Active and intelligent packaging: security, legal aspects and global market

Ebalagem ativa e inteligente: segurança, aspectos legais e mercado global

ABSTRACT
Active and intelligent packaging has been based on a interaction of the pack with food and / or the environment that surrounds it. Are on the market active packaging to reduce lipid oxidation rates, control breathing, moisture content and minimize microbial growth. Such packages contain absorbers and emitting carbon dioxide, odor absorbents, ethylene removers, aroma-emitting and antimicrobial compounds. Intelligent packagings include indicators of time and temperature, ripeness indicators and deterioration, biosensors and radio frequency identification. Due to deliberate interaction with food and / or their environment, migration of substances may pose a food safety concern, should their use be regulated in legislation. This article presents: definitions and history of active and intelligent packaging; the main types of materials developed for food contact;
future trends of active and intelligent packaging with a special emphasis on safety, legal aspects and evaluation; and the global market of active and intelligent packaging.

**Keywords:** food industry, packaging market, regulation.

**RESUMO**
A embalagem ativa e inteligente foi baseada na interação da embalagem com os alimentos e/ou o ambiente que a rodeia. Estão no mercado embalagens ativas para reduzir as taxas de oxidação lipídica, controlar a respiração, o teor de umidade e minimizar o crescimento microbiano. Essas embalagens contêm absorvedores e emissores de dióxido de carbono, absorventes de odores, removedores de etileno, compostos emissores de aroma e antimicrobianos. As embalagens inteligentes incluem indicadores de tempo e temperatura, indicadores de maturação e deterioração, biossensores e identificação por radiofrequência. Devido à interação deliberada com os alimentos e/ou seu ambiente, a migração de substâncias pode representar uma preocupação para a segurança alimentar, caso seu uso seja regulamentado na legislação. Este artigo apresenta: definições e histórico de embalagens ativas e inteligentes; os principais tipos de materiais desenvolvidos para contato com alimentos; tendências futuras de embalagens ativas e inteligentes com ênfase especial em segurança, aspectos legais e avaliação; e o mercado global de embalagens ativas e inteligentes.

**Palavras-chave:** indústria de alimentos, mercado de embalagens, regulação.

**1 INTRODUCTION**
Active and intelligent food packaging technologies have been developing due to new consumer habits, production trends and advances in packaging technology. The new eating habits of consumers, because of less time spent buying and preparing food, and the market globalization, has led to a larger distribution of food. However, the proposal about the reduction of the impact of certain plastic products on the environment was provisionally approved on October 2018 by EU parliament, and confirmed by EU ambassadors of the member states on 18 January 2019. One of the main purposes of this directive is to reduce the amount of plastic by 2021\(^1\). This measure present great challenges for the packaging industry, acting as driving forces for the development of new packaging concepts, in order to keep food products fresh, tasty and with prolonged commercial validity, allowing the maintenance, monitoring and food quality, without degrading the environment.

Traditional food packaging has been intended to protect food from external factors such as micro-organisms, oxygen, odors, and light, among others and in doing so guarantee convenience in handling and preserve food quality for a longer period of time. Thus, those packages have been designed to be as inert as possible, that is, with a minimum of interaction between food and packaging\(^2,3,4\). However, in the last decades, food packaging no longer only has a passive role in the protection and commercialization of the product, emerging innovative "active" and "intelligent"
packaging on the market, based on the deliberate interaction of the packaging with the food and its surrounding environment.

The objective of "active packaging" has been to extend the expiration date of packaged foods and to maintain or even intensify some sensory quality, by changing packaging conditions\cite{6,7,8} inserting absorbers/emitters of dioxide carbon, odor absorbers, ethylene removers, aroma emitters and antioxidant and antimicrobial compounds. The purpose of "smart packaging" has been to indicate the chemical modifications that foods have been passing through, offering their indication and monitoring the freshness and degree of maturation of food, due to the presence of indicators of time and temperature, indicators of maturation and deterioration, biosensors and radio frequency identification. These systems monitor the condition of packaged foods to give information on the quality of the food during transport and storage\cite{9}. In this way, food waste can be reduced and customer satisfaction can be optimized\cite{10}.

Due to their deliberate interaction with the food and/or surrounding environment, active and intelligent packaging sets new challenges to the assessment of their safety compared to traditional packaging, having as the main risk the hazardousness of migrating substances from packaging to food. Other risks may occur due to misuse of packaging and insufficient labeling.

For that purpose, Regulation 1935/2004 of the European Union (EU) has been created. That regulation has offered for the first time the possibility of the use of packaging with agents that could migrate to food. In the meantime, that regulation has referred to all materials and articles intended to come into contact with food, also containing general provisions on the safety of active and intelligent packaging. In 2009, Regulation 450/2009/CE came into force, that new regulation establishes specific rules for active and intelligent materials and objects to CE.

In Brazil there has been no specific regulation for active and intelligent packaging, since that new packaging concept has not yet been introduced in MERCOSUR legislation, so the use of active and intelligent packaging has been currently restricted to the substances described in the Positive Lists on materials that may come into contact with food, available in Resolution RDC, No. 17, dated March 17, 2008 and Resolution RDC No. 56, November 2012. There has not been requirement today for declaration of the ingredient on the label of the food and there has not also been requirement of the declaration of conformity issued by the packaging manufacturer. Those materials have been expected to be regulated in MERCOSUR and Brazil in the future. United States law assumes that those concepts have already been covered by current legislation.
The objective of this paper has been to review the history of active and intelligent packaging, as well as to highlight the main types and principles used, future trends with a special emphasis on safety, legal aspects and evaluation, and its global market.

2 ACTIVE AND INTELLIGENT PACKAGING: DEFINITIONS AND HISTORY

Active packaging and intelligent packaging are associated, so they have been called smart packages, although they are conceptually different.

