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REVIEW ARTICLE

Smart packaging systems for food applications: a review

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Abstract Changes in consumer preference for safe food have led to innovations in packaging technologies. This article reviews about different smart packaging systems and their applications in food packaging, packaging research with latest innovations. Active and intelligent packing are such packaging technologies which offer to deliver safer and quality products. Active packaging refers to the incorporation of additives into the package with the aim of maintaining or extending the product quality and shelf life. The intelligent systems are those that monitor the condition of packaged food to give information regarding the quality of the packaged food during transportation and storage. These technologies are designed to the increasing demand for safer foods with better shelf life. The market for active and intelligent packaging systems is expected to have a promising future by their integration into packaging materials or systems.

Keywords Active packaging · Intelligent packaging · Freshness indicator · RFID

Introduction

Traditional food packaging is meant for protection, communication, convenience and containment (Paine 1991; Robertson 2006). The package is used to protect the product from the deteriorative effects of external environmental conditionals like heat, light, presence or absence of moisture, pressure, microorganisms, gaseous emissions and so on. It also provides the consumer with the greater ease of use and time saving convenience and contain product of various size and shapes (Yam et al. 2005; Marsh and Bugusu 2007). The key safety objective for traditional packaging materials which comes in contact with food is to be inert as possible. While the smart packaging systems like active and intelligent packaging concepts are based on the useful interaction between packaging environment and the food to provide active protection to the food. Most important innovative packaging systems which are currently being used in food industry are described in detail in this review (Tables 1 and 2).

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Active packaging

Packaging may be termed active when it performs some role other than providing an inert barrier to the external environment (Rooney 1995). Active packaging can be defined as a system in which the product, package and the environment interact in a positive way to extend the shelf life or to achieve some characteristics (Miltz et al. 1995). It has also been defined as a type of packaging that changes the condition of the packaging to extend shelf life or to improve safety or sensory properties while maintaining the quality of the packaged food (Ahvenainen 2003). According to regulation 1935/2004/EC and 450/2009/EC active materials and articles are intended to extend the shelf life or to maintain or improve the condition of packaged food. They are designed to deliberately incorporate components that would release or absorb substances into or from the packaged food or environment surrounding the food (Sivertsvik 2007; Floros et al. 1997).The goal of active packaging is to enhance the preservation of food in the package and prolonging shelf life involves application of various strategies like temperature control, oxygen removal, moisture control, addition of chemicals such as salt, sugar, carbon

Table 1 Commercially available active packaging systems

Trade Name	Manufacturer	Principle	Type
Ageless	Mitsubishi Gas Chemical Co. Ltd., Japan	Iron based	Oxygen scavenger
Freshilizer	Toppan Printing Co. Ltd., Japan	Iron based	Oxygen scavenger
Freshmax, Freshpax, Fresh Pack	Multisorb Technologies, USA	Iron based	Oxygen scavenger
Oxyguard	Toyo Seikan Kaisha Ltd., Japan	Iron based	Oxygen scavenger
Zero$_2$	Food Science Australia, Australia	Photosensitive dye	Oxygen scavenger
Bioka	Bioka Ltd., Finland	Enzyme based	Oxygen scavenger
Dri-Loc®	Sealed Air Corporation, USA	Absorbent pad	Moisture absorber
Tenderpac®	SEALPAC, Germany	Dual compartment system	Moisture absorber
Biomaster®	Addmaster Limited, USA	Silver based	Antimicrobial packing
Agion®	Life Materials Technology Limited, USA	Silver based	Antimicrobial packing
SANICO®	Laboratories STANDA,	Antifungal coating	Interleavers
Neupalon	Sekisui Jushi Ltd., Japan	Activated carbon	Ethylene scavenger
Peakfresh	Peakfresh Products Ltd., Australia	Activated clay	Ethylene scavenger
Evert-Fresh	Evert-Fresh Corporation, USA	Ativated zeolites	Ethylene scavenger

dioxide or natural acids or a combination of these with effective packaging (Robertson 2006; Restuccia et al. 2010). These developments in active packaging have led to advances in many areas including delayed oxidation in muscle foods, controlled respiration rate in horticultural products, microbial growth and moisture migration in dried products. In addition, active packaging also manipulates the selectivity to modify the atmospheric concentration of gaseous compounds inside the package by coating, micro perforation, lamination, co extrusion, or polymer blending. (Brody et al. 2008).

