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Revisão

Active food packaging: a brief review of biodegradable films, edible coatings, and sachets

Embalagens ativas para alimentos: uma breve revisão de filmes biodegradáveis, revestimentos comestíveis e sachês

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ABSTRACT

Food packaging generally consists of low-cost and non-degradable plastic materials that contribute to environmental pollution. For this reason, new food-packaging systems with good mechanical and barrier properties have been developed as an alternative to replace synthetic polymers used in food packaging. In this sense, this article briefly reviews the active packaging concept and the development of biodegradable films, edible coatings, and sachets used in food preservation. These technological innovations gained increasing importance in the food industry over the years, constituting a new paradigm in the industry, as they interact desirably with food, promoting various solutions such as: extending or maintaining the shelf life, monitoring or improving the quality and safety of food products. In addition, these innovative systems have aroused the interest of researchers for their ability to prevent deterioration and maintain the fresh aspect, firmness, and brightness of foods, making them more attractive to consumers. Several studies have shown that active packaging is an efficient system for preserving fruits and vegetables. The application of biodegradable films, edible coatings, and sachets was discussed in this work, showing the benefits of their use in various food products.

Keywords: active packaging; food preservation; post-harvest; quality; shelf-life.

RESUMO

Em geral, as embalagens de alimentos consistem em materiais plásticos de baixo custo e não degradáveis que contribuem para a poluição ambiental. Por esta razão, novos sistemas de embalagem de alimentos com boas propriedades mecânicas e de barreira têm sido desenvolvidos como alternativa para substituir os polímeros sintéticos utilizados nas embalagens de alimentos. Neste sentido, este artigo oferece uma breve revisão do conceito de embalagem ativa, com destaque para o desenvolvimento de filmes biodegradáveis, revestimentos comestíveis e sachês utilizados na preservação de alimentos. Estas inovações tecnológicas têm ganhado importância crescente na área alimentar ao longo dos anos, constituindo um novo paradigma na indústria, visto que interagem de forma desejável com os alimentos, promovendo soluções diversas como: prolongar ou manter o prazo de validade, monitorizar ou melhorar a qualidade e segurança de produtos alimentícios. Além disso, esses sistemas inovadores têm despertado o interesse de pesquisadores por sua capacidade de prevenir a deterioração e manter o aspecto fresco, a firmeza e o brilho dos alimentos, tornando-os mais atrativos para os consumidores. Diversos estudos têm demonstrado que a embalagem ativa é considerada um sistema eficiente para a conservação de frutas e vegetais. A aplicação de filmes biodegradáveis, revestimentos comestíveis e sachês foi discutida neste trabalho, mostrando os benefícios de seu uso em diversos produtos alimentícios.

Palavras-chave: embalagem ativa; preservação de alimentos; pós-colheita; qualidade; validade.

INTRODUCTION

Over the years, the increase in packaging importance occurred due to several factors, such as self-service, consumer influence, company image and brand, and the opportunity for constant innovation (1,2). In addition, lifestyle change has contributed to the development of new packaging and improved packaging, which allows the extension of shelf life and monitoring of food safety and quality (3). Due to population growth and a competitive market, packaging has become essential for optimizing the use of food and inputs demanded by society and for reducing global waste (4,5). The food industry has been looking for new technologies to meet consumer demand for high-quality and safe products (6,7). The development of packaging is an activity that has been gaining more importance in the country's economy, due to the direct relationship with many production sectors, and it is essential for the food industry. Furthermore, packaging assumes the role of representing the product (8).

METHOD

A planned literature review was carried out, examining the relevant aspects considered in this systematic review. This type of study allows the construction of an article that offers important scopes for its applicability in the preservation of biologically active foods (fresh fruits and vegetables), which require post-harvest technology, and processed industrialized foods. This extends its shelf life, maintains its attributes (organoleptic and nutritional), and provides whole and safe food to consumers. This study can help guide the development of researchers' projects, as it integrates several important information clearly and explicitly for the scientific area, which can support future investigations.

RESULTS AND DISCUSSION

The evolution of packaging. The first packaging records occurred in ancient times when human beings used gourds, shells, leaves, and excavated logs provided by nature to store and transport their food. The first evidence of metals and ceramics appeared before Christ produced by the Egyptians, allowing the production of other forms of packaging (9). The development of new manufacturing processes and packaging materials originated in the industrial revolution. In 1800, cardboard was used to manufacture folding boxes (10). In 1809, the Frenchman Nicolas Appert developed a method of storing food in glass bottles closed with stoppers and submitted them to heat for a certain time, thus prolonging its useful life. This new process allowed that time to supply the troops of Emperor Napoleon Bonaparte (11).

