Chapter 19
Smart Packaging Technologies and Their Application in Conventional Meat Packaging Systems

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Introduction

Preservative packaging of meat and meat products should maintain acceptable appearance, odour and flavour and should delay the onset of microbial spoilage. Typically fresh red meats are placed on trays and over-wrapped with an oxygen permeable film or alternatively, meats are stored in modified atmosphere packages (MAP) containing high levels of oxygen and carbon dioxide (80% O_2:20% CO_2) (Georgala & Davidson, 1970). Cooked meats are usually stored in 70% N_2:30% CO_2 (Smiddy, Papkovsky, & Kerry, 2002). The function of oxygen in MAP is to maintain acceptable fresh meat colour and carbon dioxide inhibits the growth of spoilage bacteria (Seideman & Durland, 1984). Nitrogen is used as an inert filler gas either to reduce the proportions of the other gases or to maintain the pack shape (Bell & Bourke, 1996). High oxygen levels promote the oxidation of muscle lipids over time with deleterious effects on fresh meat colour and quality (O'Grady et al., 1998). In cooked meat products (e.g. cured ham) low residual levels of oxygen promote pigment denaturation which imposes a dull greyness to the meat surface (Møller, Jensen, Olsen, Skibsted, & Bertelsen, 2000). Commercially, this problem is overcome with the use of an oxygen scavenger. Oxygen scavengers are examples of entities described as 'active packaging components'.

Smart packaging is a broad term encompassing a range of new packaging concepts, most of which can be placed in one of the two principle categories: active packaging and intelligent packaging. Active packaging refers to the incorporation of certain additives into packaging systems (loose within the pack, attached to the inside of packaging material or incorporated into the packaging material) 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). 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

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F. Toldrá (ed.), *Meat Biotechnology*,

quality of packaged food' (Ahvenainen, 2003). Intelligent packaging systems are designed to monitor specific attributes of the food, or environment within the pack and provide information about the quality or safety of the product. A wide range of technologies have already been developed and commercialised to take advantage of opportunities presented by active and intelligent packaging systems.

The aim of this review is to examine the current use of active packaging and intelligent packaging technologies with meat and meat products. New or developing technologies will also be evaluated and assessed for their potential use in future meat packaging applications.

Active/Intelligent – Smart Packaging Technologies

Oxygen Scavengers

Elevated oxygen levels in food packages may significantly reduce the shelf life of meat due to colour changes, the onset of lipid oxidation, microbial growth and nutritional losses. Oxygen absorbing systems provide an alternative to vacuum and gas flushing technologies as a means of improving product quality and shelf life (Ozdemir & Floros, 2004). Modified atmosphere packaging or vacuum packaging technologies do not always facilitate complete removal of oxygen. The use of an oxygen scavenger, which absorbs residual oxygen after packaging, minimises quality changes in oxygen sensitive foods (Vermeiren, Devlieghere, Van Beest, de Kruijf, & Debevere, 1999). Existing oxygen scavenging technologies utilise one or more of the following concepts: iron powder oxidation, ascorbic acid oxidation, photosensitive dye oxidation, enzymatic oxidation (e.g. glucose oxidase and alcohol oxidase), unsaturated fatty acids (e.g. oleic or linolenic acid) rice extract or immobilised yeast on a solid substrate (Floros, Dock, & Han, 1997). More comprehensive information and details relating to oxygen scavengers can be obtained from other reviews (Floros et al., 1997; Vermeiren et al., 1999). Structurally, the oxygen scavenging component of a package can take the form of a sachet (Fig. 19.1a), label (Fig. 19.1b), film (incorporation of scavenging agent into the packaging film) (Fig. 19.2), card, closure liner or concentrate (Suppakul, Miltz, Sonneveld, & Bigger, 2003). Commercially available oxygen scavengers are predominantly based on the principle of iron oxidation (Smith, Ramaswamy, & Simpson, 1990).

