Active packaging for food applications - A review

Mahmoud Hosseinnejad

1Master of Food Science, University of Agricultural Sciences and Natural Resources, Gorgan, Iran
*Corresponding author: Email: ma.hoseinnejad@gmail.com

ABSTRACT

The purpose of food packaging is to preserve the quality and safety of the food it contains from the time of manufacture to the time it is used by the consumer. Recently, the demand for safe and high quality foods, as well as changes in consumer preferences have led to the development of innovative and novel approaches in food packaging technology. One such development is the active food packaging technology. Active packaging can be classified into two main kinds: non-migratory active packaging acting without intentional migration, and active releasing packaging allowing a controlled migration of non-volatile agents or an emission of volatile compounds in the atmosphere surrounding the food. Non-migratory active packaging is a packaging which elicits a desirable response from food systems without the active component migrating from the packaging into the food. The most well known examples of non-migratory active packaging are oxygen and ethylene absorbers. Also carbon dioxide and antioxidant releaser are examples of migratory active packaging.

Keywords: Food: Active packaging; Absorbing and releasing properties; High quality

Introduction

Packaging protects products against deteriorative effects, which may include discolouration, off-flavour and off-odour development, nutrient loss, texture changes, pathogenicity and other measurable factors (Zhou et al., 2010). In the last decades, however, one of the most innovative developments in the area of food packaging is the ‘active and intelligent’ (A&I) packaging, based on deliberate interactions with the food or the food environment. The purpose of the ‘active packaging’ is the extension of the shelf-life of the food and the maintenance or even improvement of its quality. While the purpose of ‘intelligent packaging’ is to give indication on, and to monitor, the freshness of the food (Dainelli et al., 2008; Puligundla et al., 2012). Active packaging technique enables the regulation of various aspects that may play a role in determining the shelf life of packaged foods, such as physiological (e.g., respiration of fresh fruit and vegetables), chemical (e.g., lipid oxidation), and physical (e.g., dehydration) processes as well as microbiological aspects (Puligundla et al., 2012). Active packaging includes additives that are capable of scavenging or absorbing oxygen, carbon dioxide, ethylene, moisture and/or odour and flavor taints; releasing oxygen, carbon dioxide, moisture, ethanol, sorbates, antioxidants and/or other preservatives and antimicrobials; and/or maintaining temperature control (Fig. 1).
Absorbers and emitters for active food packaging applications

Oxygen absorbers

Oxygen can trigger or accelerate oxidation and also facilitate the growth of aerobic microorganisms, lowering food quality, and shortening the shelf-life. Strategies leading to increasing the gas barrier properties include the use of active oxygen scavengers in the packaging in sachets, labels, or included in the polymer layers, or as passive nanocomposites offering a delay in the oxygen transport due to an increased tortuosity in the oxygen pathway (Brody et al., 2008; Llorens et al., 2011). Oxygen absorbers are the most widely used active packaging concepts commercialized for the first time in 1970 by Mitsubishi Gas Chemical Company (Mexis and Kontominas, 2010). Oxygen scavengers can remove oxygen that permeates through the packaging material into the package during storage and reduce residual oxygen that may have been trapped inside the package prior to sealing. Currently, one of the most effective and commonly used oxygen scavengers are oxygen scavenging sachets containing iron powder (Vermeiren et al., 2003; Byun et al., 2011; Byun et al., 2012). O2 scavenging capacity depends on the product. Commercial O2 scavengers containing active iron oxide can reduce the internal O2 content to less than 0.05% within 9 h (Ooraikul, 1991; Lee, 2010). Mexis et al. (2010) studied the effect of polyethylene terephthalate/low density polyethylene (PET/LDPE), and polyethylene terephthalate coated with SiOx/low density polyethylene (PET-SiOx/LDPE) on quality retention of dark chocolate with hazelnuts under vacuum, N2 and an oxygen absorber in the dark at 20 °C for a period of 12 months. For example reported by they changes in peroxide value of dark chocolate. Resulted showed that after 12 months of storage, chocolate packaged with the oxygen absorber, irrespective of packaging material permeability, had a very low PV ca. 1.31-1.47 meq O2/kg chocolate fat. Samples packaged in PET-SiOx/LDPE under N2 or vacuum showed a small increase in PV value (from 0.80 to 2.19 and 2.37 meq...
O2/kg chocolate fat, respectively) while for samples packaged in PET//LDPE under N2 or vacuum packaged a fivefold increase was recorded.