Literature offers several definitions of active and intelligent packaging. However, according to European Union legislation, Regulation 1935/2004 / CE and Regulation 450/2009 / CE, active materials and articles have been defined as materials and articles intended to maintain or improve the condition of packaged foods, increasing their commercial validity, being designed to contain components that deliberately release or absorb substances into the packaged food or surrounding environment. Intelligent materials and articles have been defined as materials and objects that control the state of food or the environment that surrounds it, providing information about the quality of the packaged product.

Although the concepts of active and intelligent packaging have been considered modern they belong to ancestral traditions. In Africa, Asia, and South America, vegetable leaves were, and still have been used to pack foods because of their ability to transfer food, aromatic compounds, colorings, enzymes or antimicrobial substances to food. The leaves have also been used for centuries in Mediterranean regions of Europe, to wrap traditional cheeses allowing good ripening process[2]. Historically the development of active and intelligent packaging had important milestones.

Between 1920 and 1940 the first reports have been published in Europe on the development of active and intelligent packaging. The first researches led to a packaging system that eliminates oxygen, applied by the US Army for dry food[11].

In 1960 Japan started producing oxygen absorbers using sodium hyposulphite, but that packaging has not been widely accepted because of the lack of stability during handling and storage. After years of research, the first large commercial oxygen absorbers appeared in Japan in 1970 under the trade name Ageless®, those packages have been marketed in Japan and subsequently have been introduced in the USA during that decade[11,12].

Moisture and oxygen-absorbent packaging for meat products have been the focus of the research; and have been among the first active packs to be successfully developed and applied to maintain food quality and increase their commercial expiration date[2].
The development of the retail markets for minimally processed fruit and olericulture vegetables, first seen in Europe, especially in France in the mid-1980s, led to the development of films and packaging with modified atmosphere.

Thus, in the 1980s in Japan, the first patents\textsuperscript{[13]} have been commercially used, as a result of the country's early interest in the development of oxygen-absorbent packaging, films for fresh products and several other functional materials.

In that period, films containing a variety of post-inorganic have been reported to assist in the maintenance of freshness and other aspects of increased expiration date\textsuperscript{[14,15]}.

Subsequently, due to the demands of the consumer market and trends in industrial production, many other concepts have been developed, such as ethanol emitters for bakery products, ethylene absorbers for climacteric fruits, carbon dioxide emitters / absorbers, indicators of time / temperature and oxygen, among others.

The first widely disclosed use of the term active packaging has occurred in the assessment of technologies presented at a conference in the EU in Iceland in 1987 being the term related to a time-temperature indicator, developed based on active packaging already commercially available in Tokyo in 1986. The term intelligent packaging has appeared at the same time, being mentioned in literature for the first time in 1986. The word "intelligent" has been used to explain the selectivity of permeable films used for Modified Atmosphere Packaging (MAP)\textsuperscript{[16]}.

Intelligent active packaging attracted the attention of European and US industries only in the mid-1990s\textsuperscript{[12]}. At the same time, Brazil began the works with food packaging, using the concept of plastic films that release gradual doses of the active agent in the product. The packaging has been applied using, as an active agent, the naringinase enzyme that diminishes the bitter taste of grapefruit juice, very bitter American citrus fruit\textsuperscript{[13]}. In that period, there has been a proliferation of patents and market tests that created high expectations of commercial growth process\textsuperscript{[2]}.

Despite the huge popularity of active packaging in Japan introduced in the market in the mid-1970s\textsuperscript{[12]}, its use only now beginning to increase. Lack of clear rules for such application was in fact identified in the late 1990s as one of the major impediments that prevented a wider market penetration of these materials. However, consumer and retailer skepticism about active and intelligent packaging concepts caused a 10-year delay in achieving a reasonable expansion of the market. One strong obstacle undoubtedly was the high cost, often in the range of 20% of the total packaging costs, thus active and intelligent tools were used only for premium-quality, top-end food products and not for food commodities\textsuperscript{[17,18]}.
3 CHARACTERISTICS AND MAIN TYPES OF MATERIALS DEVELOPED FOR CONTACT WITH FOOD

3.1 ACTIVE PACKAGING

The concept of active packaging materializes as a technology to enhance the safety, quality and shelf-life of the foods. Active packaging can contribute to the reduction of food waste by providing, in addition to that of providing a protective barrier against external influence, several functions associated with food preservation, namely absorbing, emitting and removing properties, temperature, microbial and quality control\textsuperscript{[18,19]}.

The active packaging has been based on the intrinsic properties of the polymer or the active substance added to that polymer. An active agent may be incorporated into the material or onto its surface, multilayer structures or particular elements associated with the package, such as sachets, labels or bottle caps\textsuperscript{[20,21,22]}.

According to Dainelli et al\textsuperscript{[2]}, active agents of diverse nature, such as organic acids, enzymes, bacteriocins, fungicides, natural extracts, ethanol, among others, may be used, and those active agents may be incorporated into biodegradable films, papers, plastics, metals or combinations of them. That diversity explains the potential for innovation in that sector, but also represents a real challenge for the safety assessment.

Active packaging can be classified into two main groups: non-migratory active packaging, where there has been no intentional migration of active agents and migratory active packaging, where there has been controlled release of the active agents in the atmosphere involving food to increase the commercial value of the product\textsuperscript{[23,24,25]} and/or change their properties desirably (Figure 1).
3.1.1 Types of active packaging: Moisture and gases absorbers or emitters

Among the active non-migratory packages, the highest application volumes have been in moisture and oxygen absorbers\(^{[26]}\). Presence of moisture and oxygen in food packages lead to rapid spoilage of food due to rapid oxidation of fats or vitamins present, or by promoting the growth of microorganisms like aerobic bacteria, yeasts and moulds\(^{[27]}\).