As early as 1810, Peter Durand received a patent for a process similar to that created by Appert, but he used tin-coated metal cans as a form of storage (11). Although the first report of plastic occurred in 1800, it was only during World War II that it began to be sold, and it is still used today (10). In addition, there was an expansion in the sale of steel and brass (5). After the Second World War, there was an increase in the demand for food, and packaging began to play a role in attracting more consumer attention (12).

Different materials can be used in the manufacture of packaging. Currently, packages develop essential functions such as containing and protecting the food, and interact with the food they package, controlling its variations, and even indicating the occurrence of these changes, aiming to increase its shelf life, as well as ensure the quality of food and providing better information about the final state of the product (13).

However, conventional packaging has been gradually losing space in the market for active packaging, defining a new paradigm for the food industry (13). The future of this technology is promising, and there are already numerous patents and studies proving its effectiveness and economic viability (14).

Panorama of the national packaging industry. The loss and waste of food lead to a great financial impact and concern with environmental pollution. One-third of all food produced worldwide (1.3 billion tons) is disposed of in garbage (7). These problems are associated with financial and managerial aspects, technical limitations in harvesting, storage, refrigeration facilities in difficult climate conditions, systems of conditions, infrastructure, packaging, and marketing (7,15).

Over time, the packaging sector has become increasingly relevant to the country's economy. Worldwide, packaging has generated over US$500 million, representing 1% and 2.5% of each country's GDP (gross domestic product). In Brazil, it accounted for R$75.3 billion in 2018 and created more than 220,000 jobs by May 2019. In terms of exports, they had a total turnover of US$245.4 million in the first half of 2019 (5).

Active packaging most used in food: Biodegradable films, edible coatings, and sachets. The packaging innovations have gained increasing importance over the years, as it has offered numerous solutions such as extending or maintaining the shelf life and improving or monitoring the quality and safety of food (16). The active packaging group (Figure 1) that has gained increasing relevance are biodegradable films, edible coatings, and sachets (17). These innovations aim to change the conditions of the environment surrounding the food to extend its shelf life and ensure the sensory properties, safety, and quality of the food (13,17,18).

Active packaging intentionally interacts with food, aiming to improve its properties (17). There are packages with different functions and techniques to respond to consumers interested in the news within this sector. Active packaging may contain substances that absorb oxygen, ethylene, moisture, and odor, and others that emit carbon dioxide, antimicrobial agents, antioxidants, and aromas. The technique is based on inserting certain additives into the packaging instead of introducing them directly into the food product (19).

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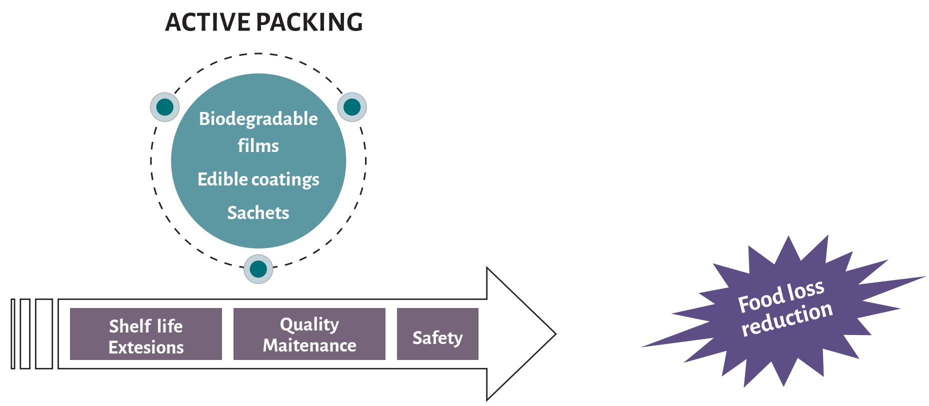
Figure 1. Active packaging functionality



