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Review article
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Active and Intelligent Packaging Food – Research and Development – A Review

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Innovation in food and beverage packaging is mostly driven by consumer needs and demands influenced by changing global trends, such as increased life expectancy, and fewer organizations investing in food production and distribution. Food industry has seen great advances in the packaging sector since its inception in the 18th century with most active and intelligent innovations occurring during the past century. These advances have led to improved food quality and safety. Active and intelligent packaging is a new and exciting area of technology which received efficient contemporary consumer response. The aim of this review article was to present active and intelligent packaging currently existing on the market.

INTRODUCTION

New food packaging technologies are developing as a response to consumer demands or industrial production trends towards mildly preserved, fresh, tasty and convenient food products with prolonged shelf-life and controlled quality. In addition, changes in retailing practices, or consumers lifestyle, present major challenges to the food packaging industry and act as driving forces for the development of new and improved packaging concepts that extend shelf-life while maintaining and monitoring food safety and quality [Dainelli *et al*., 2008]. Innovations in packaging were up to now limited mainly to a small number of commodity materials such as barrier materials (new polymers, complex and multilayer materials) with new designs, for marketing purposes. However, food packaging has no longer just a passive role in protecting and marketing a food product. New concepts of active and intelligent packaging are due to play an increasingly important role by offering numerous and innovative solutions for extending the shelf-life or maintain, improve or monitor food quality and safety [Gontard, 2000]. Food quality and shelf-life extension (*e.g.* for delicatessen, cooked meats *etc*.) Next to these, numerous other concepts such as ethanol emitters (*e.g.* for bakery products), ethylene absorbers (*e.g.* for climacteric fruits), carbon dioxide emitters/ absorbers, time/ temperature and oxygen indicators *etc*. have been developed. In a general way, the field has been extended largely as a series of niche markets owing to the current approach of packaging industries looking at it in terms of new market opportunities [Rooney, 2005]. Table 1 contains basic definitions of active and intelligent packaging.

Introduction of active and intelligent packaging can extend the shelf life of food or improve its organoleptic properties and thus prevent food losses. According to the FDA report of 2011, about 1.3 billion tons of food is thrown away every year. Every year only Europe produces 89 million tons of wasted food, and the average rubbish thrown by European household constitutes 20–30% of food purchased. New packaging solutions allow to improve the economic aspect. The interest in active and intelligent packaging is successively increasing. This is evidenced by the fact that the global market of active and intelligent packaging for food and beverages coupled with controlled/modified atmosphere packaging (CAP/MAP) increased from $15.5 billion in 2005 to $16.9 billion by the end of 2008 and it should reach $23.6 billion by 2013 with a compound annual growth rate of 6.9%. The global market is broken down into different technology applications of active, controlled and intelligent packaging; of these, CAP/MAP has the largest share of the market estimated to comprise 45.4% in 2008, probably decreasing slightly to approximately 40.5%

TABLE 1. Definitions of active and intelligent packaging.

Packaging type	Definition
Active packaging	packaging in which subsidiary constituents have been deliberately included in or on either the packaging material or the package headspace to enhance the performance of the package system
Intelligent packaging	packaging that contains an external or internal indicator to provide information about aspects of the history of the package and/or the quality of the food

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in 2013. Also, active packaging will comprise approximately 27% of the global market in 2008 but will decrease slightly to 26.9% by 2013. This segment will be worth an estimated $4.6 billion in 2008 and should reach $6.4 billion by 2013. Intelligent packaging represented a $1.4 billion segment in 2008, increasing to $2.3 billion by 2013 [Restuccia *et al*., 2010].