First those systems have been based on the elimination of moisture and oxygen through self-adhesive labels or included sachets to packaging along with food. At present, the focus has been on the development of packages where the active agent is included in the packaging material itself (mono or multilayer) or in lids, corks, cap sealers and labels\(^{[26]}\). That form of use maximizes the efficiency of the active packaging and minimizes problems arising from the inclusion of a foreign agent into the product inside the package, which can lead to misinterpretation by the consumer and harm the production line.

The oxidative mode of action differs from technology to technology depending on the active compounds applied\(^{[18]}\). Oxygen scavenging based on microorganisms entrapped in solid matrix is an interesting approach due to its environment friendly and inexpensive nature\(^{[27]}\). This technique of elimination of oxygen by microorganisms has already been used by Altieri, Sinigaglia,
Corbo, & Buonocore[28], where encapsulated aerobic microorganisms were used as “active compound”.

Ethylene absorbers have also been widely used to decrease the ripening rate of climacteric fruits, a crucial point for the import and export of fresh fruits and vegetables[18,29]. In addition, the use of such packaging encourages out-of-season marketing, expands markets and can reduce transportation costs.

The chemical reagents trap the ethylene produced by the ripening of fruits or vegetables, the reaction is irreversible[30]. However, the performance of the absorbers depends on the type of product, since the ethylene production for each food has been different[31].

The presence of unpleasant taste or odor in the product has also been a major problem for the food industry, as the formation of those arising from the chemical and enzymatic reactions of the food or the packaging itself may cause product rejection. Taste or odor absorbers are usually inserted into sachets or combined with the packaging material[32]. Although the elimination of unwanted components for flavor or odor has been recommended to improve the characteristics and quality of packaged foods, that technology should not be used to mask undesirable odors produced by pathogenic or deteriorating microorganisms or spoiled food that may endanger the health of consumers.

In the field of active migratory packaging, the inverse function of the emitters also increases the stability and guarantees the quality of several products. Steam-releasing sachets have been used in packaging for ready-to-cook fresh vegetables. Valves are placed in those packages that allow fresh vegetables to be cooked in a microwave oven in the package itself[2].

Emitters of flavor and aroma have also been a rising area, given the possibility of replenishing the flavor and aroma lost during processing and storage. In addition, that concept of packaging allows differentiating the products during the purchase, relating the acquired brand to the sensorial memories of the consumer.

The emitters can be used as a complement or substitution of food components that may be harmful to health[26]. In addition, those emitters may mask the odors generated during food storage or may interact with those odors by neutralizing them[11]. However, as with flavor and odor absorbers, that technology should not be used in a way that could endanger the health of consumers.

Aromas and flavors can be encapsulated and applied as a coating on the package, for example of the films, bottles, lids, pots and cups, or may be incorporated into the packaging material. Until the expiration date or its opening, handling and preparation of the food, the aromas and flavors are...
released, rewarding the loss during storage. The aroma can be released to the outside or into the packaging.\textsuperscript{[26,33]}

Currently the new active packaging have been known as \textit{Controlled Release Packaging} (CRP), which means, packaging that, in a controlled way, release the active compounds as antimicrobial agents, antioxidants, flavor enhancers, enzymes and nutraceutical compounds, among others. The incorporation of metals (zinc and magnesium) for color preservation, enzyme inhibitors, non-stick packaging and many other functionalities also fall into that category of active packaging, many of them produced on the basis of nanotechnologies.\textsuperscript{[26]}

\subsection*{3.1.2 Antimicrobials and Antioxidants}

Antimicrobials and/or antioxidants packaging can be classified into the two types of active packaging, those in which the active agent migrates to the surface of the food or those remain without the need of migration\textsuperscript{[26]}, also being inner packing atmosphere (\textit{headspace}) to prevent microbial growth.

Antimicrobial agents are one of the most studied active components since the foodborne outbreaks denote a major threat to public health.\textsuperscript{[18]} The presence of microorganisms on raw materials and on processed foodstuffs may be pointed out as a major reason for food loss.\textsuperscript{[19,34]}

Several antimicrobial agents can be incorporated into the packaging system and can be classified into two groups: chemical agents, such as sodium benzoate, potassium sorbate, silver ions, among others; and natural agents, such as essential oils and enzymes.\textsuperscript{[18,36]} Besides those, packaged with modified atmosphere with carbon dioxide injection are examples of antimicrobial packaging, due to their fungistatic and bacteriostatic activity, and the emitters of ethanol and CO2, due to their activity on the development of fungi in food and in their own packaging. When compounds are incorporated in plastic packaging, they generate bioactive polymers. Several chemical compounds, natural and probiotic have been had their antimicrobial potential analyzed, such as metal ions, natural extracts, organic acids and their salts, bacteriocins, fungicides, enzymes, alcohols, gases (chlorine dioxide, triclosan) and natural extracts. Antimicrobial packaging based on the imprisonment of silver ions to the polymer used has been commonly used in Japan and USA\textsuperscript{[37]}; however, those systems may present faults, leading to some degree of migration. Thus, there has been a strong need for a better understanding of the mechanisms involved in the active principles to assess the potential risks.
One of the advantages that have been leveraging the use of antimicrobial packaging in recent years, has been the possibility of using a lower concentration of synthetic chemical preservatives in foods.

The advantage of enclosing antioxidants within the packaging material surpasses the beneficial of their direct inclusion in food formulations. A multitude of antioxidant compounds are known to impart antioxidant activity to active packaging systems. Therefore, a judicious selection should be carried out by considering the food characteristics as well as health and safety issues. The tendency is to move from synthetic antioxidants, which are now suspected to be potentially harmful to human health, towards natural antioxidants with lower toxicity and higher safety\cite{18}.

