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Preeti Singh Ali Abas Wani Sven Saengerlaub

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Active packaging of food products: recent trends

Preeti Singh
Technical University of Munich, Freising, Germany
Ali Abas Wani
Department of Food Technology, Islamic University of Science and Technology, Awantipora, India, and
Sven Saengerlaub
Packaging Technology, Technical University of Munich, Freising, Germany

Abstract

Purpose – The purpose of this paper is to review the recent trends in the development of active packaging (AP) for foods.

Design/methodology/approach – The most up-to-date and pertinent studies within the literature have been included and summated in this paper.

Findings – Fresh foods are widely consumed and are becoming a major component of the international food market. During the last decades, the social and scientific modernization, the boom in customer's needs and demands, along with the major changes in the way food products are manufactured, distributed and retailed, led to the development of alternative or novel methods for the production and preservation of food products. This review will present the most comprehensive and current overview of the widely available, scattered information about the different AP technologies for the control of various critical parameters responsible for the quality and shelf life of fresh foods with an interest to stimulate further research to optimize different quality parameters.

Originality/value – This paper offers a holistic view that would guide a reader to identify the recent developments in the field of AP.

Keywords Active packaging, Fresh foods, Shelf life, Additives, Food quality, Barrier materials

Paper type General review

Introduction

Shelf life of a food is integrally related to its packaging; both product conditions and the package should be considered (Yam *et al.*, 2005). In recent years, the major driving forces for innovation in food packaging technology have been the increase in consumer demand for minimally processed foods, the change in retail and distribution practices associated with globalization, new consumer product logistics, new distribution trends (such as internet shopping), automatic handling systems at distribution centres, and stricter requirements regarding consumer health and safety (Vermeiren *et al.*, 1999; Sonneveld, 2000). Modified atmosphere packaging (MAP) and active packaging (AP) technologies are being developed as a result of these driving forces. AP is an innovative concept that can be defined as a mode of packaging in which the package, the product, and the environment interact to prolong shelf life or enhance safety or sensory properties, while maintaining the quality of the product. This is particularly important in the area of fresh and extended shelf-life foods as originally described by Labuza and Breene (1989). Other terms coined to denote such packaging include "smart",

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"functional" and "freshness preservative packaging". Various kinds of active substances can now be incorporated into the packaging material to improve its functionality and give it new or extra function (Han, 2000). Active food packaging technologies in the form of sachets or additives capable of scavenging O_2 or absorbing water vapour have been commercially available for more than two decades. However, the intensification in research and development activity relating to plastic-based active food packaging technologies in the last ten years has been spectacular. In this period, a number of AP materials have been reported and reviewed and all designed to counteract a wide range of deleterious quality and safety limiting effects, including rancidity, colour loss/change, nutrient loss, dehydration, microbial proliferation, senescence, gas build-up and off-odours.

Active packaging

A great technological development for food packaging has been developed over the past few decades to satisfy consumer demands relating to more natural forms of preservation, and methods to control packaging and storage for assurance and food safety. AP is, certainly, one of the most important innovations in this field. It is an innovative concept that can be defined as a type of packaging that changes the packaging condition, extending shelf life and improving safety or sensory properties while maintaining food quality (Suppakul *et al.*, 2003). It is a very interesting alternative to both the use of preservatives or MAP. This is particularly important in the area of fresh and extended shelf life of foods as originally described by Labuza and Breene (1989). Active packages are designed to perform a role other than to provide an inert barrier between the product and the outside environment, using the possible interactions between food and package in a positive way to improve product quality and acceptability. AP for foods is a heterogeneous concept involving a wide range of possibilities which globally can be grouped in two main goals:

1. to extend shelf life; and
2. to facilitate processing and consumption of foods.

In the first case, AP solutions include the systems studied to control the mechanisms of deterioration inside the package (i.e. O_2 scavengers, moisture absorbers or anti-microbial agents). In relation to the second goal, AP allows us to match the package to the properties of the food, to reduce costs of processing, or even to perform some processing operations in-package or to control the product history and quality. AP can be accomplished by different methods (Brody, 2001). AP is designed to enhance the properties of packaging material so that it could increase shelf life of product. Therefore, the forms and applications of AP are diverse, addressing specific situations in the protection and presentation of foods and other products.