ACTIVE PACKAGING SYSTEMS

Active packaging refers to the incorporation of certain additives into packaging film or within packaging containers with the aim of maintaining and extending product shelf life [Day, 1989]. Active packaging, however, allows packages to interact with food and the environment and play a dynamic role in food preservation [Brody *et al*., 2001; Lopez-Rubio *et al*., 2004]. In contrast to traditional packaging, active and intelligent packaging may change the composition and organoleptic characteristics of food, provided that the changes are consistent with the provisions for food. Besides the released substances will be allowed to be used as food additives. The principles behind active packaging are based either on the intrinsic properties of the polymer used as packaging material itself or on the introduction (inclusion, entrapment *etc*.) of specific substances inside the polymer [Gontard, 2000]. Besides, active packaging refers to the incorporation of certain additives into packaging systems (whether loose within the pack, attached to the inside of packaging materials or incorporated within the packaging materials themselves) with the aim of maintaining or extending product quality and shelf-life. Packaging may be termed active when it performs some desired role in food preservation other than providing an inert barrier to external conditions [Hutton, 2003]. On the other hand, active packaging has been defined as packaging, which ‘changes the condition of the packed food to extend shelf-life or to improve safety or sensory properties, while maintaining the quality of packaged food’ [Ahvenainen, 2003]. The development of a whole range of active packaging systems, some of which may have applications in both new and existing food products, is fairly new. Active packaging includes additives or ‘freshness enhancers’ that can participate in a host of packaging applications and by doing so, enhance the preservation function of the primary packaging system.

Oxygen scavengers are by far the most commercially important sub-categories of active packaging and the market has been growing steadily for the last several years. The development of oxygen scavenging systems was first based on self-adhesive labels, other adhesive devices or loose sachets to be included in the packaging with the food. A second concept, developed later, was based on the design of active substances for being included in the packaging material itself, using monolayer or multilayer materials or reactive closures liners for bottles and jars [Rooney, 2005]. Oxygen scavenging compounds are mostly agents that react with oxygen to reduce its concentration. Ferrous oxide is the most commonly used scavenger [Kerry *et al*., 2006]. To prevent scavengers from acting prematurely, specialized mechanisms can trigger the scavenging reaction. For example, photosensitive dyes irradiated with ultraviolet light activate oxygen removal [Lopez-Rubio *et al*., 2004]. Oxygen scavenging technologies have been successfully used in the meat industry [Kerry *et al.,* 2006].

Oxygen scavengers can be used alone or in combination with MAP. Their use alone eliminates the need for MAP machinery and can increase packaging speeds. However, it is usually more common commercially to remove most of the atmospheric oxygen by MAP and then use a relatively small and inexpensive scavenger to mop up the residual oxygen remaining within the food package [Day, 2003; Robertson, 2006].

Non-metallic oxygen scavengers have also been developed to alleviate the potential for metallic taints being imparted to food products. The problem of inadvertently setting off in-line metal detectors is also alleviated even though some modern detectors can now be tuned to phase out the scavenger signal whilst retaining high sensitivity for ferrous and non-ferrous metallic contaminants. Non-metallic scavengers include those that use organic reducing agents such as ascorbic acid, ascorbate salts or catechol. They also include enzymic oxygen scavenger systems using either glucose oxidase or ethanol oxidase, which could be incorporated into sachets, adhesive labels or immobilised onto packaging film surfaces [Day, 2003].

Another popular group of active packaging systems are moisture absorbers. Several companies manufacture moisture absorbers in the form of sachets, pads, sheets or blankets. For packaged dried food applications, desiccants such as silica gel, calcium oxide and activated clays and minerals are typically tear-resistant permeable plastic sachets. In addition to moisture-absorber sachets for humidity control in packaged dried foods, several companies manufacture moisture-drip absorbent pads, sheets and blankets for liquid water control in high *a*w foods such as meats, fish, poultry, fruit and vegetables. Basically, they consist of two layers of a microporous non-woven plastic film, such as polyethylene or polypropylene, between which is placed a superabsorbent polymer which is capable of absorbing up to 500 times its own weight with water. Typical superabsorbent polymers include polyacrylate salts, carboxymethyl cellulose (CMC) and starch copolymers which have a very strong affinity for water. Moisture drip absorber pads are commonly placed under packaged fresh meats, fish and poultry to absorb unsightly tissue drip exudate. Larger sheets and blankets are used for absorption of melted ice from chilled seafood during air freight transportation, or for controlling transpiration of horticultural produce. For dual-action purposes, these sachets may also contain activated carbon for odour adsorption or iron powder for oxygen scavenging [Rooney, 1995]. Interesting solutions include a carbon dioxide scavenger or a dual-action oxygen and a carbon dioxide scavenger system. A mixture of calcium oxide and activated charcoal has been used in polyethylene coffee pouches to scavenge carbon dioxide but dual-action oxygen and carbon dioxide scavenger sachets and labels are more common and are commercially used for canned and foil pouched coffees in Japan and the USA [Day, 1989; Anon., 1995; Rooney, 1995].