Comprehensive details on a variety of commercially available oxygen scavengers are presented by Suppakul et al. (2003). Ageless® (Mitsubishi Gas Chemical Co., Japan) is the most common oxygen scavenging system based on iron oxidation (Fig. 19.1). These scavengers are designed to reduce oxygen levels to less than 0.1%. Additional examples of oxygen absorbing sachets include ATCO® (Emco Packaging Systems, UK; Standa Industrie, France), FreshPax® (Multisorb Technologies Inc., USA) and Oxysorb® (Pillsbury Co., USA). Kerry, O'Grady, & Hogan (2006) reviewed a number of studies from scientific literature where oxygen scavengers (Ageless® and FreshPax®) were used to prevent discoloration in fresh beef and

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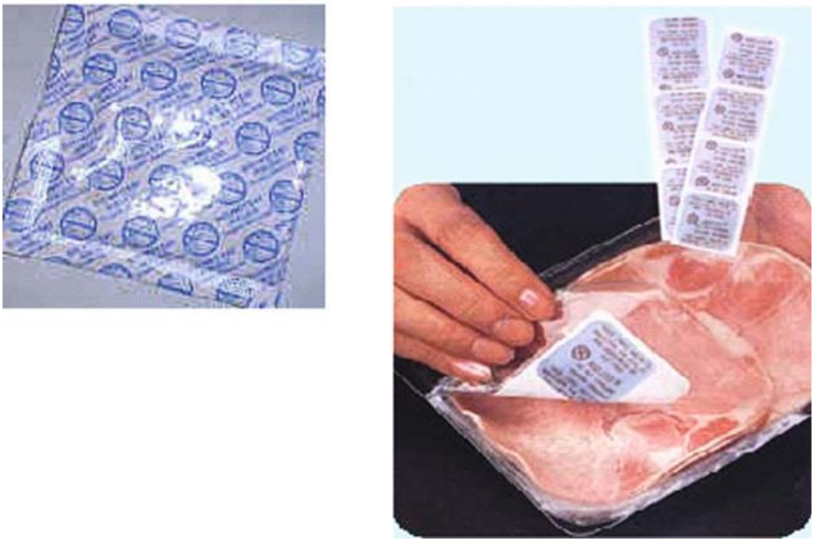

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Fig. 19.1 Ageless® sachet (a) and label (b) (Mitsubishi Gas Chemical Co., Japan)

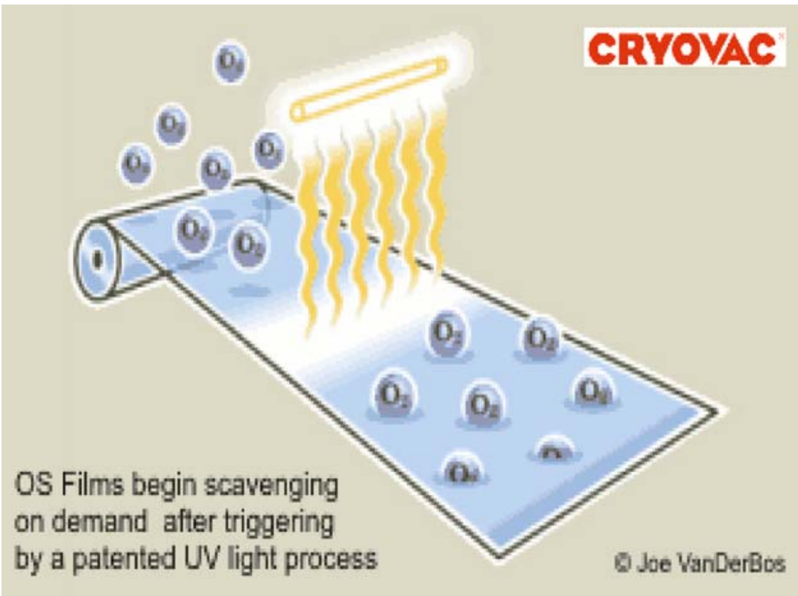

Fig. 19.2 Light-activated oxygen scavenging films (Cryovac® OS Systems, Sealed Air Corporation, USA)