**Entrapped microorganisms as biological oxygen scavengers in food packaging**

However, these oxygen scavenging sachets have several disadvantages. It has a potential risk of accidental ingestion by the consumer, especially by children and babies, and it cannot be used for liquid products (Ahvenainen, 2003; Byun et al., 2012). For these reasons, in recent years, alternative natural and biological approaches have been proposed. Oxygen scavengers based on natural and biological components could have advantages towards the consumer such as perception, recyclability, safety, material compatibility and production costs compared to currently available chemical oxygen scavengers. These include biocatalytic-based systems making use of glucose oxidase or a mixture of glucose oxidase and catalase or the use of entrapped aerobic microorganisms, capable of consuming oxygen (Anthierens et al., 2011). In fact, the cycle life of a biological oxygen-scavenger film includes the entrapment of the microorganisms in an appropriate polymeric matrix (film manufacturing), the maintenance of the desiccated film till its use (film storage and distribution), and the rehydration (film usage, obtained by putting the film in contact with the food) (Altieri et al., 2004). Anthierens et al. (2011) reported the use of endospore-forming bacteria as an active oxygen scavenger in in multilayer polyethylene terephthalate (PET), materials. The inside of the bottle is in contact with the product, allowing moisture uptake of the bottle needed for spore germination. The system allows scavenging of residual oxygen from the in-bottle environment and scavenging from atmospheric oxygen permeating through the bottle wall.

**Ethylene adsorption**

Ethylene is a plant growth regulator and plays a key role in physiological processes and during postharvest. Controlling the presence of ethylene in packages and storage environments could lengthen the shelf-life of a large amount of fresh products. Stoichiometric oxidizing systems based on potassium permanganate are typically used to control the amount of ethylene in closed environments (Llorens et al., 2011). Most suppliers offer ethylene adsorbers based on KMnO4. To be effective, KMnO4 must be adsorbed on a suitable inert carrier with a large surface area such as celite, vermiculite, silica gel, alumina pellets, activated carbon, perlite or glass. Typically, such products contain about 4-6% KMnO4. The oxidation of ethylene with potassium permanganate can be thought of as a two-step process. Ethylene (CH2=CH2) is initially oxidised to acetaldehyde (CH3CHO), which in turn is oxidised to acetic acid (CH3COOH). Acetic acid can be further oxidized to carbon dioxide and water (Ahvenainen, 2003).

\[
\begin{align*}
3\text{CH}_2\text{CH}_2 + 2\text{KMnO}_4 + \text{H}_2\text{O} & \rightarrow 2\text{MnO}_2 + 3\text{CH}_3\text{CHO} + 2\text{KOH} \\
3\text{CH}_3\text{CHO} + 2\text{KMnO}_4 + \text{H}_2\text{O} & \rightarrow 3\text{CH}_3\text{COOH} + 2\text{MnO}_2 + 2\text{KOH} \\
3\text{CH}_3\text{COOH} + 8\text{KMnO}_4 + 6\text{CO}_2 & \rightarrow 8\text{MnO}_2 + 8\text{KOH} + 2\text{H}_2\text{O}
\end{align*}
\]

Another type of ethylene scavenger is based on the adsorption of ethylene on activated carbon and subsequent breakdown by a metal catalyst (Ahvenainen, 2003). Charcoal loaded with palladium chloride has been proposed to oxidize ethylene to acetaldehyde, decelerating the maturation rate of climacteric fruits (Fujimoto et al., 1974; Llorens et al., 2011).

**Carbon dioxide scavengers and emitters**
High carbon dioxide levels (10-80%) are desirable for foods such as meat and poultry in order to inhibit surface microbial growth and extend shelf life. Removal of oxygen from the package creates a partial vacuum, which may result in the collapse of flexible packaging. Also, when a package is flushed with a mixture of gases including carbon dioxide, the carbon dioxide dissolves in the product creating a partial vacuum. In such cases, the simultaneous release of carbon dioxide from inserted sachets, which consume oxygen, is desirable. Such systems are based on either ferrous carbonate or a mixture of ascorbic acid and sodium bicarbonate (Rooney, 1995; Kerry et al., 2006). Carbon dioxide absorbers (sachets), consisting of either calcium hydroxide and sodium hydroxide, or potassium hydroxide, calcium oxide and silica gel, may be used to remove carbon dioxide during storage in order to prevent bursting of the package (Ahvenainen, 2003; Kerry et al., 2006). The reactant commonly used to scavenge CO2 is calcium hydroxide, which, at a high enough water activity, reacts with CO2 to form calcium carbonate:

\[ \text{Ca} (\text{OH})_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} \]

A disadvantage of this CO2 scavenging substance is that it scavenges carbon dioxide from the package headspace irreversibly and results in depletion of CO2, which is not always desired (Ahvenainen, 2003).