Besides the antimicrobial action, packages with antioxidants can be used to control lipid oxidation. That type of packaging acts mainly by the mechanism of free radical sequestration, thus avoiding the continuation of oxidation reactions. Synthetic antioxidants approved for contact with foods are options of antioxidant agents, as well as natural antioxidant extracts, which have been the subject of the most recent studies of that application. A proposal has been the association of that technology with the absorbers of moisture and/or oxygen, increasing the potential of protection of the food\cite{26}.

3.1.3 Packaging that facilitates freezing, self-heating or self-cooling

Electroconductive films can be used in a freezing system, which use electric current to rapidly freeze the product, minimizing oxidation and reducing the size of the ice crystals formed in the food cells. The film enables the process to preserve the flavor and texture of the food, besides increasing the expiration date of the product\cite{26}. The self-heating or self-cooled packagings have been attracting consumers because of the great appeal of convenience.

Exothermic reactions have been used for self-heating, such as water and calcium oxide or magnesium. For self-cooling, endothermic chemical reactions have been used, which steals heat from the external environment, or heat pump technology, which uses water vapor or another compound, such as CO2, as coolant for heating transfer. Those technologies are usually associated with accessories attached to the packaging\cite{26,32}.

3.1.4 Edible coatings

The use of edible coatings, films and covers have been received much attention from researchers and the food industry in recent years, mainly due to its barrier properties, to improve the
appearance of packaged food and its biodegradable characteristics, being considered ecologically correct\(^{[20,38]}\) or Eco-friendly (environmentally friendly packaging).

Films and coatings differ in their form of application: the coatings are applied and formed directly on the food, while the films are preformed separately and subsequently applied to the product\(^{[39]}\).

The coatings are formed of, at least, one component capable of forming a continuous and cohesive matrix, such as macromolecules, proteins, lipids and polysaccharides\(^{[39]}\). The edible coatings can be applied in several products in order to control gas exchange, moisture transfer and oxidation processes\(^{[38]}\). Thus, the coatings act mainly by modifying the internal atmosphere of the products reducing their degradation. In addition, edible coatings may carry additives such as antimicrobial compounds, antioxidants, increasing the expiration date and improving the characteristics of the product.

Currently, organic acids and essential oils have been added to the edible coatings in order to promote an antimicrobial action. Despite the good results obtained so far with the incorporation of essential oils into edible coatings, its great disadvantage has been the strong flavor that can alter the original flavor of the foods\(^{[30]}\).

3.2 INTELLIGENT PACKAGING

Intelligent packaging has been a pack that somehow detects some properties of packaged food and transmits that information to the manufacturer, retailer or consumer\(^{[40]}\). Those packaging systems consist of sensors, biosensors or indicators\(^{[5,41]}\) based on chemical, enzymatic, immunochemical or mechanical reactions. However, few intelligent packaging types are commonly used yet, mainly due to economic issues and acceptance of dealers/brand owners\(^{[4,10]}\).

Most sensors used in intelligent packaging systems can contain two basic functional units: a receiver and a transducer. In the physical or chemical receiver, the information is transformed into energy, which can be measured by the transducer, that is a device capable of transforming the chemical or physical energy, which carries information about the product in an analytical signal, for example sensors of ethylene to monitor the ripening of fresh fruits\(^{[42]}\).

Biosensors are organic materials such as enzymes, antigens, microorganisms, hormones, and nucleic acids. Biosensor systems have been used to detect the loss of food freshness, as well as indicate the presence of microorganisms\(^{[42]}\), its toxins or specific contaminants such as pesticides.

The indicators differ from sensors and biosensors, since they do not have components such as receivers and transducers, and communicate the information by visual changes of a device made
from natural or chemical compounds. Despite the large varieties of indicators, they can all be reasonably included within three categories: time and temperature indicators, freshness indicators and gas indicators\textsuperscript{[41]}. Despite those different definitions, nowadays, it has been observed that in the literature it has been more usual only the use of the term "indicators" for all types of packaging.

Application of indicators can facilitate the delivery of fresh food produce; observation and supervision of food produce thus decreases product waste from foodstuffs and extends shelf life. Modern indicators offer consistent and reliable responses according to their specifications\textsuperscript{[5]}.

3.2.1 Types of Intelligent Packaging

Intelligent packaging systems can be made with labels or sachets, incorporated into the packaging material or printed on them. Thus, intelligent packaging offers greater possibilities to monitor the quality of the product because they trace the critical points and provide more detailed information along the supply chain\textsuperscript{[12,43]}.

The first indicators to be designed were the diagnostic indicators, such as temperature, time, oxygen or carbon dioxide indicators\textsuperscript{[2]}, however, indirectly, those already provided information on the quality of food.

Currently, indicators of time and critical temperature are examples of intelligent packaging, gas detection devices, indicators of freshness, indicators of leaks and indicators of growth and microbial toxins\textsuperscript{[2]}.

The mechanism of action of those signals involves the rate of polymerization, diffusion or chemical and enzymatic reactions, which leads to a change of color when those changes reach critical levels\textsuperscript{[33]}. Those modifications can be used to monitor the quality of the food, the integrity of the packaging or to verify the effectiveness of the absorbing oxygen, acting indirectly in the control of the active packaging.