enhance pork and pork product quality. While many active packaging technologies are still developmental, oxygen scavengers are widely used commercially in pre-packed cooked meat products. Emco Packaging Systems, specialists in active and intelligent packaging, are a UK manufacturer and distributor for ATCO® DE 10S self-adhesive oxygen absorbing labels. Emco supply ATCO® labels for use in pre-packed sliced cooked meats, especially hams, to meat processors in Ireland, throughout the UK and in Europe. While labels used in sliced cooked meat packages scavenge between 10 and 20 cc's of oxygen, Emco have recently launched larger oxygen scavenging labels onto the market (ATCO® 100 OS and 200 OS), which scavenge between 100 and 200 cc's oxygen, for use in larger capacity packaging applications.

Cryovac® OS Systems (Cryovac Div., Sealed Air Corporation, USA) oxygen scavenging technology incorporates a polymer-based oxygen scavenger into the packaging film. The UV light-activated Cryovac® OS2000™ oxygen scavenging film (Fig. 19.2) is composed of an oxygen scavenger layer extruded into a multilayer film and can reduce headspace oxygen levels from 1% to ppm levels in 4–10 days, comparable with oxygen scavenging sachets. These films have applications in a wide variety of food products including dried or smoked meat products and processed meats (Butler, 2002). A similar UV light-activated oxygen scavenging polymer $ZERO_2^{TM}$, developed by CSIRO, Div. of Food Science Australia in collaboration with VisyPak Food Packaging, Visy Industries, Australia, forms a layer in a multi-layer package structure and has many applications including reduced discoloration of sliced meats.

Carbon Dioxide Scavengers and Emitters

Within a packaging environment, carbon dioxide functions to suppress microbial growth. Therefore a carbon dioxide generating system can be viewed as a technique complimentary to oxygen scavenging (Suppakul et al., 2003). The permeability of carbon dioxide is 3 to 5 times higher than that of oxygen in most plastic films; therefore, it must be continuously produced to maintain the desired concentration within the package (Ozdemir & Floros, 2004). High carbon dioxide levels (10–80%) are desirable for foods such as meat and poultry in order to inhibit 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). Examples of commercially available dual action combined carbon dioxide generators/oxygen scavengers are Ageless® G (Mitsubishi Gas Chemical Co, Japan) and FreshPax® M (Multisorb Technologies Inc, USA). Carbon dioxide emitting sachets or labels can also be used alone. The

Verifrais™ package, manufactured by SARL Codimer (Paris, France) has been used to extend the shelf life of fresh meats. This innovative package consists of a standard modified atmosphere packaging tray, but has a perforated false bottom under which a porous sachet containing sodium bicarbonate/ascorbate is positioned. When juice exudates from the packaged meat drips onto the sachet, carbon dioxide is emitted, thus replacing any carbon dioxide absorbed by the meat and preventing package collapse.

The inhibition of spoilage bacteria utilizing active packaging technology may reduce bacterial competition and thus permit growth and toxin production by non-proteolytic *C. botulinum* or the growth of other pathogenic bacteria (Sivertsvik, 2003). Lövenklev et al. (2004) reported that while a high concentration of carbon dioxide decreased the growth rate of non-proteolytic *C. botulinum* type B, the expression and production of the toxin was greatly increased which means the risk of botulism may also be increased, rather than being reduced, if used in modified atmosphere packaging systems. Research into the safety risks associated with the use of carbon dioxide in packaging systems is necessary.

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. Possible applications include their use in packs of dehydrated poultry products and beef jerkey (Ahvenainen, 2003).

Moisture Control

The main purpose of liquid water control is to lower the water activity of the product, thereby suppressing microbial growth (Vermeiren et al., 1999). Temperature cycling of high water activity foods has led to the use of plastics with an anti-fog additive that lowers the interfacial tension between the condensate and the film. This contributes to the transparency of the film and enables the customer to clearly see the packaged food (Rooney, 1995), although it does not affect the amount of liquid water present inside the package. Several companies manufacture drip absorbent sheets or pads such as Cryovac® Dri-Loc® (Sealed Air Corporation, USA), Thermarite® or Peaksorb® (Australia), Toppan™ (Japan) and Fresh-R-Pax™ (Maxwell Chase Technologies, LLC, USA) for liquid control in high water activity foods such as meat and poultry. These systems consist of a super absorbent polymer located between two layers of a micro porous or non-woven polymer. Such sheets are used as drip-absorbing pads placed under whole chickens or chicken cuts (Suppakul et al., 2003).