**Emitters antioxidant (antioxidant active packaging)**

Use of natural compounds in the preparation of an active packaging with antioxidant properties is a relatively new approach to the problem of the preservation of meat products. The antioxidant can be added for preservation of the polymer against oxidation or for preservation of the packaged food. Synthetic additives with antioxidant activity have been widely used in the food industry (Contini et al., 2011); but Nowadays, the tendency to reduce the use of synthetic additives in packaging has focussed interest on their substitution by natural antioxidants, particularly tocopherol, plant extracts, and essential oils from herbs such as rosemary, oregano and tea, that are safer and in most cases offer multiple health benefits (López-de-Dicastillo et al., 2012). Investigated effect antioxidant active packaging (content of 10% rosemary extract) in combination with high pressure treatment on lipid oxidation in the inner part and at the surface of chicken meat patties by Bolumar et al. (2011). Result showed that location (surface or inner part), and the type of packaging (control or antioxidant active packaging) are the two factors determining the extent of oxidation in high pressure treated chicken meat. Apparently, the antioxidant compounds from the antioxidant active package suppress the oxidation in both the surface part and the inner part and prevent formation of secondary lipid oxidation products.

Active antioxidant food packaging films were produced by the incorporation of ascorbic acid, ferulic acid, quercetin, and green tea extract into an ethylene vinyl alcohol copolymer matrix by López-de-Dicastillo et al. (2012) on lipid stability of brined sardines. The evolution of the peroxide index and the malondialdehyde content showed that, in general, the films improved sardine stability and films with green tea extract offered the best protection against lipid oxidation.

**Antimicrobial food packaging**

Antimicrobial packaging is the packaging system that is able to kill or inhibit spoilage and pathogenic microorganisms that are contaminating foods. The new antimicrobial function can be achieved by adding antimicrobial agents in the packaging system and/or using antimicrobial polymers that satisfy
conventional packaging requirements (Ahvenainen, 2003). The antimicrobial agents used for active packaging can be categorized depending on the material base as either 1) organic or inorganic or 2) chemical agents or natural agents or probiotics. The following food-grade antimicrobial agents can be used for antimicrobial food packaging systems; organic acids and their salts (acetic acid, benzoic acid, potassium sorbate, sodium benzoate, sorbic anhydride, benzoic anhydride, alkyl (ethyl, methyl, propyl) paraben, fatty acids (lauric acid, palmitoleic acid, glycerol mono-laurate), chelating agent (EDTA), metals (silver, copper, zirconium, titanium oxide), enzymes (lysozyme, peroxidase, glucose oxidase), polypeptide (lactoferrin), bacteriocin (nisin, pediocin, lacticins), chitosan, antioxidants, antibiotics, fungicides, sanitizing gas, sanitizers, phenolics, plant volatiles, plant spice/spice extracts, plant essential oils (cinnamon, oregano, lemongrass), nitrates and sulphites, and probiotics (Lee, 2010).

Antimicrobial films can be defined as three basic categories as follows: (1) Incorporation of antimicrobial substances into a sachet connected to the package from which the volatile bioactive substance is released during further storage. Common packaging materials can be utilized without the use of alternative packaging materials. (2) Direct incorporation of the antimicrobial agent into the packaging film. (3) Coating of the packaging with a matrix that acts as a carrier for the antimicrobial agent (Coma, 2008). Sachets include O2 scavengers, CO2 generators, chlorine dioxide generators, while bioactive agents dispersed in the packaging may be O2 scavenging films, silver ions, triclosan, bacteriocins, spices, essential oils, enzymes and other additives (Coma, 2008; Zhou et al., 2010). Chlorine dioxide can exist in gaseous, liquid or solid state. Its efficiency against bacteria, fungi and viruses can be delivered from a solid state, called Microspheres (Bernard Technologies, USA), through the interaction of moisture to produce a controlled and sustained release of chlorine dioxide in gaseous form. Sustained and controlled release of chlorine dioxide is related to exposure to humidity greater than 80% and light. The result is a high activity against a broad spectrum of microorganisms including actively growing vegetative cells and spores. Applications for this technology are just beginning to unfold in the food industry to reduce food safety risks for meat, poultry, fish, dairy, confectionery, and baked goods (Coma, 2008).

Conclusion

Changes in consumer preferences have led to innovations and developments in new packaging technologies. Most innovative packaging systems have the potential to increase packaging costs, and so restrict options for commercialization, especially for small and intermediate sized businesses. However, these cost increases are counterbalanced by reductions in wastage due to the enhanced quality and shelf-life of products. Therefore, a complete assessment of specific costs and benefits is the essential next step in establishing the commercial application of innovative packaging technology. Procedures of active packaging relevant to foods include; oxygen scavengers, carbon dioxide scavengers and emitters, sheets and antimicrobial packaging. However contribution and collaboration of research institutions, industry and government regulatory agencies will be key on the success of active packaging technologies for food applications.

References