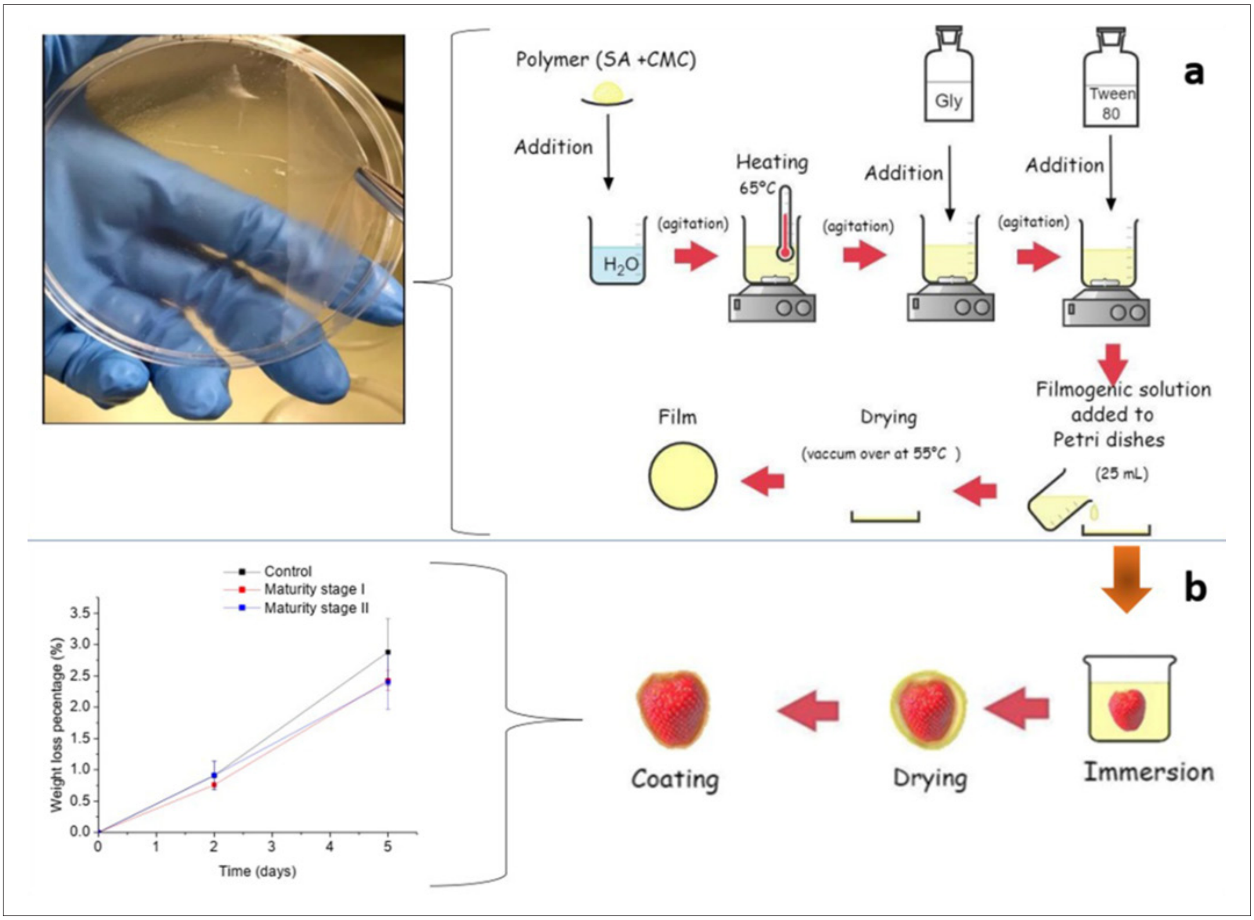
The concern with the environment and the issue of ecology have driven packaging industries to provide recyclable and/or biodegradable packaging (20). Edible coatings and biodegradable films are innovative technologies in the packaging area and have been very advantageous at a social, economic, and environmental level (21). The edible coating technique is not recent; the first report occurred in the twelfth century when the Chinese applied wax to oranges and lemons to prolong the shelf life of the fruits (22,23). As early as 1930, beeswax, carnauba, paraffin, and mineral and vegetable oils were applied to fruits to improve the visual appearance, control ripening, and delay water loss. In 1950 it already had several patents for edible films and coatings (24).

Edible coatings are formed by applying the filmogenic solution directly to the surface of the food, and after the drying process, a thin film is formed (25), as can be seen in Figure 2. To reduce water loss, edible coatings have been applied to fruits and vegetables (26). The mechanism of formation of the coating occurs as follows: the fruit is immersed in the filmogenic solution, then there is an attraction between the absorbate (polymeric species diluted in the filmogenic solution) and the absorbent (the fruit peel). After the fruit is removed from the filmogenic solution and through a drying process leading to solvent evaporation, occurs the polymer crosslinking, and there is the formation of the covering by the deposition of polymeric species dissolved in the medium, which establish weak and strong bonds with the surface of the fruit (27–29).