Although they have similar functions to the temperature indicators, the indicators of quality, freshness and maturation measure the compounds directly related to product quality, resulting from microbial development or chemical changes\textsuperscript{[26]}, thus, unlike the indicators of temperature, the signal of the quality indicator, freshness and ripening depends directly on the quality of the product and not only on the temperature history. Because of that difference, smart packages can be classified as "indirect indicator packages", based on measuring the outside condition of the packaging, and "direct indicator packages", which directly measure the quality of the food product (Figure 2)\textsuperscript{[12]}. Currently the trend in that sector has been the development of "direct indicators" due to its ability to provide more accurate and specific information on the attributes of the food.
Direct or directed-quality indicators may be volatile compounds, such as volatile compounds of microbial origin, such as carbon dioxide, nitrogen compounds, among others, or biogenic amines, toxins, as well as the pathogenic bacteria themselves. Nowadays there have been available direct indicators for the detection of the level of maturation based on the detection of volatile aromatic compounds and direct indicators for the detection of the degree of freshness of fish based on the detection of volatile. More sophisticated systems rely on depositing on the bar code, a plastic layer loaded with specific antibodies of pathogenic microorganisms, such as Salmonella or Listeria, which their presence can be detected when the bar code is read\textsuperscript{[2]}. It has also been possible to find indicators of physical shock, adulteration, anti-counterfeiting and anti-theft technology\textsuperscript{[40]}.

Despite advances in the area of smart packaging, there have been few packaging coming to market, that has been possibly due to the high cost of an indicator label, legislative restrictions and even the acceptance of retailers and brand owners who fear the use of packaging given the irregularities that may occur in the production and marketing of the product. That market restriction occurs mainly in Europe due to its rigid legislation.

Another obstacle to the use of smart packaging has been the possible flaws in packaging, which leads to mistrust on the part of the industry and consumer.
4 TRENDS IN ACTIVE AND SMART PACKAGING AND SECURITY ISSUES

During the last decade, active and intelligent packaging have experienced significant growth and change as new products and technologies have challenged the status quo of traditional forms of food and beverage packaging[44].

Among the emerging technologies, nanotechnology-based packaging have been expected to comprise a significant portion of the food and beverage packaging of the market, leading to the development of new smart packaging[45,46].

Nanotechnology uses nanoscience to manipulate and create nanometer-scale materials[46,47,48]. The most commonly used nanocomposites in the food packaging industry are clay and silver nanocomposites[30], however new packaging technologies will depend on the development of new nanomaterials and nanoparticles[45]. Copper nanoparticles and zinc nanocrystals have been used to inhibit antimicrobial development, in addition, different oxide nanoparticles, such as titanium dioxide (TiO\(_2\)), zinc oxide (ZnO), silicon oxide (SiO\(_2\)) and magnesium oxide (MgO), are found in food packaging because of their ability to act as UV blockers[46]. Some of the advantages associated with the use of those nanocomposites include the development of new food packaging materials with better mechanical, barrier, antimicrobial properties, heat and cold stability, extending the commercial validity of the product[12,46,48], being necessary for that only a small amount of nanoparticles[2]. The preferred size range is from 100 nm down to the atomic level because at this level the properties of materials can vary interestingly compared with those at a larger scale[48].

Nanoscale technologies are also under development to improve traceability and monitoring of food status during transportation and storage. Other applications include carbon nanotubes or nanosensors. The former can be used in packaging food products to alter its mechanical properties, and it has been observed that it may also exert antimicrobial effects, whereas nanosensors could be used to detect chemicals, pathogens and toxins in food[12,48].

Another expanding area has been the Radio Frequency Identification Labels (RFID), which uses radio frequency electromagnetic fields to store and transmit real-time product information for automatic identification and traceability. RFID tags are advanced data carrier with a data storage up to 1 MB[10].

RFIDs consist of an integrated circuit connected to an antenna for transmitting the information stored on the chip to a reader, the data are then passed to a central computer for analysis and decision making[33,37]. Labels are placed outside the primary packaging and do not require any associated power source since the system operates from the radio waves received from the reader.
The radio frequency field produced by the reader provides sufficient power for the tag integrated circuit\cite{45}. They have the capacity to store a large number of information, such as origin, process parameters and business information, which allows a unique identification of the product, during all phases of the supply chain\cite{47}.

The most advanced RFID systems already allow the integration of other functions, such as time and temperature indicators or biosensors, to monitor and communicate the history of the product temperature, as well as information about the quality\cite{49}. Those labels are also promising in use against forgeries, theft, and waste reduction. However, there are still limitations in nanocommunication, besides the cost in relation to the food product\cite{45}.

The packaging captures the volatile compounds released by the fruit in ripening and the label placed on the outside of the package reacts by changing color according to the ripening levels.

Another trend that is being considered as active and intelligent packaging is the *Fruit Wash Labels* sanitation seal. That seal, which has already come adhered to the fruits, have cleaning agents that allows its hygiene without the need for an additional product. That technology has been developed by Scott Amron and has still been undergoing experimentation.

Despite highlighting trends separately, currently, what has been observed is an integration among the various concepts of intelligent active packaging, so in the near future we will have on the market active and intelligent packaging with multiple functions, integrating indicators of temperature, maturation, biosensors, and others, all read in a RFID system for example\cite{50}.

Advances in the electronic technologies used to create devices on a wide range of substrates contribute to the integration of those intelligent systems. Carbon nanotubes coated with conductive polymers also offer new opportunities for the adaptation of the electrical properties of the materials, since they have better properties due to their electron transferability\cite{37}. Researches, ongoing development and cost reduction will contribute to the further adoption of that technology in the food industry.

It has been possible be seen that the development of active and intelligent packaging has been very dynamic and has been realized due to the search for practicality and safety, without, however, leaving its rational side. In that context, custom packaging design has been a real challenge and involves the use of a holistic approach based on real food needs and not just the availability of packaging materials. Nanotechnologies and active migratory and non-migratory agents play an important role, taking into account all the additional safety considerations required to use those new packaging. Sustainability issues associated with the reduction, reuse and recycling of those packages have also been of great importance in new developments.
4.1 PILLARS OF SECURITY IN ACTIVE AND INTELLIGENT PACKAGING

Safety assessment of active and intelligent packaging has been more complex than traditional food packaging. In the evaluation of traditional packaging, the migration rate of packaging components for the food, which should be limited, and the ability of the packaging to protect food from external agents are mainly considered.