Antimicrobial Packaging

Fresh meat is a highly perishable food product which, unless correctly stored, processed, packaged and distributed, spoils quickly and becomes hazardous due to microbial growth and the subsequent risk of food borne illness. Antimicrobial packaging is a promising form of active packaging especially for meat products. Since microbial contamination of meat products occurs primarily at the surface, due to post processing handling, attempts have been made to improve safety and to delay spoilage by the use of antibacterial sprays or dips. Limitations of such antibacterials include neutralisation of compounds on contact with the meat surface or diffusion of compounds from the surface into the meat mass. Incorporation of bactericidal agents into meat formulations may result in partial inactivation of the active compounds by meat constituents and therefore exert a limited effect on the surface microflora (Quintavalla & Vicini, 2002). Antimicrobial food packaging materials have to extend the lag phase and reduce the growth phase of microorganisms, in order to extend shelf life and to maintain product quality and safety (Han, 2000). Comprehensive reviews on antimicrobial food packaging have been published previously (Appendini & Hotchkiss, 2002; Suppakul et al., 2003) and more recently by Coma (2008). To confer antimicrobial activity, antimicrobial agents may be coated, incorporated, immobilised, or surface modified onto package materials (Suppakul et al., 2003). A comprehensive list of antimicrobial agents for use in antimicrobial films, containers and utensils is presented in a review by Suppakul et al. (2003). The classes of antimicrobials listed range from acid anhydride, alcohol, bacteriocins, chelators, enzymes, organic acids and polysaccharides. Examples of commercial antimicrobial materials in the form of concentrates (e.g. AgION™, AgION Technologies LLC, USA), extracts (Nisaplin® (Nisin), Integrated Ingredients, USA) and films (Microgard™ Rhone-Poulenc, USA) were also presented. Antimicrobial packages have had relatively few commercial successes except in Japan where Ag-substituted zeolite is the most common antimicrobial agent incorporated into plastics. Ag-ions inhibit a range of metabolic enzymes and have strong antimicrobial activity (Vermeiren et al., 1999). Antimicrobial films can be classified into two types: those that contain an antimicrobial agent which migrates to the surface of the food and those which are effective against surface growth of microorganisms without migration. The antibacterial activity of antimicrobial agents that are coated, directly incorporated or immobilised onto packaging films in meat and meat products has been reviewed by Coma (2008) and Kerry et al. (2006).

Sensors

In modified atmosphere packaged meats, the headspace concentrations of oxygen and carbon dioxide are useful indicators of the meat product quality. The headspace profiles of oxygen and carbon dioxide change over time as a function of factors such as product type, respiration, packaging material, pack size, volume ratios, storage conditions and package integrity. An optical sensor approach to monitor gas phases in modified atmosphere packaged products offers an alternative to the conventional methods such as GC, GC/MS and portable gas analysers.

Many intelligent packaging concepts involve the use of sensors and indicators. 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, 1998b). A sensor device must provide continuous output of a signal. The majority of sensors are composed of 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. Transducers with potential use in meat packaging systems include electrical, optical, thermal or chemical signal domains (Kerry et al., 2006). Development of a potential sensor for rapid quantification of chemical or physical indicators of food quality is known as the 'marker approach' (Kress-Rogers, 2001). Intelligent packaging incorporating gas sensor technology provides a means by which the determination of indicator headspace gases gives information on meat quality and package integrity rapidly and inexpensively.

The use of sensors in the meat industry is limited; however, significant practical steps towards more widespread use have been made (Kerry & Papkovsky, 2002). High development and production costs, strict industry specifications, safety considerations and relatively limited demand from the meat industry and consumers are considered as the main obstacles to commercial use. Greater pressure on food manufacturers to guarantee safety, quality and traceability is likely to promote future establishment of commercial sensor technology in food packaging.