Edible coatings are not intended to replace conventional packaging but have a functional role in maintaining food products' texture, nutritional value, and moisture (32,33). As it is an edible coating, the polymers used in its preparation are compounds generally recognized as safe (GRAS – Generally Recognized As Safe) and processed within the Good Manufacturing Practices (GMP) established for foods (34). Biodegradable films and edible coatings have been of interest to researchers due to their ability to prevent food spoilage and biodegradability characteristic (35). It is considered an efficient system for preserving fruits and vegetables, ensuring their fresh appearance, firmness, and shine (36). The film is defined as a thin layer preformed or formed directly on the surface of the food after the drying process (25).

In some cases, films can replace synthetic packaging (37). The casting method is the most used in the production of edible films, and it is characterized by the spreading of the film-forming solution on a smooth surface, and then the drying process occurs (38). Coatings and films are used in foods to reduce moisture loss and oxygen intake, reduce respiration, delay ethylene production, retain volatile aromas and carry additives such as antioxidants and antimicrobials (35,37).

Figure 2. Preparation of edible coating. a) mechanism of formation of filmogenic solution based on sodium alginate (SA) and carboxymethyl cellulose (CMC) plasticized with glycerol (Gly) b) application of edible coating on strawberries and its contribution to weight loss during fruit respiration (30,31).



Polysaccharides, lipids, and proteins are the classes of materials most used for forming films and coatings. However, the choice of polymeric material will depend on the characteristics of the food and its purpose (27). Generally, protein-based films and coatings can generate greater mechanical and barrier properties than those produced with polysaccharides because the structure of proteins provides high functional properties (39,40). Lipid coatings are commonly used to provide a high moisture barrier, but these materials have disadvantages such as undesirable sensory characteristics and form brittle or non-cohesive films (41). Precursor solutions for producing edible films and coatings can originate from hydrophilic or hydrophobic materials. Typically, hydrophilic materials have good solubility in aqueous media, as they have a high affinity with water due to the presence of highly polar groups (amino and hydroxyl groups), thus generating material with a high capacity to retain water into foodstuff (23,27). Due to their affinity for water, these hydrophilic coatings are not a good barrier against moisture, but they can impart a hydrated and shiny appearance to sliced fruit surfaces. On the other hand, hydrophobic coatings are generally applied to fruits with a high transpiration rate, as they present a high-water loss that causes dehydration and changes in the surface appearance. Lipid and protein-based materials are generally used (27).

The application of film based on cellulose acetate containing enzyme naringinase effectively reduced the bitterness taste of grapefruit juice (42). Antimicrobial action of cellulosic film incorporated with sodium lactate was observed in sausages (43). Paganini et al. (2021) proved a reduction of *Weissella viridescens* counts in ham covered with cellulose acetate film with oregano essential oil (44). Soares et al. (2011) studied cellulose acetate film inserted with sorbic acid and proved a reduction in microbial growth in pastry dough (45). Another study was conducted by Giuggioli and Girgenti (2017), who evaluated that the starch film was able to maintain the nutritional quality and extend the shelf life of the blueberry by 15 days (46). Edible coatings based on native starches (sorghum, wheat, potato, and rice starch) and gelatin showed effectiveness in the preservation of the crimson grapes compared to the control. There was a reduction in water loss of grapes with coating compared to uncoated (47).

Amanullah et al. (2016) observed that *Aloe vera* edible coating was effective in delaying the ripening of eggplants, as it allowed for a higher content of vitamin C, non-reducing sugars, and lower levels of total and reducing sugars, in addition to reducing in physical changes, proving to be a viable alternative for fruit preservation (48). Rojas-Graü and Tapia (2008) evaluated the effect of the coating based on alginate incorporated with sunflower oil (49). They proved efficient in conserving melons, prolonging the shelf life of 15 days since it delayed the production of ethylene responsible for the ripening of the fruit and contributed to the moisture barrier. Vieira et al. (2016) studied the chitosan-based edible coatings with *Aloe vera* on post-harvest blueberry fruit and observed inhibition of *Botrytis cinerea*, the fungus responsible for gray mold (50). Qi et al. (2011) proved the effect of chitosan-coating on quality and extended the shelf-life of fresh--cut "Fuji" apples (51). Numerous studies have shown that chitosan can ensure the quality of fruits due to its ability to minimize the respiration rate and reduce transpiration and ethylene production. In addition, the chitosan confers fungistatic and fungicidal properties (51,52).