Types of active substances

Based on the nature of spoilage, various kinds of substances have been identified. However, only few of them can be applied in AP systems. AP system falls into three different categories: scavenging, releasing and "other". Scavengers include those of O_2, ethylene, moisture and taint, whereas emitters include for carbon dioxide (CO_2) and ethanol.

Oxygen scavenger

The removal of headspace and dissolved O_2 or presence of O_2 that has been produced as a result of metabolic activities, from a wide variety of food products is of paramount importance. Small quantity of residual O_2 is detrimental from product's quality, as it may trigger a number of oxidation reactions. It is often manifested by loss of freshness, decrease in nutritive value, development of off-flavour, discolouration, etc. In the packaging of less sensitive products, much of the O_2 in air can be removed by inert gas flashing, but O_2 scavenging is still advantageous (Rooney, 1981). The use of O_2 absorbers is a relatively new additive trend in food packaging (Abe, 1994). O_2 absorbents comprise of easily oxidizable substances usually contained in sachets is available in a variety of sizes capable of absorbing 20-2,000 ml headspace O_2. Commercial O_2 scavengers technologies are based on oxidation of one or more of the following substances: iron powder, ascorbic acid, photosensitive dyes, enzymes (such as glucose oxidase and ethanol oxidase), unsaturated fatty acids (such as oleic, linoleic and linolenic acids), rice extract or immobilized yeast on a solid substrate (Floros *et al.*, 1997), enclosed normally in sachets and incorporated into the packaging polymer or a polymer layer extruded as part of the package to maintain freshness by absorbing headspace O_2 and oxygen that enters the package (Miltz and Perry, 2000; Vermeiren *et al.*, 1999). These sachets are kept inside the packaged food; they actively modify the package headspace and reduce the O_2 levels to < 0.01 per cent within one to four days at room temperature. One important advantage of AP over MAP is that the capital investment involved is substantially lower; in some instances, only the sealing of the system that contains the O_2 absorbing sachet is required. This is of extreme importance to small- and medium-sized food companies for which the packaging equipment is often the most expensive item (Ahvenainen and Hurme, 1997).

On the basis of reaction style. In this, the O_2 scavenging reaction commences as soon as the absorbent is exposed to air. In moisture dependent types, the O_2 absorption reaction occurs only after moisture has been absorbed from the food. The later types are easier to handle, as they do not react immediately upon exposure to air. The absorbent based on reaction style is presented in Table I.

Reactant	Function	Application	Absorption speed (days)
Iron	$O_2 \downarrow$	Self-working type. Dry $a_w < 0.3$	4-7
		Tea, nuts. Medium a_w ($a_w < 0.65$)	1-3
		Dried beet. High a_w ($a_w > 0.65$)	0.5
		Cakes. Moisture dependent type High a_w ($a_w > 0.65$) pastas	0.5
Catechol	$O_2 \downarrow$	Self-working type. Medium a_w ($a_w < 0.65$) nuts	
Iron + calcium	$O_2 \downarrow$ and $CO_2 \downarrow$	Self-working type. Roasted coffee	3-8
Ascorbic acid	$O_2 \downarrow$ and $CO_2 \uparrow$	Self-working type. Medium a_w ($a_w < 0.65$) nuts	1-4
Ascorbic acid + iron	$O_2 \downarrow$ and $CO_2 \uparrow$	Moisture dependent type. High a_w ($a_w > 0.85$). Cakes	
Iron + ethanol/zeolite	$O_2 \downarrow$ and ethanol $\uparrow$	Moisture dependent type. High a_w ($a_w > 0.85$)	

Table I. Classification of oxygen absorbents

On the basis of reaction speed. These can be grouped as immediate effect, general effect and slow effect types (Harima, 1990). The average time for O_2 absorption is 0.5 to one day for the immediate type, one to four days for the general type and four to six days for the slow-reacting type. The reaction time depends on the temperature of storage and the water activity (a_w) of the food.