Oxygen scavengers

The most widely used active packaging technology for foods today are oxygen scavengers. The presence of oxygen in a

Table 2 Commercially available intelligent packing systems

Trade Name	Manufacturer	Type
O_2 Sense ™	Freshpoint Lab	Integrity indicator
Novas®	Insignia Technologies Ltd.	Integrity indicator
Ageless Eye®	Mitsubishi Gas Chemical Inc.	Integrity indicator
Freshtag®	COX Technologies	Freshness indicator
Sensorq®	DSM NV And Food Quality Sensor International	Freshness indicator
Timestrip Complete®	Timestrip UK Ltd.	Time temperature
Timestrip®PLUS Duo	Timestrip UK Ltd.	Temperature indicator
Monitormark^{tm}	3M^{TM}, Minnesota	Time temperature indicator
Fresh-Check®	Temptime Corp	Time temperature indicator
Onvu^{tm}	Ciba Specialty Chemicals And Freshpoint	Time temperature indicator
Checkpoint®	Vitsab	Time temperature indicator
Cook-Chex	Pymah Corp	Time temperature indicator
Colour-Therm	Colour Therm	Time temperature indicator
Thermax	Thermographic Measurements Ltd.	Time temperature indicator
Timestrip®	Timestrip Ltd.	Integrity indicators
Novas®	Insignia Technologies Ltd.	Integrity tndicators
Easy2log®	CAEN RFID Srl	RFID
Intelligent Box	Mondi Plc	RFID
CS8304	Convergence Systems Ltd.	RFID
Temptrip	Temptrip LLC	RFID

package accelerates the oxidative deterioration of food. Oxygen facilitates the growth of aerobic microbes, off flavor and odour development, colour changes and nutritional losses and overall shelf life stability of muscle foods (Hogan and Kerry 2008). Therefore control of oxygen levels in food packages is important to limit the rate of such spoilage reactions in food. Even though the oxygen sensitive foods can be packed in modified atmosphere packaging (MAP) or vacuum packaging, but it do not remove oxygen completely. Oxygen which permeates through the packaging film cannot be removed through the system. By the use of oxygen scavengers, which absorbs the residual oxygen after packaging, quality changes in oxygen sensitive foods can be minimized (Vermerien et al. 1999; Kerry et al. 2006). The oxygen absorbers are designed to reduce oxygen levels to less than 100 ppm in package headspace. The commercially available oxygen scavengers utilize one or more of the following technologies: iron powder oxidation, ascorbic acid oxidation, photosensitive dye oxidation, enzyme oxidation, saturated fatty acid oxidation, immobilized yeast on solid material etc. (Floros 1997; Vermeiren et al. 1999). Majority of currently available oxygen scavengers are based on iron powder oxidation in the form of small sachets containing various iron based powders containing as assortment of catalysts. The chemical substances react with the water supplied by the food to produce a reactive hydrated metallic reducing agent that scavenges oxygen within the food package (Day 2008). The oxygen scavengers could be used to create oxygen free conditions in the headspace of packages with medium barrier properties (Sivertsvik 2003, 2007). The oxygen scavengers can be used alone or in combination of MAP. Relatively inexpensive oxygen scavengers are used to remove the residual oxygen remaining in the MAP (Day 2003, 2008; Robertson 2006). An alternative to sachets include package inserts in the form of cards, sheets or layers coated onto the inner walls of the package (Rooney 1995). Incorporation of oxygen scavenger into the package eliminates the risk of accidental rupture of the sachets and inadvertent consumption of their contents (Suppakul et al. 2003). Oxygen scavenging compounds can be dispersed or blended with high permeability films like polyethylene. Which allow rapid diffusion of oxygen and water from the headspace or from food to the reactive ingredients. However the capacity of oxygen scavenging plastic films and laminates are considerably lower than iron based oxygen scavenger sachets or labels (Day 2008).

Carbon dioxide absorbers and emitters

Carbon dioxide can be added to the packaging environment to suppress the microbial growth in certain products such as fresh meat, poultry, fish, cheese, and backed goods (Lopez-Rubio et al. 2004) and to reduce the respiration rate of fresh produce (Labuza 1996). Therefore high CO_2 levels (10–80 %) are desirable for such food items to extend the shelf life (Labusa1996). In the case of oxygen scavenger packs, oxygen removal creates a partial vacuum which may result in package collapse in flexible packages. Also when a package is flushed with a mixture of gases including CO_2 and O_2, the CO_2 dissolves in the product creating a partial vacuum (Kerry et al. 2006; Vermeiren et al. 1999) due to the solubility of CO_2 at lower temperatures (Sivertsvik et al. 2004). The method of dissolving sufficient amount of CO_2 into the product in one to two hour in pure CO_2 prior to retail is called as soluble gas stabilization (SGS) (Sivertsvik 2000). Commercial manufacturers of CO_2 releasers include Mitsubishi Gas Chemical Co. Ltd. (Ageless TM type G), and Multisorb Technologies Inc. (FreshPax Type M)® USA. Standard MAP tray with perforated false bottom with sachet can be applied for muscle foods. The exudates from the food acts with the sachet to release CO_2 to the package and prevents package collapse (Kerry et al. 2006).

