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Active packaging systems for a modern society

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Abstract : Nowadays, there has been a change in the paradigm of food packaging. Active packaging of food is a good example of an innovation that goes beyond the traditional functions of the package in which the package, the product and its environment interact to extend the shelf life of food or to improve its safety or sensory properties, while maintaining the quality of the packed food. Market growth is expected for active packaging with leading shares for moisture absorbers, oxygen scavengers, microwave susceptors and antimicrobial packaging. The material chosen for the packaging has a high influence on the antimicrobial compound migration, a topic that has been specifically addressed in this article, providing an overview of the most relevant scientific works published in the last decade concerning the use of different packaging materials. Nevertheless, apart from the beneficial antimicrobial action, active packaging can be responsible for the transfer of nondesirable substances, which must be controlled in order to guarantee the compliance of the established regulations and the consumers' safety. The ultimate goal of an active packaging system should be the reduction of food loss and waste, extending product shelf life and reducing waste by clarifying the suitability of a product for consumption. This article reviews: (1) the different categories of active packaging concepts and currently available commercial applications, (2) latest packaging research trends and innovations, and (3) the growth perspectives of the active packaging market.
Key words: Active packaging, Shelf life, Antimicrobial, Antioxidant.

1. Introduction

Packaging is extensively used for preserving, distribution, marketing fruits, vegetables, is frequently used in combination with other protection methods[1,2]. Food packaging technology is continuously evolving in response to growing challenges from a modern society. Major current and future challenges to fast-moving consumer goods packaging include legislation, global markets, longer shelf life, convenience, safer and healthier food, environmental concerns, authenticity, and food waste[3]. Every year a growing amount of edible food is lost along the entire food supply chain. Annual food waste generation estimates in Europe are around 89 million tonnes varying considerably between individual countries and the various sectors[4]. Spoilage of raw meat along the food supply chain (production, retailers, consumers) represents a loss which could be as high as 40%[5]. Active packaging is an innovative concept in which the package, the product, and the environment interact to prolong the shelf-life, or to enhance safety or sensory properties, while maintaining the quality of the product. This concept, which is of special importance in the area of fresh and extended shelf-life foods[6] have recently benefited with the use of nanotechnological materials including nanocoatings and nanoparticles[7]. The antimicrobial properties of silver nanoparticles (AgNPs), for example, have been increasingly exploited in consumer products such as deodorants, clothing, bandages, as well as in cleaning solutions and sprays[8] as antimicrobial agents[9]. It has been reported that some antimicrobial agents may affect the physical properties, processability or machinability of the packaging material. Interest in active packaging as an approach to improve the quality and increase the shelf-life of food products has grown[10]; antioxidant active packaging has been a particular focus of attention[11]. The amount and rate of release of the antioxidant compounds are fundamental to the extent and duration of the protective effect of the packaging; studies have been undertaken on the production of controlled-release packaging that optimizes the characteristics of the plastic polymer to regulate the release of the active substances[12].

Most important active packaging concepts applied to muscle foods include moisture absorbers, antimicrobial packaging, carbon dioxide emitters, oxygen scavengers, and antioxidant packaging. The aim of this review is to provide an update of the current commercial applications as well as to present an overview of research trends and innovations in active packaging systems for muscle based foods. Concluding remarks include future trends and expected growth of active packaging systems in food preservation.

2. Moisture absorbers

Excess water developed inside the package of high water activity products such as muscle based foods promotes bacterial and mould growth, resulting in quality losses and a reduction of shelf life. The control of excess moisture in food packages is important to inhibit microbial growth and enhance product presentation. An effective way of controlling excess water accumulation in a food package that has a high barrier to water vapour is to use a moisture absorber[13]. The most common moisture absorbing systems consist of a super absorbent polymer located between two layers of a microporous or nonwoven polymer. This material is supplied as sheets of various sizes that are used as drip-absorbing pads typically found in tray-formatted (overwrap and modified atmosphere) fresh muscle food products[10].

3. Carbon dioxide emitters

This type of active packaging is frequently associated with modified atmosphere (MAP) systems in order to balance out CO_2 losses due to dissolution into the meat and permeation through the packaging material[14]. CO_2®FreshPads (CO_2 Technologies) are used for meat, poultry, and seafood packaging[15]. Drip losses from muscle foods are absorbed into pads and react with citric acid and sodium bicarbonate present in the pad resulting in the generation of carbon dioxide[10]. Paper Pak Industries have launched UltraZap® XtendaPak pads, amore evolved version of CO_2 generators. It is designed as an absorbent pad for fresh meat, poultry and fish that has a double antimicrobial effect due to the incorporation of a CO_2 emitter and an antimicrobial substance[16]. According to the information contained in the patent, the antimicrobial agent used would mainly consist of a mixture of citric and sorbic acids[17]. A recent CO_2 emitter application has been developed for fish fillets by a Norwegian company, Vartdal Plastindustri AS, also available for meat packaging[18].