Oxygen scavenging films. Sachet-based scavengers, though easy to handle, are unsuitable for use with liquid products. Hence, several research groups and manufacturing companies have been engaged in developing O_2 scavenging plastics. The incorporation of non-iron-based O_2 removers directly into plastic package materials has gained momentum. There has been great encouragement in this front, through the development of co-extruded stretch blow moulding of polymers into a monolayer plastic structure. Ciba™ Shelfplus™ O_2 scavenger (now owned by Albis Plastics GmbH) is a polymer-based additive that can be incorporated directly into the walls of the package. It can be incorporated into either an existing layer within the package or as a distinct scavenging layer. One of the benefits of this technology is that the active O_2 scavenging is automatically triggered when in contact with moisture, either from filling or retort. Because it is moisture activated, it works most effectively in applications such as high-moisture content foods (Morvillier, 2006). Some of the commercially developed O_2 scavenging films are presented in Table II.

CO_2 generating or scavenging

A complementary approach to O_2 control is to incorporate a CO_2 generating system into a film or add it as a sachet. This approach is widely recommended practice in MAP and controlled atmospheric storage of fresh produce, where higher CO_2 concentration is must to retard many unfavourable biochemical reactions. Permeability of CO_2 through plastic films is three to five times higher than the O_2. Hence, a generator is needed for some application. CO_2 emitters developed commercially are based on the reaction between bicarbonate, an acid together with water vapour that results in production of CO_2. One of the products that have been benefited most by the development in AP is the ground coffee. The loss of aroma substances during aging process is the major quality deteriorative reaction. The CO_2 produced in this process has to be removed to ensure proper aroma in the product. CaOH (slacked time) is most commonly used scavenger of CO_2 and incorporated in number of formulations (Brody, 2002). The shelf life of ground fresh coffee tripled when a sachet containing iron powder and CaOH was added in flexible bags. However, controlling the level of both O_2 and CO_2 may have some adverse effect on metabolic activity of fruits and vegetables.

Table II.
Commercially available anti-microbial films

Films	Components	Feature
OXBAR	MXD-6 polyamide with polyester containing a cobalt sheet	Zero oxygen permeability
Nylon MXD-6 type	MXD-6 nylon with polyester	Withstand pasteurization temperature
Diene type	Polybutadiene with polyester	Zero oxygen permeability
Laminates	Ethylene vinyl alcohol and polydiene	Oxygen and CO_2 barrier with no flavour change
	Added benzo acrylate polymer	No off-flavour

Ethanol emitters

Despite its widespread use as a germicidal agent, few studies have evaluated ethanol as a preservative for food products (Lopez-Rubio *et al.*, 2004). Ethyl alcohol has been shown to increase the shelf life of bread when sprayed onto the surface of the product prior to packaging indicating its potential as a vapour phase inhibitor (Seiler, 1978). Another model of atmosphere modification is manufactured by the Freund Company Ltd of Japan and sold under the name of Ethicap® or Antimold 102. Ethicap® is a sachet placed alongside food and it releases ethanol vapour into the package headspace. The released ethanol vapour (0.5-2.5 per cent (v/v)) then condenses on the food surface and acts as a microbial inhibitor (Labuza and Breene, 1989). Vanilla and other compounds are used to mask the alcohol flavour. Ethicap® sachets come in various sizes ranging from 0.6 to 6 or 0.33 to 3.3 g of ethanol evaporated. The size and capacity of the sachet used depends on the weight of the food, a_w of the food, and the desired shelf life of the product. This sachet is being used for many bakery, cheese and semi-dried fish products. The vapour deposits on the food surface, eliminating the growth of molds and pathogens (Shapero *et al.*, 1978). Pre-baked buns ($a_w = 0.95$) packaged with different amounts of Ethicap®, into gamma sterile PE-LD bags (M3/N&/2x.06 with a thickness of 80 μm) and stored at room temperatures, delayed mold growth for 13 days (Franke *et al.*, 2002). Another kind of ethanol vapour generator produced by Freund, Japan is termed Negamold. This compound, like Ethicap®, is moisture dependent. Both work with product having $a_w > 0.85$. On the other hand, Negamold also acts as O_2 absorbent as well as an ethanol vapour generator. Studies done by Smith *et al.* (1990) have shown that ethanol vapour generation are effective in controlling ten species of molds including *Aspergillus* and *Penicillium* species, 15 species of bacteria including *Salmonella*, *Staphylococcus* and *Escherichia coli*, and the species of spoilage yeast. Other studies conducted by Smith *et al.* (1987) investigated the effect of ethanol vapour on the growth of *Saccharomyces cerevisiae*, the main spoilage microorganism in gas-packaged apple turnovers. The results showed that when Ethicap® was incorporated into the packaged product, yeast growth was completely suppressed and the packages appeared normal at the end of the 21-day storage period. This study demonstrated the usefulness of ethanol vapour for the shelf-life extension of a fruit-filled bakery product subject to secondary spoilage by yeast. Ethanol has been generally regarded as safe in the USA as a direct human food ingredient. As a permitted additive, there is no objection to its use at levels up to 2 per cent by product weight (CFR, 1990).