Carbon dioxide scavengers are used to remove excess CO_2 in packages. CO_2 scavengers are mainly used in fresh roasted coffees which produce significant amount of CO_2 if hermetically sealed in packs directly after roasting leads to the bursting of package (Day 2008). Mitsubishi Gas Chemical Company offers sachets specially for CO_2 scavenging. The use of CO_2 scavengers replaces the 'aging' process after coffee roasting and thereby prevents the loss of desirable coffee volatiles (Brody et al. 2001).

Antimicrobial packing

Antimicrobial packing is a form of active packaging in which the packaging acts to reduce, inhibit or retard the growth of microorganisms that may be present in the packaged food or packaging material itself (Appendini and Hotchkiss 2002). To control undesirable microorganisms on foods, antimicrobial substances can be incorporated in or coated onto food packaging materials (Labuza and Breene 1989). Natural antimicrobial agents include extracts from spices like cinnamon, allispice, clove, thyme, rosemary, oregano and other plant extracts like onion, garlic, radish mustard and horseradish. Other natural antimicrobials are derived from substances produced from fungal and bacterial action like polypeptide nisin, natamycin, pediocin, and various bacteriocins (Nicholson 1997). Antimicrobial package material can be classified into two types: those containing antimicrobial agents that migrate to the surface of the packaging material, and those are effective against surface microbes without migration of the active agent to the foods (Han 2000). The direct surface application of antibacterial substances onto food have limited applications because the active substance are neutralized on contact or diffuse rapidly from the surface to the food. The incorporation of antimicrobial agent to meat formulations may result in partial inactivation of active compounds by meat constituents and therefore exert a limited effect on surface micro flora (Quintavalla and Vicini 2002).

The antimicrobial food packaging material has to extend the lag phase and reduce the growth phase of microorganisms in order to extend the shelf life and shelf life safety (Han 2000). The major potential food applications for antimicrobial agents include meat, poultry, bread, cheese, fruits and vegetables (Labuza 1987). Bioactive agents including antimicrobials are incorporated into polymers are used for drug and pesticide delivery, textiles, surgical implants and other biomedical devices. Silver substituted zeolite is the most common antimicrobial agent used in Japan. Silver ions inhibit a wide range of metabolic enzymes and it has a strong antimicrobial activity with a broad spectrum. The silver zeolite is laminated as a thin layer on the food contact surface of the laminate. Silver ions release from the laminate when the aqueous solution from the food enters the exposed cavities of the porous structure (Ishitani 1995; Quintavalla and Vicini, 2002). Commercial examples of silver substituted zeolites include Zeomic®, Apacider®, AgIon, Bactekiller and Novaron. Antimicrobial enzymes like lactoperoxidase and Lactoferrin, antimicrobial peptides like megainins, cecropines, defensins, natural phenols like hydroquinons and catechins, fatty acid esters, antioxidant phenolic, antibiotics and metals like copper are incorporated into polymers (Hotchkiss 1997; Appendini and Hotchkiss 2002).

Packaging systems that release volatile antimicrobials include chlorine dioxide, sulphur dioxide, carbon dioxide and ethanol. In this system, polymer need not be directly in contact with the food. Here the antimicrobial agents are directly incorporated into the polymer or into the carriers that may be extruded or coated into the packaging materials. The packaging material used for the volatile antimicrobial system should possess high barrier properties to prevent the loss through permeation (Appendini and Hotchkiss 2002). Spraying ethanol onto foods or sachets generating ethanol can be applied. Ethicap® and Antimold® are ethanol releasing sachets acts by absorbing moisture and releasing ethanol vapour (Smith et al. 1995). Ethanol vapour generators are mainly used for high moist bakery products, cheese and fish. Heating the product before consumption can be used to evaporate the ethanol from the product. Chlorine dioxide is another antimicrobial agent effective against bacteria, fungi and viruses. Chlorine dioxide can be generated by using sodium chlorite and acid precursors which are embedded in a hydrophobic and hydrophilic phase of a copolymer. Moisture from the food when come in contact with the hydrophobic phase, acid is released which reacts with the sodium chlorite releasing chlorine dioxide (Smith et al. 1995).