Ethanol emitters are a sub-set of preservative releasing technologies although ethanol emitters are usually in sachet forms as opposed to impregnated preservative releasing films. The use of ethanol as an antimicrobial agent is well documented. It is particularly effective against mould but can also inhibit the growth of yeasts and bacteria. Several reports have demonstrated that the mould-free shelf-life of bakery products can be significantly extended after spraying with 95% ethanol to give concentrations of 0.5–1.5% (w/w) in the products. However, a more practical and safer method of generating ethanol is through the use of ethanol-emitting sachets [Rooney, 1995; Labuza & Breene, 1989; Day, 2003]. The size and capacity of the ethanol-emitting sachet used depends on the weight of food, the *a*w of the food and the desired shelf--life required. When food is packed with an ethanol-emitting sachet, moisture is absorbed by the food and ethanol vapour is released and diffuses into the package headspace. Ethanol emitters are used extensively in Japan to extend the mould--free shelf-life of high-ratio cakes and other high moisture bakery products by up to 2000% [Rooney, 1995; Day, 2003]. Latou *et al.* [2010] analyzed shelf-life extension of sliced wheat bread using either an ethanol emitter or an ethanol emitter combined with an oxygen absorber as alternatives to chemical preservatives. Data recorded in the present study clearly show that active packaging in combination with a high barrier packaging material (PET-SiOx//LDPE) can substantially extend the shelf-life of sliced bread. Based on sensory (texture) and microbiological data, shelf-life was *ca*. 4 days for no preservatives (WOP) samples, 6 days for bread containing commercial preservatives (WP) samples, 24 days for samples containing the ethanol emitter (EE) and at least 30 days for samples containing the ethanol emitter combined with an oxygen absorber (EE + OA).

The development of unpleasant flavours as a consequence of food processing can be the result of thermal degradation of components, such as proteins, or of reaction such as the Maillard reaction. In 1979 Chandler & Johnson showed that substantial quantities of limonin could be removed by acetylated paper, following earlier work involving cellulose acetate gel beads [Chandler, 1968]. Franzetti *et al.* [2001] presented that unpleasant smelling volatile amines, such as trimethylamine, associated with fish protein breakdown are alkaline and can be neutralised by various acidic compounds. Besides, spice-based essential oils have been studied for antimicrobial effects: for example, oregano oil in meat [Skandamis & Nyachas, 2002], mustard oil in bread [Suhr & Nielsen, 2005], oregano, basil [Suppakul *et al*., 2003], clove, carvacol, thymol, and cinnamon. Mexis *et al.* [2009] examined the coupled effect of an O_2 absorber and oregano essential oil on shelf-life extension of Greek cod roe paste (tarama salad) stored at 4 °C. They showed that the addition of oregano essential oil had a small preservative effect on tarama salad while the use of O_2 absorber substantially increased product shelf-life (*i.e.* 24 *vs.* at least 60 days).