In active and intelligent packaging, more factors must be controlled, since the inclusion of substances in the packaging material may alter its permeability, mechanical properties, and sealing ability, which can lead to changes in the food and consequent loss of safety. Thus, more targeted legislation should be formulated to meet the quota of active and intelligent packaging available in the market.

Initially Dainelli et al.\cite{2} describe that safety in relation to active and intelligent packaging should be based on three main pillars:

1. Labeling in order to avoid misuse and misunderstanding by users or consumers, as an example to prevent sachets from being ingested.
2. Migration of active and intelligent substances as well as of all degradation products according to their toxicity.
3. Effectiveness of packaging in some cases, the ability of the packaging to perform the intended function can raise safety concerns, for example, the use of oxygen absorbers improperly inducing microbial resistance or providing erroneous information about the presence of bacteria pathogenic to direct indicators.

Despite the existence of those three pillars, other factors must also be taken into account when setting safety in active and intelligent packaging. The reassessment of those three initial pillars also becomes necessary to support such an innovative and expanding field. Thus, four new pillars should be discussed and added to those three existing ones (Figure 3):

1. Legislation should be re-evaluated and, when possible more flexible, as also commented by Dainelli et al.\cite{2}, with the inclusion of new guidelines.
2. The labeling and reliability of active and intelligent packaging should be improved to prevent errors in use or identification of the information recorded on the packaging. Thus, it has been necessary to require the declaration of the active agent on the food label, the declaration of conformity issued by the packaging manufacturer, with presentation of calibration reports of the system used, and the presence of easily understood and prominent information about the correct reading of the indicators.

\cite{2}
3. Toxicological issues should also be addressed. Nanoparticles, for example, can bind to undesirable substances and migrate into the food, so full understanding of the effect of introducing nanostructures into active and intelligent packaging has to be ensured, the toxicity of the various active agents as antibacterial substances, the products generated in the reaction of a compound or any other agent that migrates to the food should also be studied.

4. The environmental and economic performance of active and intelligent packaging should be evaluated to reduce the environmental impacts associated with its production, use and disposal. Thus, ways to reduce, reuse and recycle active and intelligent packaging, as well as the risks of the accumulation of those packaging or its active agents in the environment, should be studied.

The commercial viability of an active and intelligent packaging has not only been limited to the extent of expiration date and greater food safety, but can also result in logistical advantages. Those include reduced food waste, the possibility of transporting mixed products in the same place for long periods (land or sea transport), and the greater ease of storage and handling. However, as with any other new technology, an assessment of its risks needs to be performed regardless of the apparent benefits.
5 LEGISLATION IN ACTIVE AND INTELLIGENT PACKAGING: NATIONAL, INTERNATIONAL AND FUTURE PERSPECTIVES

Despite the increasing commercialization of active and intelligent packaging systems, until 2004 when the first UE regulation has been enacted there have been no specific methods in the legislation to determine the suitability of active and intelligent packaging. However, regulations like that have not been the reality of many countries, and as a result, legislation that applies to traditional packaging materials has been applied to active and intelligent packaging systems, a fact that occurs in MERCOSUR where Brazil is inserted.

In Brazil the Positive Lists on packaging materials that can come into contact with food have been followed, available in Resolution RDC, nº 17, of March 17, 2008 and Resolution RDC No. 56, of November 2012. The RDC nº 91 of May 2001 establishes the general criteria and classifies materials for packaging and equipment in contact with food. However, since active and intelligent packaging focuses on the deliberate interaction of the packaging with the food and/or the surrounding environment, such regulations become incipient.

The European Union Regulation 1935/2004 / EC offered for the first time the opportunity of using active packaging, as it allowed the application of materials or active agents that could deliberately migrate to food. It also brought general provisions on the safety of active and intelligent packaging and set out the framework for the evaluation process established by the European Food Safety Authority (EFSA) for any substance that comes into contact with food regardless of its degree of toxicity.

EFSA's safety assessment focuses on three risks related to exposure of chemicals. Those include the migration of active or intelligent substances, the migration of their products of degradation and/or reaction from those substances and their toxicological properties. Besides, information has been collected on the effectiveness of the intelligent packaging and the intended effects with the use of the active packaging, and such packaging must be verified by the manufacturer with the presentation of reports.

In 2009, the Regulation 450/2009 / EC, also of European Union detailed specific rules for the safe use of active and intelligent materials and agents, in addition to the general requirements established by Regulation 1935/2004 / EC. That new regulation, which is still in force, provided a partial explanation for the lack of penetration of active and intelligent packaging in the EU, compared to Japan, the United States and Australia, where more flexible regulations allow technological innovations in the sector of food packaging.
Just as in Brazil, in those countries there are no specific regulations related to active and intelligent packaging, because according to Restuccia et al.[12] and Robertson[16] they consider that if substances used in active packaging have no toxicological concern, do not result in undesirable migration into a food, do not give rise to taste or odor problems and are not be used to deceive the consumer in any way, such components are not of concern, toxicological analysis have not been required or has been greatly minimized by exposure assessment. Thus, considering the regulatory requirements for new active and intelligent packaging technologies, it can be seen that in the United States they have not been very different from the requirements for traditional packaging materials, being subject to authorization regulated by the Food and Drug Administration (FDA).

In Europe, all active packaging systems that intentionally release substances into the food must comply with the legislation for direct food additives (Regulation 1333/2008 / CE), that is, the released substance must be listed on the country's Positive List of Additives and its use must characterize a technological need, however, they must also comply with the provisions of Regulation 1935/2004 / EC and its implementing measures.

Packaging that does not intentionally migrate active agent to the food must meet the specific requirements of Regulation 1935/2004 / EC and its lack of migration to food must be duly substantiated. Although it is a non-migratory agent, the substances used cannot be carcinogenic, mutagenic or toxic.