Some antimicrobial packaging uses covalently immobilized antibiotics or fungicides to suppress the growth of microbes (Brody et al. 2002). Examples of antimicrobials with functional groups are peptides, enzymes, polyamines and organic acids. Some polymers like chitosan are inherently antimicrobial and are used in films and coatings. Chitosan has been used as a coating to protect fresh vegetables and fruits from fungal attack. It also acts as a barrier between the nutrients contained in the product and microorganism (Cuq et al. 1995).

Antimicrobial edible coatings and films prepared from polysaccharides, proteins and lipids have variety of advantages like biodegradability, edibility, biocompatibility, aesthetic appearance, barrier properties etc. Whey protein coatings and films can incorporate adequate amounts of edible antimicrobial agents like lysozyme, nisin, potassium sorbate etc. (Gennadios et al. 1997; Cha and Chinnan 2004; Lopez-Rubio et al. 2004). Ming et al. (1997) used pediocin or nisin fixed on cellulose casing to inhibit the growth of Listeria monocytogenes on ham, Turkey meat and beef. Nisin and lysozyme in soy protein and corn zein films are used to inhibit *Lactobacillus plantarum* and Escherichia coli on laboratory media (Dawson et al. 1997; Padgett et al. 1998).

Moisture control

A major cause of food spoilage is the presence of moisture and the purpose of moisture regulator is to lower the water activity of the product to suppress the microbial growth (Vermeiren et al. 1999). In the case of fresh fruits and vegetables, respiration followed by condensation occurs when one part of the package is cooler than the other areas. Soluble nutrients leach into the water causing low consumer appeal and microbial spoilage. Moisture content in the pack causes softening of dry crispy products, caking of hygroscopic products like milk powder, instant coffee powder, sweets etc. (Anon 1995; Vermeiren et al. 1999).

Moisture absorbent pads, sheets and blankets are used for controlling liquid from foods like fish, meat, poultry, fruits and vegetables. Large sheets and blankets are used for absorbing melted ice during the air freight transportation of chilled fish (Day 1998). Drip absorbent sheets basically consist of two layers of a micro porous polymer like polyethylene or polypropylene sandwiched with a superabsorbent polymer in the form of free flowing granules (Rooney 2005). Thermarite® Pvt. Ltd. (Australia), Toppan™ (Japan), Peaksorb® (Australia), Luquasorb™ (Germany), Fresh-R-Pax™ (Atlanta) are some of the commercial moisture absorbent sheets, blankets and trays. Desiccants are mainly used in products like cheese, chips, nuts, candies, spices etc. Desiccants like silica gel, molecular sieves, calcium oxide are used for dry foods while micro porous bags or pads of inorganic salts and protected layer of solid polymeric humectants are used to buffering the humidity inside the cartons

(Day 1998; Brody et al. 2001). Commercial examples of sachets include MINIPAX® (USA), STRIPPAX® (USA), Desipak® (USA), Tri-Sorb® (USA), 2-in-1™ (USA), and the moisture absorbing labels include DesiMax® (USA) (Vermeiren et al. 1999).

Antioxidant release

Antioxidants are widely used in food to improve the oxidation stability of the food to prolong the shelf life. Antioxidants are incorporated in packaging films as a source of antioxidants in some foods since the increased consumer demand for reduced antioxidants and additives in foods. Antioxidant incorporation can also stabilize the polymer inorder to protect the films from degradation (Smith et al. 1990; Rooney 1995). The effect of Butylated Hydroxy toluene (BHT) incorporated HDPE packs for oat flake was studied by Han et al. (1987). The outward migration of BHT was 70 % and 25 % of the BHT was found in the cereal. The outward loss can be prevented by using an extra polymer layer with low permeability (Miltz et al. 1995). But the effect of BHT on human health is been questioned due to accumulative effect of BHT in human adipose tissue (Wessling et al. 1998). Incorporating natural antioxidants like Vitamin C, and E on packaging films can reduce oxidative reactions like development of rancid odour and colour changes in fatty fishes. Vitamin E is also safe and effective for low to medium water activity cereal and snack food products (Labusa and Breene 1989; Day 2003) and proved to be stable under processing conditions with excellent solubility in polyole fins (Wessling et al. 1998; Vermeiren et al. 1999).