Packaging containing natural preservatives and antioxidants undoubtedly has a high potential. Active packages with antioxidant properties have received special attention, since they are one of the most promising alternatives to traditional packaging, in which antioxidants are incorporated into or coated onto food packaging materials to reduce oxidation of the food, which is one of the main causes of food spoilage [López-de-Dicastillo *et al.*, 2012]. Antimicrobials reduce the growth rate and maximum population of microorganisms (spoilage and pathogenic) by extending the lag phase of microbes or inactivating them [Quintavalla & Vicini, 2002]. Using antimicrobial or antioxidant agents in active food packaging is relatively recent, and causes consumer concerns regarding their safety due to their possible migration into foods [Vermaeiren *et al*., 1999; Han, 2003]. For this reason, there is growing consumer preference for natural agents which have been isolated from microbiological, plant, and animal sources [Nicholson, 1998]. Active substances of biological origin have a powerful wide-spectrum activity with low toxicity, and are expected to be used for food preservation as a means of active packaging [Han, 2003]. Vojdani & Torees [1989, 1990] have examined the diffusion barrier properties of a variety of polysaccharide-based films and they have found that methyl cellulose offers the greatest potential as a substrate for the antimicrobial agent potassium sorbate. Further work established that creating multi-layer films of methyl and hydroxypropyl methyl cellulose would allow slower, thus more effective, diffusion of potassium sorbate into a potential food product. The addition of fatty acids such as lauric, palmitic, stearic and arachidic acids was also found to be effective for lowering the diffusion of potassium sorbate in cellulose-based films. The group of natural antimicrobial agents includes nisin – a bacteriocin produced by *Lactococcus lactis*. Fang & Lin [1994] used nisin in combination with modified-atmosphere packaging in a study involving cooked pork which was inoculated with *Pseduomonas fragi* and *Listeria monocytogenes*. Both microorganisms were effectively reduced in number by the modified-atmosphere/ nisin combination during refrigerated storage of the cooked pork [Fang & Lin, 1994]. Granda-Restrepo *et al*. [2009] developed polyethylene films with α-tocopherol and measured its release into milk powder. Gemili *et al*. [2010] studied the release of ascorbic acid and L-tyrosine from a cellulose acetate-based film. Garces *et al*. [2003] patented an antioxidant varnish, based on the addition of plant extracts for food protection, and Nerin *et al.* [2006] reported its efficiency in the stabilization of beef meat. López-de-Dicastillo *et al*. [2012] studied active antioxidant films for the packaging of oxygen-sensitive foods, based on an ethylene–vinyl alcohol copolymer (EVOH 29) and four natural antioxidants. They used EVOH because it is a common packaging material that is well known for its excellent oxygen barrier properties and its highly hydrophilic nature [Aucejo *et al*., 2000].

The consumption of probiotic foods includes the development of packaging materials that adequately protect and preserve the therapeutic activity of probiotic foods. Besides, Mattila-Sandholm *et al*. [2002] reported that the packaging materials and the storage conditions are important factors for the quality of products containing probiotic microorganisms. Miller *et al*. [2002] studied the influence of two types of packaging material: high oxygen barrier polystyrene of 300–350 lm thickness and a high gas barrier material with a multilayer structure (HIPS/tie/EVOH/tie/PE, trade name NUPAK) added to high impact polystyrene – on the level of dissolved oxygen in probiotic yogurt throughout shelf-life. Also, active packages with incorporated oxygen barrier materials or films with selective permeability properties have potential applications in the packaging of probiotic food products [daCruz *et al*., 2007]. Dave & Shah [Dave & Shah, 1997] studied the behavior of *L. acidophilus* in yogurts filled into glass and high-density polyethylene containers for 35 days. The level of dissolved oxygen in the glass packages remained low, whereas the oxygen levels in the plastic packages significantly increased. Jansson *et al*. [2002] investigated the survival of bifidobacteria in fermented milk filled into packages with varying degrees of crystallinity and polarity. The results were surprising in that the increase in crystallinity of a polymeric material directly influences its barrier properties, thereby reducing permeability. However, contrary to the expected, the bacterial counts did not vary proportionally to the degree of crystallinity of the packaging material. Talwalkar *et al*. [2004] investigated the effect of packaging materials on the survival of probiotic bacteria in yogurt by monitoring the oxygen concentration during storage. Kudelka [2005] analyzed the effect of pasteurization and package type on the acidity of probiotic yogurts made from goat's and cow's milk during 21 days refrigerated storage. Others studied the effect of the packaging material and the storage temperature on the viability of microencapsulated bifidobacteria [Hsiao *et al*., 2004].

INTELLIGENT PACKAGING SYSTEMS

Intelligent packaging (also described as smart packaging) is packaging that in some way senses some properties of the food it encloses or the environment in which it is kept and which is able to inform the manufacturer, retailer and consumer of the state of these properties. Although distinctly different from the concept of active packaging, features of intelligent packaging can be used to check the effectiveness and integrity of active packaging systems [Hutton, 2003]. Intelligent packaging devices are capable of sensing and providing information about the function and properties of packaged food and can provide assurances of pack integrity, tamper evidence, product safety and quality, and are being utilized in applications such as product authenticity, anti-theft and product traceability [Summers, 1992; Day, 2001]. Intelligent packaging devices include sensors, time-temperature indicators, gas sensing dyes, microbial growth indicators, physical shock indicators, and numerous examples of tamper proof, anti-counterfeiting and anti-theft technologies. Information on intelligent packaging technology can be obtained from other reference sources [Summers, 1992; Day, 1989, 2001].