There are absorber sachets; these systems eliminate unwanted compounds (oxygen, ethylene, carbon dioxide, excess water) from the free space of the package or around the food, which stimulates rapid deterioration of the food product (3,53). In 1977, the iron-based oxygen absorber was commercialized in sachet form by Mitsubishi Gas Chemical Inc (54). Oxygen absorbing sachets can considerably reduce the oxygen content inside the package, restricting it to levels below 0.01% (100 ppm), in addition to maintaining these levels during storage, ensuring the quality of the food product, and extending its shelf life (18,55). High concentrations of O_2 in many foods facilitate microbial growth, promoting the development of undesirable tastes and odors, color change, and nutritional loss, causing a significant reduction in their shelf life (55). The sachet is a highly permeable technology to oxygen and water vapor, and under favorable humidity conditions, it absorbs residual oxygen to produce stable iron oxide. Metal composition absorbers are based on the principle of iron oxidation in the presence of water (56). According to Robertson (2016), the mechanism involves the oxidation of iron in the presence of water and oxygen, in several steps (55), as expressed by the equations below

$$\mathrm{Fe} \rightarrow \mathrm{Fe}^{+2} + 2e^- \qquad (1a)$$

$${}^{1}/_{2}\, O_2 + H_2O + 2e^- \rightarrow 2\mathrm{OH}^- \qquad (1b)$$

$$\mathrm{Fe}^{+2} + 2\mathrm{OH}^- \rightarrow \mathrm{Fe(OH)}_2 \qquad (2)$$

$$\mathrm{Fe(OH)}_2 + {}^{1}/_{4}\, O_2 + {}^{1}/_{2}\, H_2O \rightarrow \mathrm{Fe}(OH)_3 \qquad (3)$$

$$\mathrm{Fe} + {}^{3}/_{4}\, O_2 + {}^{3}/_{2}\, H_2O \rightarrow \mathrm{Fe}(OH)_3 \qquad (4)$$

$$2\mathrm{Fe}(OH)_3 \rightarrow \mathrm{Fe}_2O_3 \cdot 3H_2O \qquad (5)$$

Equations 1 to 3 generate $Fe(OH)_3$. However, there is another alternative to be the product in a single step, through equation 4. Equation 5 is obtained by the reaction of two molecules $Fe(OH)_3$ to generate the non-toxic and stable oxide ($Fe_2O_3 \cdot 3H_2O$), and this chemical process depends on the storage temperature and moisture from the food product, that is, food water activity (55). One of the main active components of O_2 absorbers is metallic iron. Among the benefits stand out the low cost and easy oxidation in the presence of oxygen (57). Several brands of absorbents and other compounds are marketed worldwide. These oxygen absorption systems can usually occur by the following mechanisms: oxidation of ascorbic acid, iron powder, and unsaturated fatty acids such as oleic and linoleic acid (58). Among the options of oxygen absorbers available on the market, about 90% are in the form of sachets, which have reducing agents such as iron oxide in their formulation for more cost-effectiveness. Absorbers with ascorbic acid and its salts have been used to prevent the transmission of undesirable odor and taste to foods, above all to solve problems related to metal detectors during export inspections (14).

Ethylene absorber sachets are intended to control the ethylene content in the free space of the package or around the food, which leads to reduced metabolism, extending the shelf life of packaged fresh fruits and vegetables (59). In climacteric fruits, ethylene (C_2H_4) is a natural maturation hormone responsible for accelerating their respiration rate (60). An ethylene absorbing system has been used to maintain the acceptable visual appearance and organoleptic quality of the fruits since the ethylene hormone accelerates senescence, softens, and increases chlorophyll degradation. Therefore, controlling ethylene levels is key to extending fruits' post-harvest shelf life. (43). Ethylene absorbers such as potassium permanganate, crystalline aluminosilicates, silica gel, aluminum oxide, clays, and zeolites can gradually eliminate ethylene (13,61). Potassium permanganate ($KMnO_4$) has been widely used in ethylene absorption as it is a cheap market system that can be incorporated in sachet form (62). Due to its toxicity, potassium permanganate cannot come into contact with food; so, about 4 to 6% of $KMnO_4$ is added to sachets (63,64).