4. Oxygen scavengers

Oxygen scavengers based on the inclusion of microorganisms which may have advantages regarding consumer perception and sustainability, have been developed as an alternative to chemical scavengers. Anthierens et al. (2011) incorporated Bacillus *amyloliquefaciens* spores as an active agent in polyethylene terephthalate, 1,4-cyclohexane dimethanol[19]. Incorporated spores could actively consume oxygen for minimum 15 days, after an activation period of 1–2 days at 30 °C under high humidity conditions. Enzymes such as glucose oxidase/catalase have also been proposed as oxygen scavenging systems[20]. Recently, enzymes embedded in barrier coatings for active packaging have been tested in food applications[21].

5. Antimicrobial packaging

Antimicrobial packaging is an alternative method to overcome the limitations of antimicrobial agent as food preservative, because antimicrobial agent is interacted in the complex food system and it cannot selectively target the food surface where spoilage reactions occur more intensively[22, 23].

An important number of antimicrobial silver-based masterbatches are available in the market: Biomaster®, AgIon®, Irgaguard®, Surfacine®, IonPure®, d2p®, Bactiblock®. LINPAC Packaging Ltd. has teamed up with Addmaster to develop a range of antimicrobial trays and lidding solutions containing Biomaster® silver-based additive to reduce the growth of foodborne pathogens such as Salmonella, Escherichia coli and Campylobacter in fresh meat[24]. Similarly, Food-touch® from Microbeguard Corp. is an antimicrobial specialty paper containing Agion® silver based additive (Sciessent LLC) used as interleavers for fresh fish fillets during transportation in boxes[25].

Nanopack Technology and Packaging SL in collaboration with IRTA is developing a range of interleavers (Sanic films) able to extend the shelf life of vacuum packed meat products[26]. Some companies offer other antimicrobial packaging solutions for meat products. SANICO® (Laboratories STANDA) is a natamycine-based antifungal coating for sausages[27]. Many research groups have developed antimicrobial solutions for meat packaging containing nisin in order to delay the growth of spoilage microorganisms and foodborne pathogens[28]. Most of the literature concerned with the effect of active packaging on yeasts focused on organisms that are responsible for food spoilage (Table 1), however some studies included the human pathogen *C. albicans*. These studies are out of the scope of this article, however these technologies can be used for medical applications.

Table 1. List of active packaging films tested for their antimicrobial effects on yeasts[29].

Organism	Medium	Technique	Active packaging Molecules tested	Concentration
Candida albicans	Agar medium	Patented coating on PP films with EO's	Oregano, cinnamaldehyde, thymol, carvacrol	2, 4% (w/w)
Candida krusei	Baby carrots	Pullulan coatings	Caraway EO	0.12-10% (w/v)
Rhodoturola mucilaginosa	Agar medium, Pears	PE film with nanoparticles	TiO_2	na
Saccharomyces cerevisiae	Liquid medium	Cellulose films	Cloisite® 30B, carvacrol and cinnamaldehyde	3, 5% (w/w), 10% (w/w)
Saccharomycopsis fibuligera	Agar medium, Apples	Pullulan coatings	Sweet basil extract	3-15% (w/v)

6. Antioxidant packaging

An alternative to oxygen scavenging to prevent food oxidation by active packaging is the inclusion of antioxidants in packaging materials. Oxidative processes are one of the primary mechanisms of quality deterioration in meat and meat products[30].Research on active packaging for muscle foods has focused predominantly on the use of antimicrobial agents, while the development of antioxidant applications is growing. Active substances with different mechanisms of action have been investigated, and the current trend is to reduce the use of synthetic additives in packaging and their substitution by natural antioxidants, particularly tocopherol. Plant extracts, and essential oils from herbs such as rosemary, oregano, and tea, are of great interest as natural antioxidants, in most cases can offer health benefits, and their use is becoming highly relevant to muscle foods[31]. Metal-chelating active packaging is another promising novel approach to control lipid oxidation in food, however, not much research has been conducted in this area.

Ünalan, Korel, and Yemenicioglu (2011) incorporated Na2EDTA into films to inhibit the lipid oxidation of ground beef patties[32]. Lee (2014) highlighted the need for active packaging that provides antioxidant and antimicrobial functions since many natural essential oils contain ingredients with both activities[33]. Antimicrobial and antioxidant chitosan films have been developed with the addition of green tea extract and rosemary essential oil for food packaging[34].

6.1. Essential oils (EOs)

There are several natural products used as raw materials in the flavor and fragrance industry. These raw materials might be found in the shape of essential oils[35, 36, 37].

Numerous studies have demonstrated that plant extracts contain diverse bioactive components that can control mould growth. The metabolites produced by plants are a promising alternative to fungicides because plants generate a wide variety of compounds, either as part of their development or in response to stress or pathogen attack. The indiscriminate and excessive use of fungicides in crops has been a major cause of the development of resistant pathogen populations, resulting in the use of higher concentrations of these antifungals and the consequent increase in toxic residues in food products[38]. Natural plant protectants, such as essential oils (EOs) and their major components, that show antimicrobial property activities, low mammalian toxicity and less environmental effects[39] could be used as alternatives to chemical fungicides. EOs and their components are gaining popularity due to their volatile nature, which facilitates the use of small concentrations that are safe for consumption[40]. The principal applications of films or modified atmosphere packaging, MAP, containing EOs to control moulds were concerned with *Penicillium*, *Aspergillus*, and *Botrytis cinerea*, Table 2.