Besides, intelligent packaging systems attached as labels, incorporated into, or printed onto a food packaging material offer enhanced possibilities to monitor product quality, trace the critical points, and give more detailed information throughout the supply chain [Rodrigues & Han, 2003]. Intelligent tags such as electronic labelling, designed with ink technology in a printed circuit and built-in battery radio-frequency identity tags, all placed outside the primary packaging, are being developed in order to increase the efficiency of the flow of information and to offer innovative communicative functions. Diagnostic indicators were first designed to provide information on the food storage conditions, such as temperature, time, oxygen or carbon dioxide content, and thus, indirectly, information on food quality, as an interesting complement to end-use dates [Dainelli *et al*., 2008]. Indicators are called smart or interactive because they interact with compounds in the food. Microwave heating enhancers, such as susceptors and another temperature regulation methods, are sometimes regarded as intelligent methods as well.

Time–temperature indicators or integrators (TTIs) are defined as simple, cost-effective and user-friendly devices to monitor, record, and cumulatively indicate the overall influence of temperature history on the food product quality from the point of manufacture up to the consumer [Taoukis & Labuza, 1989; Giannakourou *et al*., 2005]. Temperature indicators show whether products have been heated above or cooled below a reference (critical) temperature, warning consumers about the potential survival of pathogenic micro-organisms and protein denaturation during, for example, freezing or defrosting processes. Furthermore, TTIs have also been applied to assess the pasteurization and sterilization process [Mehauden *et al*., 2007; Tucker *et al*., 2007, 2009].

The visible response thus gives a cumulative indication of the storage temperature to which the TTI has been exposed. TTIs may be classified as either partial history or full history indicators, depending on their response mechanism. Partial history indicators do not respond unless a temperature threshold has been exceeded and indicate that a product has been exposed to a temperature sufficient to cause a change in product quality or safety. Full history TTIs give a continuous temperature-dependent response throughout a products history and constitute the main focus of interest for research and commercial exploitation [Kerry *et al.,* 2006]. Besides, time table indicators display a continuous temperature-dependent response of the food product. The response is made to chemical, enzymatic or microbiological changes that should be visible and irreversible, and is temperature dependent [Rodrigues & Han, 2003]. Wanihsuksombat *et al*. [2010], characterized a prototype of a lactic acid-based time-temperature indicator for monitoring food product quality. Four lactic acid-based TTIs were made in different substrate concentrations. Color changes associated with the diffusion of lactic acid were monitored. In the vapor diffusion of lactic acid, an irreversible color change of a chemical chromatic indicator (from green to red) clearly and progressively occurred due to pH reduction. The temperature dependence of these TTIs kinetics was characterized isothermally in the range of 4–45°C, yielding activation energy (Ea) of, approximately, 50 kJ mol^{-1}. Figure 1 depicts color changes of TTI at 4, 18

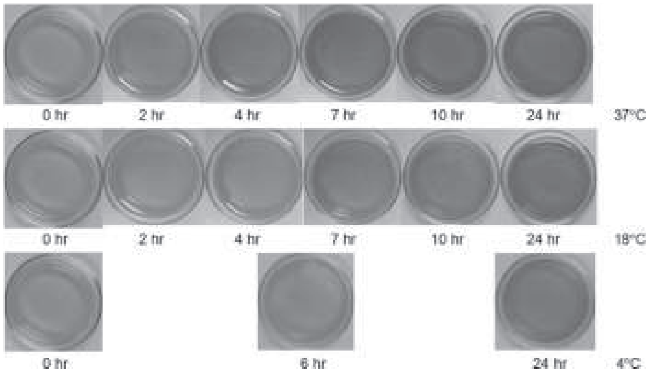

FIGURE 1. Color changes of a lactic acid-based TTI indicator at different temperatures [Wanihsuksombat *et al*., 2010].

and 37°C. Lactic acid is monoprotic, having a hydrogen atom which may dissociate from the parent molecule, forming hydrogen ions (H^+) and lactate ions ($CH_3CH(OH)COO^-$) with pKa of 3.85 at 25°C [Doores, 1993].