The Regulation 450/2009 / CE, brought other safety guidelines. That regulation states that nanotechnology cannot be used without further evaluation, even when direct contact with packaged food is impossible because of a functional barrier. All types of nanoparticles intended for use in food packaging should be evaluated until more information is available on that new technology, and the maximum level of migration is 0.01 mg per kg of feed.

Labeling has also been covered by those new EU regulations. However, it must also comply with the requirements established in other regulations in force in the country related to the sale of food and the labeling of food additives.

In order to avoid that inedible parts of active and intelligent packaging to be accidentally ingested, Regulation 450/2009 / CE recommends the labeling "INEDIBLE" and where technically possible, with the symbol reproduced in annex I to that Regulation (Figure 4). That information must be visible, clearly legible and indelible in sachets or any other inedible active agent. Regulation (EC) No. 450/2009 “on active and intelligent materials and articles intended to come in contact with food” is most important legislation in this field[17].
Figure 4. Symbol for "Inedible" parts in labeling material in contact with food. Source: Regulation 450/2009 / CE.

It is worth mentioning that according to the European regulations, there still have been some specific directives for each type of active and intelligent packaging, which must be followed according to the intended framework, for example, has a directive to test the migration of active agents in contact with food and for compliance testing (82/711 / EEC and 85/572 / EEC), for the regulation of direct food additives (89/107 / EEC), for the sale of food (79/112 / EEC), for the labeling of food additives (89/109 / EEC), among others.

Despite apparent benefits to consumer safety, the EU Regulation was criticized by Heckman\textsuperscript{[51]}, being seen as a commercial attempt and not as something to fill a regulatory gap as it brings unnecessary regulatory complications and of questionable value.

Criticism aside, it can be seen that the evaluation of active and intelligent packaging has been expensive and, due to the complexity of those systems, many variables can be introduced into the process of risk assessment.

There are many problems related to the safety of active and intelligent packaging, undue migration, compounds of unexpected reactions, ingestion of inedible parts, microbial resistance due to incorrect use of indicators or growth of pathogenic or deteriorating microorganisms

Nanotechnologies have also been heavily focused on issues related to the safety of active and intelligent packaging, since despite the few data on toxicity and oral exposure of nanoparticles, several food packages containing those compounds are being developed. According to Restuccia et al.\textsuperscript{[12]}, the small size of the nanoparticles leads to assume unique chemical and physical properties that are different from their macro-scale counterparts, such as the high surface-to-volume ratio that allows a greater capacity of absorption and migration\textsuperscript{[2]}, which leads to another worrying fact that has been the effect of nanoparticles in the environment and throughout the food chain.
RISE OF THE GLOBAL MARKET FOR ACTIVE AND INTELLIGENT PACKAGING: 2002-2022

Packaging has been an essential component of the market as it affects virtually every industry. Each product, even organically grown food, needs some form of packaging for its protection during transportation, handling, storage and use. 99.8% of all food and beverage items have some form of packaging. For that reason, the food and beverage industry has been constantly evolving, being developed new technologies to improve product quality, extend its commercial validity and positively impact product profitability, reducing waste and deterioration\(^\text{[12]}\).

Food waste is one of the main issues for international organization such as FAO and the interest is growing in most of the countries, in particular in industrialized ones. Wasting food is not only an ethical and economic issue but it also depletes the environment of limited natural resources\(^\text{[52]}\). In 2002, the global market, which includes active, controlled, intelligent packaging and advanced packaging components, was responsible for about US $ 1.4 million, with more than 80% represented by oxygen absorbers and moisture absorbers (40% each), mainly applied in the areas of optical devices, electronic tools, medical and pharmaceutical preparations, among others. Food packaging represented a very small fraction of the market that year and it has almost been entirely concentrated in Japan. Despite the lack of expressiveness, the food packaging sector has been identified as the market with rapid growth due to expectations of increased consumption of perishable foods prepared in Modified or Controlled Atmosphere Packaging (MAP / CAP), a field considered ideal for packaging applications with oxygen absorbers\(^\text{[2]}\).

In 2005, the global market increased from US $ 15.5 billion to US $ 16.9 billion by the end of 2008, with an increase of US $ 23.6 billion expected by 2013, with an annual growth of 6.9%. Oxygen absorbers, moisture controllers remained market leaders accounting for 37% and 16% of the world market for active packaging, respectively\(^\text{[12]}\); however the ethylene absorbers and the edible coatings have also been significant to the market.

Although they have been significant in the market, antibacterial films have been well accepted almost exclusively in Japan. They have been an example of the strong influence that regulatory issues can exert on the market for those materials: the use of antibacterial films in food packaging has always been questioned, because the industries could compensate the lack of hygiene using such films\(^\text{[2]}\).

Intelligent packaging represented a segment of US$ 1.4 billions in 2008. The smart packaging industry has been spearheaded by electronic surveillance technologies such as radio
frequency labeling (RFID and other quality indicators such as time and temperature indicators and biosensors. However, it is questionable whether the RFID tag alone can be classified as active or intelligent food packaging materials, because according Dainelli et al.\cite{2}, they do not exactly match the definition of “interacting with food or the atmosphere in which the food is exposed, providing information about the quality of the food and its storage conditions”.

In 2011 there have been a bigger growth than predicted by research carried out in 2010 for the global packaging market, an increase of US$ 0.9 billion have been forecast, rising from US$ 1.4 billion in 2008 to US$ 2.3 billion in 2011\cite{12}. However, according to research conducted by the BBC American Research Institute in 2011, the global packaging market (which includes active, controlled, intelligent packaging and advanced packaging components) reached US$ 31.4 billion, increasing to US$ 33.3 million billion in 2012 and totaled almost US$ 42.5 billion in 2014\cite{53}.