Ethylene scavengers

Ethylene is a natural plant growth hormone which accelerates respiration of fruits and vegetables, induces fruit ripening, fruit softening and senescence even at low concentration (Abeles et al. 1992). It causes yellowing of vegetables, russet spotting on lettuce and has detrimental impact on shelf life of many fruits and vegetables (Zagory 1995). Potassium permanganate immobilized on inert minerals are available in sachets for packages and blankets that can be placed in product holding rooms without integrating into the food contact packaging material (Labuza and Breene, 1989; Day 2003). Activated carbon base with various metal catalysts also removes ethylene effectively. Activated charcoal impregnated with palladium catalyst is also used to scavenge ethylene from fresh produce. SedoMate® (Japan), Neupalon™ (Japan), Hatofresh® (Japan) is some of the commercial sachets based on activated carbon capable of scavenging ethylene (Rooney 2005; Takashi 1990). Use of activated clay (zeolite) that is embedded in polyethylene bags are marketed by Japanese and Korean companies in United States and Australia. Electron deficient nitrogen containing trienes incorporated ethylene permeable packaging is also used to scavenge ethylene from fresh produce. Films used are silicon polycarbonates, polystyrenes, poly ethylenes and polypropylenes (Brody et al. 2001). Use of 1-methylcyclopropane (1-MCP) is another alternative to minimize the effect of ethylene (Blankenship and Dole, 2003).

Flavor or odour absorbers and releasers

The volatile compounds that accumulate inside the package as a result of food degradation such as aldehydes, amines and sulfides can be selectively scavenged (Day 2008). Flavor scavengers prevent the cross contamination of pungent odour while transportation of mixed loads. Odour proof packages were developed for the transportation of Durian fruit by Morris (1999). The package consist of an odour impermeable plastic like polyethylene tetraphthalate (PET) or polyethylene of suitable thickness together with a port to allow for the passage of respiratory gases and a sachet made from a mixture of charcoal and nickel to absorb odor. Volatile amines formed due to the protein breakdown in fish muscle can be removed by incorporating acidic compounds like citric acid in polymers (Hoshino and Osanai, 1986). The ANICO bags (Japan) made from film containing ferrous salt and an organic acid such as citric acid or ascorbic acid is capable of oxidizing the amines (Rooney 1995). Flavor scalping of polyethylene was studied by Sajilata et al. (2007). Use of high barrier packaging materials can also prevent the absorption of other nonfood odours like taints (Brody et al. 2008).

Other active packaging systems

Packaging of ready meals in self heating packaging is an important application of active packaging in future. According to EC/450/2009, self heating packaging is packaging with the ability to heat food contents without external heat sources or power. Self-venting packaging is packaging that controls the steam or pressure in the pack, venting the steam when the required pressure temperature level is reached. Microwavable active packaging is designed to ameliorate the heating behavior of food by shielding, field modification and use of susceptors (Regier 2014). Microwave susceptors consist of aluminium or stainless steel deposited on substrates like polyester film or on paperboard resulting in even heating, surface browning and crisping (Perry and Lentz 2009; Ahvenainen 2003; Kerry et al. 2006). Sira Crisp™ (Sirane Ltd.) and SmartPouch® (VacPacInc) are some of the commercially available microwave susceptors (Sirane 2011; VacPac 2014). Steam valves which allow the easy release of steam during microwave cooking are also attached along with the active microwave packs. Flexis^{TM} Steam Valve (Avery Dennison Corp) is a commercial pressure sensitive steam valve that can be applied to most of the flexible food packaging lidding films or moulded containers for the purpose of steaming or cooking convenience food in a microwave oven. It provides a hermetic seal that initially protects the contents of the product and becomes self venting during cooking process. It regulates a gradual temperature balance throughout the cooking process to maintain food quality (Avery Dennison 2011).

Intelligent packaging

The concept of internal migration of preservatives to food and the communication function of the package to facilitate decision making are related with intelligent packing (Oltis and Yalcin 2008). According to EC/450/2009, intelligent materials and articles means materials and articles which monitor the condition of packaged food or the environment surrounding the food. Intelligent packaging systems provide the user with information on the conditions of the food or its environment (temperature, pH).It is an extension of the communication function of traditional packaging and communicates to the consumer based on its ability to detect, sense and record the changes in the products environment (Restuccia et al. 2010; Realini and Marcos, 2014). In contrary to active components, intelligent components do not have the intention to release their constituents into the food. The intelligent packaging can also contribute to improving Hazard Analysis and Critical Control Points' (HACCP) and Quality Analysis and Critical Control Points' (QACCP) systems (Heising et al. 2014), which are developed to onsite detection of unsafe food, identify potential health hazards and establish strategies to reduce or to eliminate their occurrence. It also helps to identify processes that strongly affect the quality attributes and efficiently improve the final food quality (Vanderroost et al. 2014). Basically there are three intelligent systems; sensors, indicators and radiofrequency identification (RFID) systems (Kerry et al. 2006; Vanderroost et al. 2014).