Moisture scavenging (absorbing and controlling)

It is generally known that storage of fresh food products in moist and warm environments favour mould spoilage, and studies have shown that the growth of moulds on various materials is related to the relative humidity (RH) of their surroundings. Use of a humidity regulating packaging material may keep the RH inside a package at a controlled level and prevent issues with condensation occurring, and hereby prevent that the storage conditions become favourable for mould growth. For moisture-sensitive foods, excess moisture in packages can have detrimental results: for example, caking in powdered products, softening of crispy products such as crackers, and moistening of hygroscopic products such as sweets and candy. Conversely, too much moisture loss from food may result in product desiccation. Moisture control agents help control a_w, thus reducing microbial growth, remove melting water from frozen products, prevent condensation from fresh produce and keep the rate of lipid oxidation in check (Vermeiren *et al.*, 1999). Desiccants such as silica gels, natural clays and calcium oxide are used with dry foods while internal humidity controllers are used for high-moisture foods. Desiccants usually take the form of internal porous sachets or perforated water-vapour barrier plastic cartridges containing desiccants. In solid foods, a certain amount of moisture may be trapped during packaging or may develop inside the package due to generation or permeation. Unless it is eliminated, it may form a condensate with the attendant spoilage and/or low consumer appeal, moisture problems may arise in a variety of circumstances, including respiration in horticultural produce, melting of ice, temperature fluctuations in food packs with a high-equilibrium RH, or drip of tissue fluid from cut meats and produce (Rooney, 1995). Their minimization via packaging can be achieved either by liquid water absorption or humidity buffering. Some of the moisture scavenging systems is presented in Table III.

Anti-microbial releasing

The anti-microbial AP technology is based on anti-microbial agents that are immobilized with the polymeric structure or incorporated in plastic resins, before film casting (Kim *et al.*, 2008). This technology can be divided into two types: preservatives that are released slowly from the packaged materials to the food surface or preservatives that are firmly fixed and do not migrate into the food products (Appendini and Hotchkiss, 2002). Both are assumed to control growth of undesirable microorganisms. A wide range of anti-microbial substances, e.g. organic acids, bacteriocins, spice extracts, thiosulphates, enzymes, proteins, isothiocyanates, antibiotics, fungicides, chelating agents, parabens and metals, has been considered to have possible anti-microbial activity when incorporated in or coated onto food packaging materials (Rooney, 1995). Most of the anti-microbial packaging materials so far have been based on synthetic plastics, and especially on low-density polyethylene (LDPE). One of the key problems of the AP technologies resides in the controlled release of the anti-microbial agent from the polymer film (Choi *et al.*, 2001). Benzoic anhydride has been incorporated into LDPE films, which exhibited anti-mycotic activity when in contact with media and cheese. About 1 per cent benzoic anhydride completely inhibited *Rhizopus stolonifer*, *Penicillium* spp. and *Aspergillus toxacarius* growth on potato dextrose agar. Levels of 0.5-2 per cent benzoic anhydride delayed mould growth on cheese (Weng and Hotchkiss, 1993). Poly(ethylene-co-methacrylate acid) (PEMA) has been combined with benzoic acid and sorbic acid to form an anti-microbial food packaging material. The results showed that PEMA films not only absorbed benzoic and sorbic acids into the structure but also inhibited the microbial growth of *Aspergillus niger* and *Penicillium* sp. (Wenig *et al.*, 1999). Also the sorption and permeation behaviour of allyl isothiocyanate vapour in polyamide film has been studied. The barrier of the polyamide against allyl isothiocyanate can be weakened by moisture uptake in high humidity, thus activating the release of anti-microbial allyl isothiocyanate vapour (Lim *et al.*, 1998). In another study by Vartiainen *et al.* (2003), traditional food preservatives like sodium benzoate, sodium nitrite, potassium sorbate and sodium lactate were incorporated into synthetic plastics, LDPE, poly(maleic acid-co-olefine), polystyrene and polyethylene terephthalate aimed at producing anti-microbial packaging material for foodstuffs.