Kim *et al*. [2012] developed a new enzyme-based TTI prototype using an advantageous enzyme, laccase, which has simple discoloration kinetics and is widely available. Laccases (EC1.10.3.2) are copper-containing enzymes that are traditionally used for many industrial processes including paper processing, prevention of wine discoloration, detoxification of environmental pollutants, oxidation of dyes, and production of chemicals from lignin [Couto& Toca Herrera, 2006; Riva, 2006; Viswanath *et al*., 2008]. Laccase has the interesting ability to discolor several dyes and a very broad range of substrate specificity, including phenolic compounds, diamines, aromatic amines, benzenethiols and even some inorganic compounds such as iodine [Xu, 1996]. In addition, laccases are present in fungi, higher plants and a few bacteria [Octavio *et al.*, 2006; Xiao *et al*., 2004]. The hue value for researchers was found to be highly correlated with the concentration of laccase reaction product and determined as the color response variable.

Oxygen and carbon dioxide indicators can also be used to monitor food quality. They can be used as a leakage indicator or to verify the efficiency of, for example, an oxygen scavenger. Most of these indicators are based on color change as a result of a chemical or enzymatic reaction. These indicators have to be in contact with the gaseous environment inside the package and hence are in direct contact with the food [De Jong *et al*., 2005]. Conventional oxygen indicators are known to use methylene blue (MB, methyl thionine chloride), a dye that reversibly changes its color upon oxidation and reduction [Sumitani *et al*., 2004].

Lee *et al*. [2008] developed a new range of colorimetric oxygen indicators that are irreversible, reusable, and UV-light activated. Such "intelligent ink" oxygen sensors comprise a UV-absorbing semiconductor, such as TiO_2, a redox-indicator, such as methylene blue, a sacrificial electron donor, such as triethanolamine, and an encapsulating polymer such as hydroxyethyl cellulose; the ingredients are mixed together, with water as the solvent, to form an ink. The ink can be coated or printed subsequently onto a variety of substrates to produce a blue oxygen indicator film, which, when activated by UV light, becomes colourless. The activated, that is, UV-photo-bleached, film remains colorless unless, or until, exposed to oxygen, at which point the reduced methylene blue is reoxidized back to its original blue form. The indicator is not active until it is exposed to UV light. During irradiation, nano-crystalline semiconductor SC is triggered. During this process, there is a pair of electrons that is called a "hole". It enables SC (e-, h +) present in the solution to oxidize SED. Electrons generated in this reaction are the particles of semiconductor SC (e-), and the electrons reduce the dye to a colorless form Dox Dred. The reduced form of the dye quickly returns to its original color in the presence of oxygen. This cycle can be repeated inducing UV index [Mills, 2005].

Lawrie *et al*. [2013] presented a simple inkjet-printed, UV-activated oxygen indicator. Inkjet printing is now becoming increasingly popular in the packaging industry. The most common applications of inkjet printing in the food packaging industry [Leach & Pierce, 1999] are: date-stamps, batch codes and any other variable information required on a package, with most food packages marked in some manner by inkjet printing. Inkjet-printing is becoming increasingly popular for functional [Magdassi, 2010] as well as standard, colored--inks. Such functional inks include electrically-conductive inks for flexible displays or sensors [Wu *et al.,* 2009; Courbat *et al*., 2010], ceramic inks for printing on tiles [Magdassi, 2010] and inks which can be printed to form 3D structures. Inkjet printing itself falls under two broad classifications: continuous inkjet (CIJ) printing and drop on demand (DOD) inkjet printing [Leach & Pierce, 1999; Magdassi, 2010]. Of the two, DOD inkjet-printing is a much simpler and more environmentally-friendly system and is increasingly being used in the packaging industry to print directly on packages still on the packaging line, or on a web of polymer material similar to a flexo printing system. The most common DOD inkjet-printing method, used here, is piezoelectric inkjet (PIJ) printing whereby the oscillation of a piezo crystal [Magdassi, 2010; Kui & Tay, 2003] creates a pressure pulse, forcing an ink droplet out of the print head, and onto the substrate.