Sensors

A sensor can be 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; Kerry et al. 2006). Sensors provide continuous out put of signals. Most of the sensors contain two main functional parts, a receptor and a transducer.

Biosensor

Biosensors are used to detect, record and transmit information pertaining to biological reactions (Yam et al. 2005). Biosensors contain bioreceptors and transducers (Alocilja and Radke 2003). The bioreceptor recognizes the target analyte and the transducer converts biochemical signals into quantifiable electronic response (Yam et al. 2005). The bioreceptors may be either organic or biological materials like enzyme, hormone, nucleic acid, antigen, microbes etc. The transducers may be of optical, acoustic or electrochemical. Food Sectinel System® (SIRA Technologies Inc.) is a commercial biosensor developed to detect the food pathogens. Specific antibodies are attached to the membrane forming part of the sensor or the barcode. The pathogens cause localized dark bar formation results the barcode unreadable (Yam et al. 2005). ToxinGuard® (Toxin Alert, Canada) is visual diagnostic system based on antibodies printed on polyethylene based plastic packaging material which detect the targeted pathogens such as *Salmonella sp*., *Campylobacter sp*., *E coli*., *Listeria sp*. (Bodenhamer et al. 2004). Pospiskova et al. (2013) developed a biosensor for the detection of biogenic amines formed due to the decarboxylation of amino acids or by amination and transamination of aldehydes and ketones due to microbial action. Biosensors for the detection of xanthine, (adenine nucleotide degradation product in animal tissue) was developed by Arvanitoyannis and Stratakos (2012) by immobilization of xanthine oxide onto the electrodes made of materials such as platinum, silver and pencil graphite (Devi et al. 2013; Dolmaci et al. 2012; Realini and Marcos 2014).

Gas sensor

Gas sensors are used for detecting the presence of gaseous analyte in the package. It include oxygen sensors, carbon dioxide sensors, water vapour sensor, ethanol sensor, metal oxide semiconductor field effect transistors, organic conducting polymers and piezoelectric crystal sensors etc. (Kress-Rogers 1998, Kerry et al. 2006).Optical oxygen sensors are been described by Papkovsky et al. (2002). Such systems are based on the principle of luminescence quenching or absorbance changes caused by direct contact with the analyte. Optochemical sensors are used to detect the quality of products by sensing gas analyte such as hydrogen sulphide, carbon dioxide and volatile amines (Wolfbeis and List 1995). The optochemical sensing methods are of three types including fluorescence based system using a pH sensitive indicator, absorption based colourimetric sensing and energy transfer approach using phase fluorimetric detection (Neurater et al. 1999; Mills et al. 1992).pH sensitive dyes can be used to develop sensors for the detection of basic volatile amines in fish, meat and poultry. Indicators based on methyl red/cellulose membrane, curcumin/bacterial cellulose membrane respond through visible colour changes to volatile amines released during fish spoilage (Kuswandi et al. 2012, 2014).

Printed electronics

Printed electronics is an emerging technology on flexible substrates using electrically functional inks. The unique properties of printed electronic sensors include light weight, bendable, rollable, portable and foldable. Possibility of creating sensors on a variety of substrates each shaped and individually tailored to operate uniquely (Vanderroost et al. 2014). The flexible printed chemical sensors contain a receptor printed on top of a printed transducer. Molecular imprinting is another promising technique for selected molecules. The analyte molecules are incorporated into a pre polymeric mixture and allowed to form bonds with the pre polymer. Once the polymer has formed, the analyte molecules are removed leaving the cavity with the analyte molecules shape. The targeted molecule can thus be identified since the shape of the cavity is specific to the molecule of interest (Realini and Marcos 2014; Kelly et al. 2005).