As per the observations of Han (2000), silver and zinc zeolites are among the most popular compounds for anti-microbial packaging material. When the film comes

Table III.
Moisture scavenging systems

System	Structural component	Food product	Company
Tyrek®	Heat-sealed salt in spun-bonded polyolefin film sachets	Fresh produce	Raw chemicals
CHEFKIN	Duplex sheets, liquid glucose embedded in between an exterior water barrier and an inner water-vapour permeable film	Fish and fresh dry fruits and vegetables	Chefkin, Japan
Crisper F	Sheet made of aluminium metallized film with non-woven fabric on the reverse side	Meat, fish, fresh fruits and vegetables	Kagaka Kogyo, Japan
Drip absorbent sheets	Super absorbed polymer in between two layers	Fish, poultry, meat and fresh produce	Thermarite®, Australia; Toppan™, Japan

in contact with the food product, the zeolites release the zinc and silver ions, which disrupt the normal biochemistry of the microbial cells. According to him, mustard extract is also effective against gram-negative bacteria, such as *E. coli* and *Salmonella*. Bacteria identification and food quality monitoring using biosensors; intelligent, active and smart food packaging systems; and nanoencapsulation of bioactive food compounds are few examples of emerging applications of anti-microbials for the food industry. Lysozyme containing whey protein films markedly inhibited the growth of spoilage bacteria (Neethirajan and Jayas, 2010). Padgett *et al.* (1998) demonstrated the anti-microbial activity of lysozyme and nisin in the soy protein isolate films and corn, zein films. These film/coatings may carry approved chemical active substances as well as natural active substances like enzymes, proteins, natural oils, fatty acids, natural anti-oxidants, etc. In another study at Clemson University, Cooksey (2001) worked with films produced from chitosan, a carbohydrate extracted from shrimp and crab shells. Chitosan has both anti-bacterial and anti-fungal properties. There are few chemical anti-microbial agents that are used commercially to control microbial growth in foods (Han and Floros, 1997). Many of these chemicals, like sodium propionate, have been used for many years with no indication of human toxicity. Some of the potential anti-microbial packaging applications has been summarised in Table IV.

Anti-oxidants release

Whereas the absorbing systems eliminate the O_2 by "magnetizing" it towards reagents, releasing systems "channel" reagents into their immediate environment. Hereto, one or more chemicals migrate off the packaging. As early as the 1980s, additives such as butylhydroxyanisole (BHA) and butylhydroxytoluene (BHT) were incorporated into wax liners for the cereal industry (Labuza and Breene, 1989). The additives were released from the liner by diffusion into the cereal flakes to protect the food from lipid oxidation. The release of BHT from an anti-oxidant AP consisting of co-extruded films made of LDPE, enriched with 8 mg/g of the anti-oxidant in the LDPE layer, complies with the legal limit established for food products (Soto-Cantú *et al.*, 2008). According to their observation fruits, vegetables as well as whole grains, as part of an overall healthful diet, have a potential to delay the onset of many age-related diseases triggered a continuing research aimed at identifying their anti-oxidant agents. Since the major role of food packaging is to retard the natural processes that lead to food spoilage, anti-oxidants and free radical scavengers are used for this purpose. Traditional food producers resolved the oxidation reaction by addition of synthetic anti-oxidants. Although intensively applied for meat derivatives, the addition of synthetic additives to fresh meat is not permitted. Therefore, a preferable option is the use of natural anti-oxidants. Recent studies (Nerin *et al.*, 2006; Bentayeb *et al.*, 2007) describe a new AP consisting of a polypropylene (PP) film in which a rosemary extract containing natural anti-oxidants is immobilized. The results showed that, compared to normal PP, the active film containing natural anti-oxidants efficiently enhanced the stability of both myoglobin and fresh meat against oxidation processes. The authors consider it a promising way to extend the shelf life of meat-based products. Moreover, among the O_2 reduction advances in packaging have been the introduction of polyvinylidene chloride-coated films, incorporation of polyvinyl alcohol as an O_2 barrier layer, and the use of vacuum-deposited aluminium to reduce O_2 penetration to packaging products. Additionally, consistent levels of anti-oxidants in food might be achieved by the