There are also indicators based on fluorescence. The reaction is based on the phosphorus layout that has been extinguished when in contact with molecular oxygen. Luminescent compounds are placed in the gas permeable and impermeable to ion materials such as silicone rubber or an organic polymer, such as poly(vinyl chloride), to create thin film, oxygen indicators [Mills & Thomas, 1997]. One of the most popular is tris (4,7-diphenyl-1,10-phenanthroline) ruthenium (II) perchlorate, *i.e.* $[Ru(dpp)_3](ClO_4)_2$, where dpp is the complexing ligand, 4,7-diphenyl-1,10-phenanthroline. The most commonly-employed leak indicator used in food packaging is a colorimetric redox dye-based indicator [Mills, 2005].

According to Mills [2005], an ideal oxygen indicator for the food packaging industry should also exhibit an irreversible response towards oxygen. The indicator should illustrate why this latter feature is so desirable it is worthwhile considering the response of a reversible oxygen indicator in a MAPed food package that, in a not too unlikely scenario, some time later develops a small leak. Obviously, the indicator will show no oxygen is present in the package until the leak develops, at which time it will indicate the presence of oxygen. However, if the leak is small, it is very possible that the subsequent rapid increase in microbial growth will be such that within a short time the oxygen in the atmosphere in the package will be converted to carbon dioxide and the rate of bacterial metabolism will be matched by the rate of oxygen ingress. Besides, an ideal oxygen indicator should be easily incorporated into the food package and so is best applied as an ink, which must be printable on paper and plastic. In the food industry such an ink falls under the umbrella heading of intelligent packaging. Besides, this technology is able to monitor and/or give information about the history and/or quality of the packed food [Mills, 2005].

Changes in the concentration of organic acids such as n-butyrate, L-lactic acid, D lactate and acetic acid during storage offer potential as indicator metabolites for a number of meat products [Shu *et al*., 1993]. Color-based pH indicators offer potential for use as indicators of these microbial metabolites. Another example of microbial indicators is the system based on immunochemical reactions that occur in the barcode [Goldsmith, 1994], and the barcode will become unreadable when a particular microorganism is present [Rodrigues & Han, 2003]. Kraśniewska & Gniewosz [2012] reported on investigations conducted with nisin being introduced into a film from methylcellulose (MC) and hydroxypropylmethylcellulose (HPMC), which are fine carriers of bactericidal substances and additionally are characterized by resistance and elasticity. The films formed were found to well inhibit the growth of *Micrococcus luteus*.

Ethanol, like lactic acid and acetic acid, is an important indicator of fermentative metabolism of lactic acid bacteria. Randell *et al*. [1995] reported an increase in the ethanol concentration of anaerobically MA packaged marinated chicken as a function of storage time. The Lawrence Berkeley National Laboratory has developed a sensing material for the detection *of Escherichia coli* 0157 enterotoxin [Cheng & Stevens, 1998]. The material is composed of cross-polymerized polydiacetylene molecules that can be incorporated into the packaging film. As the toxin binds to the molecules, the color of the film changes permanently from blue to red [Smolander, 2000].

Many intelligent packaging concepts involve the use of sensors. A sensor is defined as a device used to detect, locate or quantify energy or matter, giving a signal for the detection or measurement of a physical or chemical property to which the device responds [Kress-Rogers, 1998]. To be qualified as a sensor, a device must be able to provide continuous output of a signal. Most sensors contain two basic functional units: a receptor and a transducer. In the receptor, physical or chemical information is transformed into a form of energy, which may be measured by the transducer. The transducer is a device capable of transforming the energy carrying the physical or chemical information about the sample into a useful analytical signal [Kerry *et al.,* 2006]. O'Riordan *et al.* [2005] examined the migration of active components of two metalloporphyrin and one ruthenium dye-based oxygen sensors and established their stability, safety and suitability for large scale use in food packaging applications. Others examined the potential of platinum based disposable oxygen sensors as a quality control instrument for vacuum-packed raw and cooked meat and MA-packed sliced ham. Direct contact of sensors on the foods provided accurate oxygen profiles over time and correlated well with conventional (*i.e.* destructive) headspace analysis [Fitzgerald *et al*., 2001].