Chemical sensor

The chemical sensor or the receptor is a chemical selective coating capable of detecting the presence, activity, composition, concentration of particular chemical or gas through surface adsorption. Presence of particular chemicals are being observed and converted into signals by transducer. Transducers are of either active or passive depends on the external power requirement for measurement (Vanderroost et al. 2014). Carbon nano materials like nanoparticles, grapheme, graphite, nano fibers and nanotubes are applied in chemical sensors because of their excellent electrical and mechanical properties along with the high specific surface area (Vanderroost et al. 2014). Nano based sensors can be used to detect pathogens, chemical contaminants, spoilage, product tampering, track ingredients or products through the processing chain (Nachay 2007; De-Azeredo 2009; Liu et al. 2007). Recent advance in sensors are the use of optical transducers which do not need the electrical power and it can be read out from a distance by using VU, visible or IR light. Silicon based such optical transducers are composed of optical circuits which are integrated in silicon semiconductor material (Yebo et al. 2012).

Electronic nose

Electronic nose are other systems used to mimic the mammalian olfactory system within in an instrument designed to obtain repeatable measurements allowing identification and classification of aroma mixtures present in the odour. It generates a unique response to each flavor, odour or savour. Nose system consist of an array of either chemical or biosensors with partial specificity and statistical methods enabling the recognition of simple of complex flavor, odour or savour (Gardner and Bartlett 1993;Vanderroost et al. 2014). Electronic nose system was proved to be successful in the quality evaluation of fresh yellowfin tuna and vacuum packed beef (Blixt and Borch 1999; Dobrucka and Cierpiszewski 2014). The aroma emitted by fruits and vegetable canindicate the quality of marketed products. Gomez et al. (2006) studied the volatile compounds produced during various stages of tomato using PEN 2 E nose and differentiated the ripeness stages. Rajamaki et al. (2004) studied the quality of modified atmosphere packed broiler chicken cuts using electronic nose. The electronic nose results were compared with those obtained by microbiological, sensory and head space gas composition analysis. The e-nose could clearly distinguish the chicken packages with deterioration from fresh packages.

Indicators

Indicators can be defined as substances that indicate the presence, absence or concentration of another substance or the degree of reaction between two or more substance by means of a characteristic change, especially in colour (Hogan and Kerry 2008).

Freshness indicators

Freshness indicators provide the product quality information resulting from microbial growth or chemical changes within a food product. The reaction between the microbial growth metabolites and the integrated indicators within the package provide visual information regarding the microbial quality of the product (Kerry et al. 2006; Kuswandi et al. 2013). In 1999, COX Technologies, USA launched FreshTag® colourimetric indicator labels that react to volatile amines produced during storage of fish and seafood products (Hogan and Kerry 2008), however the product was discontinued in 2004 (Kerry 2014; Realini and Marcos, 2014). A colourimetric chitosan bio based pH indicator was developed by Yoshida et al.(2014) with a potential to be used as indicators of metabolites derived from microbial growth such as n-butyrate, L-lactic acid, D-lactate and acetic acid. Carbon dioxide produced in meat products during storage is also an indication of food spoilage. Carbon dioxide indicators were developed by the researchers of Sejong University consisting of aqueous solutions of chitosan or whey protein isolate. The carbon dioxide presence was detected by the changes in transparency by the pH dependent whey (Jung et al. 2012; Lee and Ko 2014). The disadvantages of freshness indicator on colour changes are colour changes indicating contamination can occur in products free from any significant sensory or quality deterioration. The presence of certain target metabolite is not necessarily an indication of poor quality (Hogan and Kerry 2008),

Time temperature indicator (TTI)

Temperature is one of the most important environmental factor determining the kinetics of physical, chemical and microbial spoilage in food products. According to EC/450/2009, Time temperature indicators are meant to give information on whether a threshold temperature has been exceeded over time and or to estimate the minimum amount of time a product has spent above the threshold temperature (time temperature history). These labels provide visual indications of temperature history during the distribution, and storage. There for they can inform about the temperature abuse for chilled or frozen products. There are three basic types of TTI available in market: critical temperature indicators, partial history indicators and full history indicators (Singh 2000). Basically TTIs are small tags or labels that keep track of time-temperature of a perishable commodity from the point of production to the end consumer (Fu and Labuza 1995). Currently available commercial TTIs are diffusion, enzymatic and polymer based systems. 3 M Monitor Mark® and Freshness Check® of 3 M Company, USA are commercial diffusion based time temperature indicators. The VITSAB® is an example of commercial enzymatic TTI in which a colour change induced by a drop in pH resulting from the controlled enzymatic hydrolysis of a lipid substrate. Lifelines Freshness Monitor®, Fresh-Check (lifelines Technology Inc., USA) are temperature dependent polmerisation reaction TTIs. OnVu™ (Ciba Speciality Chemicals, Inc., Switzerland) contain benzopyridines, an organic pigment that change colour with time at rates determined by temperature (Hogan and Kerry 2008). The indicator is activated by exposure to UV light to become dark blue and the colour gradually fades with time (O'Grady and Kerry 2008). FreshCode (Varcode Ltd.) and Tempix (Tempix AB) are based on barcodes printed with fading inks that disappear due to temperature abuse (Tempix, 2014; Varcode 2014).