Table IV. Anti-microbial packaging systems

Anti-microbial agents	Mechanism	Current status
Radiation Radioactive materials Laser excited materials UV-exposed films Far infrared emitting ceramic powders	Sterilization of packaging materials and equipments Creation of anti-microbial peptides on polyamide	Radiation sterilization not yet approved
Gases Sulphur dioxide flushing Chlorine dioxide Hydrogen peroxide Ozone	Prevents growth of moulds Incorporation of sodium chlorite in packaging films and gas is generated upon reaction with oxygen May be applied on the surfaces of wraps and sheets	Used for preservation of fresh grapes and berries Effective, but chances of secondary effects on foods Approved by regulatory authorities as surface sterilizants
Volatile substances Allylisothiocynate Horseradish extract Eugenol	Again may be used for surface sterilization of packaging material or incorporated into packaging material Being natural can be a component of edible coatings	Not compatible with a majority of food products, as they impart undesirable flavour Being natural have potential to get regulatory approval
Ethanol vapours	Ethanol emitters absorbed in silica pads and embedded in sachets made from ethylene vinyl acetate copolymer. Migrate to headspace in packaging material and prevent growth of moulds and yeast	Commercially available sachets (Ethicap) is available and is in use for cakes, bread and cheeses Also act as anti-staling agent in baked products during refrigerated storage
Fungicides Benomyl Imazalil	Covalently coupled to an inomeric plastic films named surlyn As part of shrink wrapping films Imazalil impregnated films	Found effective against mycotxigenic fungi at experimental level and have potential for future application in minimizing post harvest losses of fruits and vegetables
Silver salts	Loaded on carrier materials like zeolite which is added to plastic films and sheets	Require regulatory approval
Organic acid and their derivates Potassium sorbate, sorbic acid anhydride, benzoic acid, sodium benzoate	Added in LDPE, wax coating of cheeses. Anhydride of acids are more effective than salts	Approved food preservatives. Mechanism of migration has been thoroughly investigated
Others Lysozyme Nisin Triclosan (diphenylether)	Added with edible coatings	Experimental level

controlled release of anti-oxidants from biodegradable plastic films, such as polylactide, polyglycolide and the copolymers such as poly(lactide-co-glycolide) or PLGA (Cheng *et al.*, 1998). The diffusion-controlled release of BHA and BHT from food package liners into dry food products, such as cereal, has been studied earlier (Miltz *et al.*, 1995).

Conclusion

AP is largely a series of innovation of the last two decades. The substantial amount of progress is still going on. The introduction of AP requires re-appraisal of the normal requirement that there should not be any interaction between food product and packaging substances. It will have a wider application in future where emphasis is on minimally processed and reduced additive safe food products. Suitable designing, better understanding of interactions, safety and regulation through enforcement will certainly enhance consumer's faith in AP substances. As consumers search for better tasting, low-preparation foods, the food industry will continue to develop packaging ingredients and processing options. Packaging technology innovations and ingenuity will continue to provide right package, for baked products, that is consumer oriented, product enhancing, environmentally responsive, and cost effective, but continued research and development by the scientific and industry sectors will be needed.

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Corresponding author
Preeti Singh can be contacted at: preeti_ndri@rediffmail.com

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