a varied group of fermented plant foods, which makes packaging and preservation difficult. Combinations of calcium hydroxide ($Ca(OH)_2$, CAS Reg. No. 1305-62-0) with activated carbon and calcium hydroxide with zeolites were used, different concentrations co-extruded with low density polyethylene. Kimchi (150 g) were placed in the different packages and stored at 10, 4 and 0 °C. The study demonstrated that it is possible to combine physical and chemical CO2 absorption techniques to keep the demanding conditions necessary for packaging and preserving Kimchi under control without deterioration of the container for up to 4 weeks at different temperature levels (Lee et al., 2019).

Agar-based biofilm has been developed, incorporated sodium carbonate (Na_2CO_3, CAS Reg. No. 497-19-82) and / or sodium glycinate ($C_2H_4NO_2Na$, CAS Reg. No. 6000-44-8) as CO_2 absorbers, for the conservation of Chinese or shiitake mushrooms (*Lentinula edodes*). For this, 200 g in were placed in high-density polyethylene trays inside polypropylene bags. The biofilms with the active components were added and stored at 10 °C for 5 days. The results indicate that the container with the film with sodium carbonate presented minor color variation in the mushrooms, with respect to the initial values. The firmness of the mushrooms in the active containers, maintained values very similar to the initial value (4.15 N), compared to the control, which decreased considerably to 3.63 N. In general, the calcium carbonate films, feature better results in the quality indexes of the mushrooms after 5 days of storage (Wang et al., 2015).

Ethylene absorbers

Ethylene (C_2H_4, CAS Reg. No. 74-85-1), is a gaseous plant hormone that significantly influences the development of flowering, ripening, separation, as well as the senescence of the fruits (Van de Poel et al., 2015). Triggers multiple biochemical changes that accelerates metabolism, promoting the aging and deterioration of fruits and vegetables, even in low temperature conditions (Li et al., 2018; Wei et al., 2021). This needs adequate post-harvest handling to hold the quality of fresh products for as long as possible. Feature various studies have been carried out that contribute to absorbing and controlling the levels of ethylene in the headspace of the containers.

A recent study evaluated the ability of triticale flour films (*x Triticosecale Wittmack*) with two different concentrations of potassium permanganate ($KMnO_4$, CAS Reg. No. 7722-64-7) (0.7 and 1.4 mg cm^{-2}) for the control of ethylene release in the packaging of cherry tomatoes (*Solanum lycopersicum* var. *Cerasiforme*). These were placed inside commercial plastic boxes containing the tomatoes, sealed, and stored at room temperature (23 ± 2 °C) and at 4 °C for 20 days, turning them into active and control trays. Quality was primarily focused on the measurement of weight loss, firmness, and brix index (°Brix). After 20 days of storage, at both temperatures, it was found that cherry tomatoes in active boxes showed a better conservation situation compared to tomatoes in control boxes, these variables were evaluated at 0, 3, 6, 9, 12, 15, and 20 storage days. Specially, the significant differences in the weight losses of tomatoes, which in the active trays a and b, reached a loss of 15.57 and 16.16 %, respectively, compared to the control, which lost 35.95 %. Despite observing an apparent improvement in the firmness of the tomatoes in active trays, 8 and 10 N, compared to the 5N control, it does not reach statistically significant differences. The measurements of the °Brix, indicate that the control tomatoes reached values of 8 °Brix compared to the tomatoes in the active trays (a and b), they reached 5.8 and 6 °Brix. These variations linked to the films impregnated in KMnO4, are an indication of the effectiveness in the absorption and elimination of ethylene (Aragüez et al., 2020).

It has been reported that it was possible to use a paper-based packaging material to extend the shelf life of fresh common mushroom (*Agaricus bisporus*). For this, they used food packaging paper (with a basis weight of 80 g/m^2) supplied by Victoria Paper (Zhejiang, China), to which they incorporated different agents, such as 1-methylcyclopropene (1-MCP) (C_4H_6, CAS Reg. No. 3100-04-7), $KMnO_4$ and cinnamon EO (*Cinnamomum Zeylanicum*), individually and combined. All the treatments used, showed better results compared to the control container. However, the functional role with the mixture of all the components was able to effectively delay the darkening and weight loss of the mushrooms. These even had an acceptable quality with a weight loss of 4.66 %, firmness of 0.79 kgf, luminosity of 86.11, and brown index of 36.18 after the sixth day of storage (Ni et al., 2021).

A study has been carried out to evaluate the efficiency in the absorption of ethylene of different components: nano zeolite promoted by palladium (Pd), nano zeolite promoted by $KMnO_4$, 1-MCP, calcium chloride ($CaCl_2$; CAS Reg. No 10043-52-4), salicylic acid ($C_7H_6O_3$, CAS Reg. No 69-72-7), and ultraviolet radiation. As measured in the presence of different concentrations of these, stored at 7 °C and at a relative humidity of 90 %, for 35 days. A rapid increase in ethylene was observed in the control container, on the contrary, the containers containing palladium did not reflect an increase in the ethylene concentration. The other treatments performed in a stepwise manner in the absorption of the ethylene generated as follows. Other treatments with a performance range in the uptake of ethylene were $KMnO_4$ > 1-MCP > salicylic acid = $CaCl_2$ > ultraviolet radiation. In general, the different treatments managed to preserve the quality characteristics of the tomato (Cultivar Valouro), increasing its shelf life (Mansourbahmani et al., 2018).