An interesting intelligent solution is "electronic nose". This is an analytical tool composed of an array of sensors which respond to volatile compounds by changing their electrical properties [Blixt & Borch, 1999]. The samples can then be classified as acceptable or unacceptable, referencing a sensory evaluation or microbiological analysis catalog. The response of the electronic nose has been found to be consistent with microbiological analysis and volatile concentration determination of the product [Gram & Huss, 2000]. It has also been proved to be successful in the quality evaluation of fresh Yellow fin tuna and vacuum-packaged beef [Blixt & Borch, 1999]. "Doneness" indicators are convenience-, quality- and temperature-indicating packaging systems. They detect and indicate the state of readiness of heated foods. The "ready" button indicators are commonly placed in poultry products. When a certain temperature has been reached, the material expands and the button pops out, telling the consumer that the poultry product is frilly cooked [Ahvenainen, 2003].

RFID technology (Radio Frequency Identification) does not fall into either sensor or indicator classification but rather represents a separate electronic information-based form of intelligent packaging. RFID uses tags affixed to assets (cattle, containers, pallets, *etc*.) to transmit accurate, real-time information to a user's information system. RFID is one of the many automatic identification technologies (a group which includes bar-codes) and offers a number of potential benefits to the meat production, distribution and retail chain. These include traceability, inventory management, labour saving costs, security and promotion of quality and safety [Mousavi *et al.*, 2002]. Prevention of product recalls is also considered an important role of RFID technology [Kumar & Budin, 2006]. RFID technology has been available for approximately 40 years although its broad application to packaging is a relatively recent development [Kerry *et al.,* 2006]. Wamba *et al*. [2006] show that using RFID in a retail industry can improve shipping, receiving and put-away processes corresponding to suppliers, distribution centers (DCs) and retailers, respectively. Gandino *et al*. [2007] propose a traceability system based on RFID technology for a fruit warehouse. Meuwissen *et al*. [2002] indicate the importance of the traceability system and analyze its potential costs and benefits by applying RFID technology to the British livestock industry. Besides, Karkkainen [2003] indicated that adopting RFID technology can improve replenishment productivity as well as reduce stock loss in the supply chain of short-shelf-life products. Jones *et al*. [2005] reported that RFID technology can be used throughout the supply chain for the UK retail foods industry, including tighter management and control of the supply chain, reduced shrinkage, reduced labour costs, improved customer service and improved compliance with traceability protocols and food safety regulations. Chen *et al*. [2008] proposed an integrated traceability system for the entire food supply chain by RFID technology. In their study, the food production can be traced so that consumers can get the complete food production information to choose and buy the safety food. Kumar & Budin [2006] also concluded that RFID plays a crucial role in the prevention of food product recalls. Innovative applications of RFID are still rare in the restaurant industry. Ngai *et al.* [2008] developed an RFID-based sushi management system in a conveyor-belt sushi restaurant to enhance competitive advantage. Their case study showed that RFID technology can help improve food safety, inventory control, service quality, operational efficiency and data visibility in sushi restaurants. As competition between restaurants intensifies, restaurants must integrate innovative technologies with business management processes to enhance customer service and improve competitiveness [Kumar *et al.*, 2005]. This situation motivated the development of this RFID-based e-restaurant system with customer-centric service to enhance customer satisfaction and perceived value [Lee *et al.*, 2008].

RFID tags can be classified according to two types: active tags function with battery power, broadcast a signal to the RFID reader and operate at a distance of up to approximately 50 m. Passive tags have a shorter reading range (up to approximately 5 m) and are powered by the energy supplied by the reader (giving them essentially unlimited life). Common RFID frequencies range from low (~125 kHz) to UHF (850–900 MHz) and microwave frequencies (~2.45 GHz). Low frequency tags are cheaper, use less power and are better able to penetrate non-metallic objects. These tags are most appropriate for use with meat products, particularly where the tags might be obscured by the meat itself and are ideal for close-range scanning of objects with high water content [Kerry *et al*., 2006].

CONCLUSIONS

Changes in consumer preferences have led to innovations and developments in new packaging technologies. Research and development in the field of active and intelligent packaging materials is very dynamic and develops in relation with the search for environment-friendly packaging solutions. Active and intelligent packaging is becoming more and more widely used for food products. Application of this type of solution contributes to the improvement of the quality of consumer life. Besides, innovation systems will improve the product's quality, enhance the safety and security of foods, and consequently decrease the number of retailer and consumer complaints.

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