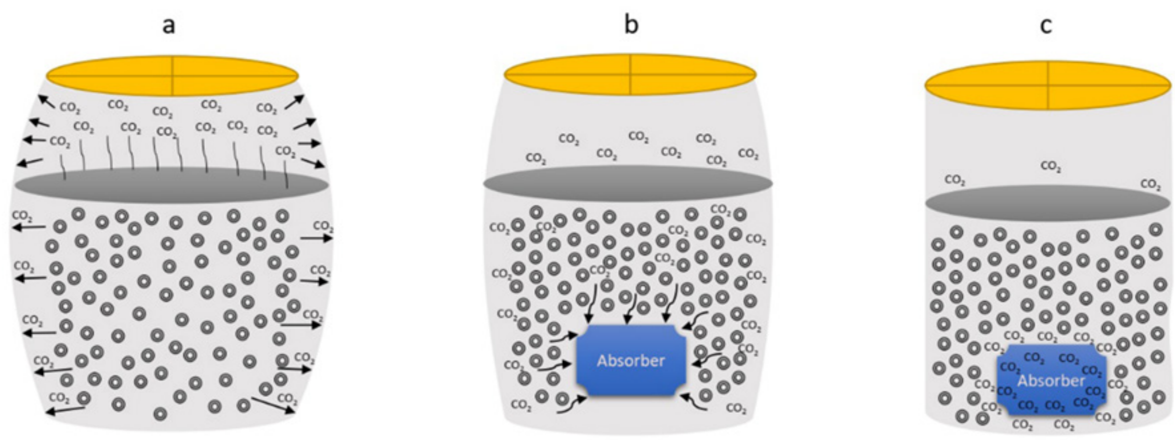
The moisture controller sachet aims to remove the unwanted accumulation of liquid water in plastic packaging due to food products' transpiration. Furthermore, this accumulation can promote the proliferation of fungi and bacteria. Moisture absorbers have application in fruits, vegetables, cheese, meat, chips, peanuts, sweets, and spices. There is great interest in absorbing humidity but also in controlling moisture in the vapor phase to reduce water activity on the surface of food and prevent food discoloration (65). These moisture-absorbing sachets are widely used in Japan, the United States, Germany, and Australia. A range of dehydrated products in Japan needs protection from moisture damage. These sachets in the United States are applied to dehydrated products such as snacks and cereals and are produced by the companies Multisorb Technologies, Inc., United Desiccants, and Baltimore Chemicals. In Japan, the manufacturer of moisture absorbers is Toppan Printing Co. Ltd (61,65,66).

Dupont Chemicals produces the tear-resistant plastic sachet, called Tyvek®, which may contain desiccants such as silica gel, calcium oxide and natural clay, which are used for dehydrated foods (67).

Carbon dioxide absorbing sachets are particularly used for foods such as fresh ground or roasted coffee that generate large amounts of carbon dioxide. Therefore, they should not be vacuum sealed after roasting as the carbon dioxide generated can accumulate inside, which can puff up or break the package. They require protection as they can absorb moisture and oxygen from the environment, leading to loss of aroma and volatile flavors (66,68). The mechanism of absorption of CO_2 (Figure 3) and O_2 occurs through the oxidation of iron and calcium hydroxide (54,69). Sachets with the absorption of CO_2 and O_2 are marketed for canned coffee and laminated with aluminum foil in Japan, China, and the United States (66).

In addition, a high concentration of carbon dioxide in the package can contribute to the delay of microbial growth in products such as meat and poultry. However, in other foods, it can cause deterioration, stuffing, and rupture of the package (66,70).

Figure 3. CO_2 absorption effect in coffee. a) generation of internal pressure inside the container without absorber, b) CO_2 migration phenomenon and c) internal pressure control by absorber effect



CONCLUSION

Active packages have great potential for application in the food market, as they aim to extend their shelf life, ensuring the quality and safety of food products. In addition, the increase in consumer demand for fresh and preservative-free products is generating great interest in developing new packaging. Several improvements have been achieved and proven through research. Thus, active packaging is a promising trend in the food packaging sector. Active packaging has attracted the attention of many researchers worldwide due to its various applications, such as chitosan-based edible coatings and films on fruit to maintain quality and reduce microorganism proliferation and *absorber* sachets (oxygen, ethylene, carbon dioxide, excess water) to increase the shelf-life of fresh products.

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