It has been shown that through the development of active films of Ch and titanium dioxide nanocomposite, it was possible to delay the ripening process and extend the shelf life of tomato fruit, due to the proven degradation of ethylene. For this, Kaewklin et al. (2018) packed fresh tomatoes in low-density polyethylene bags with the active films. They were stored at 20 ° C and 85 % relative humidity. After 15 days of storage, considered as determining factors in the quality of fresh products, ethylene in the headspace, firmness, weight loss, total solids content, etc. The analysis of the headspace of the samples showed that the ethylene present in the active containers was considerably reduced in relation to the control containers. Reductions of approximately 50 and 25 % were found for the titanium dioxide and Ch films, respectively. Tomatoes packed with the titanium dioxide film maintained a significantly higher firmness levels of 12.5 Newtons (N) versus 8 N for the control tomatoes. The tomatoes used as controls showed significantly greater weight losses than the samples packed with the Ch and titanium dioxide films. The total solids content of the samples packed with titanium dioxide films was significantly lower than the total solids of the Ch film and the control (Kaewklin et al., 2018).

Intelligent packaging

One of the main functions of food packaging is communication, focused on providing information on the characteristics of the food at the time of packaging and its lifetime under specific storage conditions. With the development of new innovative technologies, this function has evolved over until today, with the emergence of the concept of intelligent packaging (Vanderroost et al., 2014). This type of packaging aims to make known in real time and updated, the quality status of the food it contains (Kuswandi & Jumina, 2020). In essence, intelligent packaging can be defined as that capable of identifying, detecting, tracking, recording, applying logical reasoning and communicating external or internal changes in the product environment, to the manufacturer, the retailer and the buyer of the status of these properties (Ait-Oubahou et al., 2019; Borah & Dutta, 2019; Dey & Neogi, 2019; Ghaani et al., 2016).

Based on their characteristics and functionality, intelligent packaging can be classified in various ways. Some of the different types of intelligent packaging, oriented according to the specific function they can perform and the specific food applications on which they function adequately are shows in Table 4.

TABLE 4
Examples of intelligent packaging uses for different foods, including fruits and vegetables and modes of action.

Intelligent Packaging	Operating Principle	Food Applications
Sensor	Detection of biological and chemical compounds (enzymes, DNA, microbial) Detection of chemical compounds (reactive dyes, pH indicators, gas, etc..	Water, fish, poultry products, meat, milk, fruits, vegetables, beverages
Freshness indicators	Detection of biological compounds Detection of chemical compounds Ethylene gas detection pH detection	Meat, fish, poultry, fruits, vegetables, milk, drinks
Integrity indicators	Oxygen-$C0_2$ indicators	Fish, meat, poultry, fruits, vegetables
Time-temperature indicator	Diffusion Enzymatic reactions Microbial reactions Photochemical reactions Polymerization reactions Chemical reactions	Fish, meat, poultry, perishable products. juices, fruits, vegetables
Radio Frequency Identification	Radio frequency technology	For individually packaged and bulk food products

Source / Fuente: Kuswandi & Jumina (2020).

Tabla 4. Ejemplos de envases inteligentes para diferentes alimentos, incluidas frutas y vegetales y modos de acción.

A great variety of studies have been carried out to verify the efficiency of different intelligent packaging applications on different types of food and operations. The microbial spoilage of food is accompanied by a pronounced production of CO2. This allows the use of sensors that use this indicator metabolite to visually warn about the state of freshness of packaged foods (Perez de Vargas-Sansalvador et al., 2017; 2019; Rukchon et al., 2014; Saliu & Della-Pergola, 2018).

The use of a colorimetric indicator as an application of a chemical barcode has been reported to monitor the deterioration of skinless chicken (*G. gallus domesticus*) breasts. Cellulose-based labels impregnated with two groups of colorants sensitive to pH variations, were used inside the packages. One contained a mixture of bromothymol blue and methyl red (M), while the other contained bromothymol blue, bromocresol green, and phenol red (P). Sterile polyethylene trays (168 mL) were used with 135 g of chicken breast. These were heat sealed and and stored at 4 and 10 °C. Periodic evaluations were carried out to determine the quality of the product and the variations in the color of the indicator. The results indicate that the minimum deterioration of the skinless chicken breasts occurs from 11 % of CO_2 in the headspace of the container, for the samples packed at 4 °C, it occurred at 6.12 days and 2.78 days, for samples stored at 10 °C. It was found that the progressive generation of CO_2 corresponds to the pattern of chemical deterioration. This showed a spectrum from light green to yellow orange for the M indicator and from violet to green for the P indicator. The responses of the indicator were correlated with the microbial growth patterns of the skinless chicken breast samples, which allowed to monitor the deterioration in real time. This allowed a rapid and sensitive detection of metabolites from the decomposition of chicken breasts (Rukchon et al., 2014).