Gas Sensors

Gas sensors are devices which respond reversibly and quantitatively to gaseous analytes by changing the physical parameters of the sensor. Systems currently available for gas detection include amperometric oxygen sensors, potentiometric carbon dioxide sensors, metal oxide semiconductor field effect transistors, organic conducting polymers and piezo-electric crystal sensors (Kress-Rogers, 1998a). Conventional systems for oxygen sensors based on electrochemical methods have a number of limitations (Trettnak, Gruber, Reiniger, & Klimant, 1995) including consumption of analyte (oxygen), cross-sensitivity to carbon dioxide and hydrogen sulphide and fouling of sensor membranes. They also involve destructive analysis of packages.

In recent years, a number of instruments and materials for optical oxygen sensing have been reported (Papkovsky, Ponomarev, Trettnak, & O'Leary, 1995; Trettnak et al., 1995). Such sensors are usually comprised of a solid-state material and operate on the principle of luminescence quenching or absorbance changes caused by direct contact with the analyte. They are chemically inert, do not consume analytes, and provide a non-invasive technique for gas analysis through translucent materials.

Approaches to opto-chemical sensing include: a fluorescence-based system using a pH sensitive indicator (Wolfbeis, Weis, Leiner, & Ziegler, 1988), absorption-based colorimetric sensing realised through a visual indicator (Mills, Qing Chang, & McMurray, 1992), and an energy transfer approach using phase fluorimetric detection (Neurater, Klimant, & Wolfbeis, 1999). The latter allows for the possibility of combining oxygen and carbon dioxide measurements in a single sensor through compatibility with previously developed oxygen sensing technology. Most carbon dioxide sensors, however, have been developed for biomedical applications and the use of existing carbon dioxide sensors in food packaging applications is currently not feasible (Kerry & Papkovsky, 2002).

Fluorescence-Based Oxygen Sensors

Fluorescence-based oxygen sensors represent the most promising systems to date for remote measurement of headspace gases in packaged meat products. A number of disposable oxygen sensing prototypes have been developed which may be produced at low cost and provide rapid determination of oxygen concentration (Kerry & Papkovsky, 2002). The active component of a fluorescence-based oxygen sensor usually consists of a long-delay fluorescent or phosphorescent dye encapsulated in a solid polymer matrix. The dye-polymer coating is applied as a thin film coating on a suitable solid support. Molecular oxygen, present in the packaging headspace, penetrates the sensitive coating through simple diffusion and quenches the luminescence by a dynamic, i.e. collisional, mechanism. Oxygen is quantified by measuring changes in luminescence parameters against a pre-determined calibration. The process is reversible and clean; neither the dye nor the oxygen is consumed in the photochemical reactions involved, no by-products are generated and the whole cycle can be repeated.

Materials for oxygen sensors must meet strict sensitivity and working performance requirements in order to meet the suitability requirements for commercial intelligent packaging applications. They must also have fluorescence characteristics suited to the construction of simple measuring devices. Fluorescence and phosphorescence dyes with lifetimes in the micro-second range are best suited to oxygen sensing in food packaging. Other necessary features include suitable intensity, well resolved excitation and emission long wave bands and good photo-stability characteristics of the indicator dye. Such features allow sensor compatibility with simple opto-electronic measuring devices (LEDs, photodiodes etc), minimise interference by scattering and sample fluorescence and allow long-term operation without recalibration (Papkovsky et al., 1995). Materials using fluorescent complexes of ruthenium, phosphorescent palladium(II)- and platinum(II)-porphyrin complexes and related structures have shown considerable promise as oxygen sensors (Papkovsky et al., 1991; Papkovsky et al., 1995).