Market growth looks promising and the global market value for 2017 is projected to be about US$ 44.3 billion\cite{54} and US$ 48.3 billion by 2020 at a compound annual growth rate (CAGR) of 2.2% by 2020\cite{53}.

In 2011, the market has been dominated by controlled packaging (US$ 12.4 billion); active packaging has been alongside the market share with almost $ 8.8 billion in sales, growing to $ 11.9 billion in 2017. Sales of smart packaging have been almost $ 3.8 billion in 2011, the market has been valued at US$ 12.6 billion in 2016 and is forecast to reach US$ 19.8 billion by 2021 with a CAGR of 9.4% over the forecast period\cite{55,56}.

Oxygen and moisture absorbers remained market leaders, with the main types of active packaging products being marketed in 2012\cite{57}.

As a percentage between 2010 and 2015, packaging with advanced technology accounted for 5% of the entire packaging market, of which 5%, 54% have been modified atmosphere packaging, 35% active packaging and 11% intelligent packaging\cite{58}.

The growth for smart packaging will be significantly higher than that of active packaging and will be driven by rapid advances to newer and emerging technologies, such as the electronic codes printed on the packaging\cite{57}.

The FREEDONIA group\cite{59} in its report about active & intelligent packaging forecasts an expansion of the demand for active or intelligent packaging in the US of 7.3 percent annually to $4.0 billion in 2019. Intelligent packaging demand will see the faster growth, advancing at a double-digit rate and reaching $1.5 billion in 2019 as products such as time-temperature indicators and smart labels and tags become more common.
The FREEDONIA group in its report about active & intelligent packaging forecasts an expansion of the demand for active or intelligent packaging in the US of 7.3 percent annually to US$ 4.0 billion in 2019. Intelligent packaging demand will see the faster growth, advancing at a double-digit annual rate. Intelligent packaging such as time-temperature monitors and smartphone-enabled interactive labels and tags will be the fastest growing segment.

Nanotechnology has been projected to have an impact of at least US$ 3 trillion on the world economy by 2020. According to the forecast of the European Institute of Health and Consumer Protection, the market for food packaging based on nanoparticles is expected to reach US$ 20 billion by 2020 and the market for active and intelligent packaging has been expected to reach US$ 32.7 billion growing at a CAGR of 11.0% by 2022. Gains will also be aided by increased use of electronic tags (RFID) along with time and temperature indicators due to the increasing demands of sensitive drugs to temperature and more demanding food safety regulations that require more control and traceability.

Although the food packaging market has been expanding according to Stratistics MRC, the pharmaceutical industry will be the higher growing segment.

Considering the dissemination of active and intelligent packaging on the EU market, it should be mentioned that the problems of acceptance by user industries, as well as the more conservative behavior of European consumers on food innovations, have been key points that still need to be addressed. If compared to Japan, USA or Australia, the penetration of active and intelligent packaging in European markets has been limited.

Nowadays, another fact that should be considered for the low diffusion of active and intelligent packaging in the EU has been the existence of inflexible regulations to the point of not following the technological innovations of the food packaging sector.

Brazil also faces problems to inserting active and intelligent packaging in the market. According to FAPESP research Magazine, the variety of packaging found in Brazil has still been restricted to the profile of the Brazilian market, where large volumes are of low added value. The most of the packages developed here continue only in the laboratory phase of experiments.

Overall, the food industry and retailers have also been reluctant to invest in smart active packaging. The concern is due to the fact that the packaging may report processing, distribution or storage failures, which would increase the quantity of unsold foodstuffs leading to financial losses and disrepute in the brand or market network.

Despite the difficulties faced, the growth of the active and intelligent packaging market is being driven by the increasing use of packaged foods, especially those that have been sold in smaller quantities.
portions and are of ready consumption, such as microwave meals\textsuperscript{[64]}, individual fast food, and foods with a lower content of synthetic chemical additives, which can be preserved by adding natural substances, such as packaging with essential oils\textsuperscript{[65]}. However, the technical limitations and high costs of those packages has still been a limitation for the market\textsuperscript{[41,45]}.

In the future, the development of new technologies will lead to new generations of better performing products and more competitive prices, which will stimulate greater market acceptance. However, for that to be achieved, the safety and benefits of smart active packaging have to be better demonstrated to increase the number of products launched on the world market. It has also been expected to increase the use of active compounds derived from natural resources, as well as the incorporation of packaging materials developed with biodegradable polymers.

7 CONCLUSION

The concept of "packaging" as a simple tool for food marketing has been changing to match the needs of consumers and the food industry. New of active and intelligent packaging systems, which allow greater safety and better traceability of food, are being developed.

However, recognizing the benefits of those technologies by the food industry and increasing consumer acceptance has been necessary for market expansion, which can be achieved through the development of environmentally friendly packaging (Eco-friendly), which have been more widely accepted because they are made from renewable sources.

Active and intelligent packaging has long been marketed without specific safety concerns, so the creation of EU regulations has provided greater food safety and transparency for consumers. Despite the lack of flexibility in some of its directives, regulations such as those have been extremely important and should be covered in other countries, like Brazil, which is part of MERCOSUR.

Ensuring the safety of active and intelligent packaging has been a costly task, given the complexity of the systems, which often introduce many variables for risk assessment. Thus, the development and validation of migration tests reliably detect the migration of active agents can pose a serious challenge as well as risk assessment for nanoparticles.

Although there have been many obstacles, the market for active and intelligent packaging has been on the rise, which shows that sector will be a tool with high market potential. The main obstacles that limit the sector have been legal restrictions on old laws, inflexible regulations, and industry and consumer disbelief in acquiring those products. However, as legislation becomes more coherent, legal requirements are met, and industries and consumers quantify economic benefits and
improve food quality and/or safety, it has been very likely that presence of active and intelligent packaging in supermarket shelves.

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