Research has been conducted to establish the CO_2 detection performance of a food grade mixture consisting of an amino acid (*L-lysine*) a polypeptide (*ε-poly-L-lysine, EPL*) and natural dyes (anthocyanins, extracted from the red cabbage (*Brassica oleracea* L.). This mixture in concentrations of 0.01 % (w / v) in distilled water, was sensibly reactive, exposed to 2.5 % of CO_2, changing from blue to purple in less than five minutes (Saliu & Della-Pergola, 2018).

Multiple studies have been carried out using anthocyanins for the elaboration of sensors applied in intelligent packaging to identify the quality status of food (Ge et al., 2020; Kurek et al., 2019; Liang et al., 2019; Liu et al., 2019; Moazami-Goodarzi et al., 2020; Moradi et al., 2021). This is because anthocyanins are very sensitive to changes in pH, which favors the identification and separation of the color gamut (Kurek et al., 2019; Liang et al., 2018; 2019).

A film based on Ch, lemon balm EO (*Melissa officinalis*), and PSE (*P. granatum*) for the preparation of a sensor that allows detecting the state of the cream cheese spoilage (Pirsa et al., 2020). For this, the Ch films were impregnated with different concentrations of the extracts considered, placing 2 x 4 cm sections of this in the upper part of the container. The results indicate that the film that contained the PSE reacted by changing from purple green to red with the deterioration of the cream cheese, due to its acidification as a consequence of proteolysis (Pirsa et al., 2018).

It is possible to used polyphenolic compounds, rich in anthocyanins, extracted from blackberries (*Morus alba* L.) applied on k-carrageenan films. To it, different concentrations (0, 1, 2, 3 and 4 %) by weight of the blackberry extract were incorporated. 15 mL of fresh pasteurized milk was placed in sterilized 100 mL beakers sealed with polyethylene films, to a constant temperature of 40 °C, accelerate the milk deterioration process. In a period of 20 hours, various acidity and pH measurements were made to the milk, given the close relationship that these parameters have with the level of deterioration of the milk (Zhai et al., 2018). At the same time, the treated films were exposed to 5 mL of the spoiled milk, to evaluate the color variations. The films were found to change color, initially from purple to pinkish tones, as the pH decreases. This indicates that it is possible to use this tool as an indicator of the deterioration of pasteurized milk (Liu et al., 2019).

Multiples studies have been reported that confirms the presence of anthocyanins susceptible to pH variations, in grains of black rice (*Oryza sativa* L.), grown mainly in Southeast Asia, with characteristics of functional foods, antioxidant, and antimicrobial (Hou et al., 2013; Loypimai et al., 2016; Pang et al., 2018; Pedro et al., 2016).

It is possible to use of black rice anthocyanins, incorporated in green nanocomposite film, based on oxidized chitin nanocrystals and gelatin, to monitor the freshness of Chinese white shrimp (*Penaeus chinensis*) and shows quality changes through visible color variations. For this, Ge et al. (2020) added the anthocyanin extracts at the rate of 0, 20, 40, 80, and 100 mg per 100 mL of the film-forming solution. Two white shrimp of similar size were placed in a sterilized 9 cm diameter Petri dishes, they were covered with each of the prepared films. The plates were then sealed with polypropylene films and placed in an artificial chamber at 25 °C and 75 % relative humidity. The results showed that the color in the films with 20 and 40 mg of the extract, varied from purple to grayish blue after storage for shrimp, while the films with 80 and 100 mg changed to brown. In all cases, the color variations were consistent with the measured pH variations (Ge et al., 2020).

Conclusions

A wide variety of recent studies show the effectiveness in adapting and using new techniques and tools in food packaging, increasing the shelf life of different foods and, at the same time, maintaining their safety levels, ensuring their consumption. This has been achieved by modifying the traditional inert characteristic of the container towards a more dynamic role, interacting with its content, the environment and the human being. Adding functions and characteristics such as antioxidants, antimicrobials, eliminate or neutralize compounds, communication, etc.

The development of active and intelligent packaging focuses preferably on the use of agents of natural origin. In addition, it is necessary to specifically evaluate each class of food against the different types of agents used, knowing and understanding the possible interactions that can occur between the food and its packaging. It is necessary to identify the minimum concentrations required to obtain the expected results, without affecting the physicochemical and organoleptic properties of the packaged food.

The growth and versatility of these containers are having a significant impact on society through the economic growth caused by their manufacture and marketing. In addition to the notable increase in studies and academic publications that seek to verify the operation of different components and materials.

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Notes

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Enlace alternativo

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