7. Market share and perspectives of active packaging systems

The global market for advanced packaging systems that includes active, controlled, intelligent packaging, and advanced packaging components was at $31.4 billion in 2011 and $33.3 billion in 2012. The market growth looks promising and the overall market value for 2017 is projected to be nearly $44.3 billion, after increasing at a compound annual growth rate (CAGR) of 5.8%[41].

Oxygen scavengers and moisture absorbers are by far the most commercially important sub-categories of active packaging[42]. Gas scavengers were the leading active packaging product type in 2012 in the USA[43]. According to Freedonia Group Inc., gas scavenger demand will climb at a fast rate due to expanded applications for oxygen scavengers. Additionally, active packaging growth will be stimulated by solid prospects for microwave susceptor packaging and by solid increases for self-venting packaging. Rapid growth from a low base is anticipated for antimicrobial packaging, encouraged by technological developments. However, cost and performance factors will still be a limitation[43]. The company predicts strong gains for time–temperature indicator labels, based on growing cost competitiveness together with the increased presence of temperature-sensitive drugs and the heightened focus on food safety through the supply chain.

Table 2. List of active packaging films tested for their antimicrobial effects on moulds[29].

Organism	Medium	Technique	Active packaging Molecules tested	Concentration
	Agar medium	PP films containing EO	Cinnamon	2, 4, 6%
	Cherry tomatoes	HPMC based films with food	Mineral salts, organic acid salts, parabens	2.0% (w/w)
	Bread	Crosslinked gliadin films	Cinnamaldehyde, natamycin	1.5, 3.0, 5.0 % and 0.5% (w/w)
	Agar medium	Commercial coating on PET films containing EO	Cinnamon	2, 4, 6, 8%
	Agar medium	Patented coating on PP films containing EO	Cinnamon	2, 4, 6%
	Agar medium	Patented coating on PP films containing EO	Cinnamon	2, 4, 6%
	Agar medium	Chitosan coatings	Fe-TiO2 nanoparticles	0.5 g/g chitosan
	Agar media, Cheddar cheese	MC-HPMC blend based coating on polyester –starch blend based films with EO's	Linalool, carvacrol, and thymol	0.48, 1.43, 2.38% (w/w)
C. capsici	Agar medium Bell pepper	Chitosan coatings with EO	Lemongrass	0.5, 1% (v/v)
Monilinia fructicola	Plums	HPMC-lipid coatings	Mineral salts, organic acid salts, parabens	0.2, 1, 2% (w/w)
P. expansum	Agar medium	Patented coating on PP films	Cinnamon	2, 4, 6%
P. commune	Agar medium	Alginate and alginate/chitosa n films	Potassium sorbate and natamycin	0.17-1.33 g/g, 0.005- 0.08 g/g
A. parasiticus	Pistachios	CMC films	Potassium sorbate	0.25, 0.5, 1 % (w/v)
Penicillium spp	Agar medium	Amaranth, chitosan, and starch edible films with EO	Oregano	0.25, 0.50, 0.75, 1, 2, 4% (v/v)

8. Other active packaging systems

FreshCase® packaging (Bemis Company Inc.) is a special active packaging solution that allows red colour formation in vacuum-packed meat. The packaging system consists of a multilayer film containing sodium nitrite that is converted to nitric oxide gas when it comes in contact with meat. The nitric oxide gas combines with myoglobin in the meat to give the typical red colour of fresh beef[44]. There are a range of commercially available materials that act as microwave susceptors such as Sira-Crisp™susceptors (Sirane Ltd.) and SmartPouch® (VacPac Inc.)[45]. Examples of commercial applications are listed by Bohrer (2009) for lasagne and meat pies[46], and by Regier (2014) for frozen entrees[47], hot dogs, pizza and sandwich as meat-containing foods. Steam valves that allow release of the vapour created during microwave heating are other active components of packaging. Flexis™ Steam Valve (Avery Dennison Corp.) andMicVac® (SEALPACGmbH) are examples of valves that allow steam release once a defined pressure point is reached[48].

9. Conclusion

Natural products once served as the only source of medicines for mankind[49,50]. Active packaging is receiving considerable attention as an emerging technology that can be used to improve the quality and stability of food, reducing the direct addition of chemicals and the need for changes in formulation. Among these technologies, antioxidant active packaging systems based on the incorporation of antioxidant agents in the package are being developed as a way of improving the stability of oxidation-sensitive food products. Active materials have proved to work by releasing antioxidant agents to the food product and/or by reducing the presence of reactive oxygen species which act as initiators of oxidation processes. These developments are to be designed and optimized for each specific product and in brief, they will be ready to be implemented by the food industry.

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