Integrity indicators

A leak indicator to package ensures package integrity throughout the production and distribution chain. Visual oxygen indicators in MAP foods with low initial oxygen are studied by Davies and Gardner (1996); Mattila-Sandholm et al. (1995). Visual oxygen indicators with redox dyes change its colour with changes in oxygen concentration. Disadvantage of such system is that the device should be highly sensitive and the residual oxygen in the package are susceptible to indicators. Oxygen comes through leakage may also be consumed by the natural microbes present in the food (Mattila- Sandholmand et al. 1998).

Ageless Eye®(Mitsubishi Gas Chemical company) is oxygen indicator tablets which indicate the presence or absence of oxygen by colour change. It indicate the lack of oxygen (<0.01 %) by turning pink. At an oxygen level of 0.5 % or more, the tablet turns blue. The presence of oxygen will be indicated in five minutes or less, while the change from blue to pink may take three hours or more (Mitsubishi Gas Chemical 2014). EMCO Packaging, (UK) has launched reversible and non reversible oxygen indicator labels for the visual indication of pack integrity (EMKO packaging 2013).

Radiofrequency identification (RFID)

Radiofrequency identification (RFID) is an automatic identification technology that uses wireless sensors to identify items and gather data without human intervention. An RFID is based on tags and readers (Tajima 2007; Hong et al. 2011). Most RFID tags store some sort of identification number based on which reader can retrieve information about the ID number from a database and acts upon it accordingly (Todorovic et al. 2014). RFID tags are of two categories; passive and active. Passive tags rely on the power supplied by the reader. When radio waves from the reader are encountered by a passive RFID tag, the coiled antenna within the tag forms a magnetic field. The tag draws energy from it and sends the information encoded in the tags memory. Semi passive RFID tags use battery to maintain memory in the tag or power the electronics that enable the tag to modulate the Electro magnetic waves emitted by the reader antenna. Active RFID tags are powered by an internal battery, used to run the microchips circuitry and to broadcast a signal to the reader (Vanderroost et al. 2014).

RFID has been successfully applied to traceability control and supply chain management processes because of its ability to identify, categorize and manage the flow of goods (Jones et al. 2004; Sarac et al. 2010; Ruiz-Garcia and Lunadei 2011). Studies indicate that RFID is more advanced than the zebra black and white paper; the barcode system for food traceability (Jedermann et al. 2009).It provides supply chain visibility, which enables fast automated processes at the supply chain visibility which enables fast and automated processes at supply chain level such as exception management and information sharing (Tajima 2007). Mountable, non integrated and no flexible sensor based RFID with tags are available in the market to monitor the temperature, relative humidity, light exposure, pressure and pH of products. These tags detect the possible interruptions of cold chain which are harmful to the food quality and safety (Vanderroost et al. 2014).

Legal aspects of intelligent packing

Article 3 of EC/1935/2004 states that food contact materials should not transfer constituents to food in quantities that could endanger human health. Substances that bring about an unacceptable change in the composition and substances that bring about deterioration in organoleptic characteristics. Commission regulation No 450/2009 states that the individual substances or group/combination of substances which make up the active or intelligent component should be safe and comply with the requirements of the framework regulation No. 135/2004 and regulation no 450/2009. Articles 4(d) and 11 of EC No 450/2009 specify that active and intelligent materials should be labeled as non-edible to avoid the accidental consumption. The labeling also should not mislead the consumer. Articles 12 and 13 specify that information should be provided throughout the package chain including consumer to ensure the correct use of these materials and articles.

Conclusion

Various smart packaging technologies are developing in recent years which are being integrated to the packaging systems to meet the requirements of food supply chain. Adoption of suitable packaging technologies by the food industry can be useful to extend the shelf life, improve quality, safety, and provide information about the product. Research on these smart packaging technologies can result in further improvement of the existing system. In future untapped opportunities exist for smart packaging to offer consumer benefits and convenience.

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