The combination of indicator dye and encapsulating polymer medium determines the sensitivity and effective working range of such sensors. For the purpose of food packaging applications, dyes with relatively long emission lifetimes ($\sim$ 40–500 μs) such as Pt-porphyrins combined with polystyrene as polymer matrix appear to offer greatest potential (Papkovsky, Papovskaia, Smyth, Kerry, & Ogurtsov, 2000). Other polymers with good gas-barrier properties such as polyamide, polyethylene teraphthalate and PVC are not suitable for oxygen sensing as oxygen quenching is slow in such media. The use of plasticized polymers is also unsuitable due to toxicity concerns associated with potential plasticizer migration. Information regarding sensor fabrication and criteria to be considered for commercial sensor uptake, in food packaging, is reviewed by Kerry et al. (2006) and Kerry & Papkovsky (2002).

The ability of fluorescence-based oxygen sensors to accurately determine oxygen levels has been demonstrated in packaged beef, poultry and pork products (Fitzgerald et al., 2001; Papkovsky, Smiddy, Papkovskaia, & Kerry, 2002; Smiddy, Fitzgerald, et al., 2002; Smiddy, Papkovskaia, Papkovsky, & Kerry, 2002; Smiddy, Papkovskaia, et al., 2002;). The development of oxygen sensors is indicative of a move towards commercialisation of indicator-based intelligent meat packaging systems. It has been estimated that each sensor should cost less than €0.01 to produce (Kerry & Papkovsky, 2002) and impact minimally on packaged meat production costs.

Biosensors

The recently developed biosensor technologies represent an additional area with potential for application in intelligent meat packaging systems. Biosensors are compact analytical devices which detect, record and transmit information pertaining to biological reactions (Yam, Takhistov, & Miltz, 2005). They consist of a bio-receptor specific to a target analyte and a transducer to convert biological signals to a quantifiable electrical response. Bio-receptors are organic materials such as enzymes, antigens, microbes, hormones and nucleic acids. Transducers may be electrochemical, optical, or calorimetric and are system dependent. Intelligent packaging systems incorporating biosensors have the potential for extreme specificity and reliability. Market analysis of pathogen detection and safety systems for the food packaging industry suggests that biosensors offer considerable promise for future growth (Alocilja & Radke, 2003).

Toxin Guard™ (Toxin Alert, Ontario, Canada), a commercially available biosensor, is a patented diagnostic system incorporating antibodies printed on polyethylene-based plastic packaging capable of detecting target pathogens such as *Salmonella sp.*, *Campylobacter sp.*, *Escherichia coli 0517* and *Listeria sp.* (Bodenhammer, 2002; Bodenhammer, Jakowski, & Davies, 2004). When food packaging comes into contact with targeted bacteria, a positive test, indicated by a dramatic visual signal, alerts the consumer or retailer. Toxinguard™ can be targeted to detect freshness degradation, as well as the presence of specific food hazards such as pesticides or indicators of genetic modification.

Bioett AB (Lund, Sweden) has developed a system based on a biosensor for temperature monitoring. The Bioett System monitors the accumulated effect of temperature on products over time. The system consists of a chip-less RF circuit with a built-in biosensor which can be read with a handheld scanner at various points in the supply chain. Information is stored in a database and can be used to analyze the cold chain and validate that the agreed temperature has been maintained. A Time Temperature Biosensor (TTB), attached to 5 kg cases of frozen meat balls, is activated at source. The biosensor registers the accumulated temperatures that the product has been exposed to and this information can be used to optimize and monitor the cold-chain distribution system. A scanner can read the biosensor via radio waves (radio frequency) and also uniquely identifies the goods using a barcode system. The scanner also incorporates a software defined radio subsystem which can also be used for reading of RFID tags. Such systems give an insight into products that are likely to become mainstream in years to come.

Indicators

Indicators may be defined as substances which indicate the presence, absence or concentration of another substance, or the degree of reaction between two or more substances by means of a characteristic change, especially in colour. By contrast with sensors, indicators are not composed of receptor and transducer components and communicate information directly through a visual change (Kerry et al., 2006). A number of commercially available indicators are available for use with packaged meats and meat products.

Integrity Indicators

Non-invasive indicator systems provide qualitative or semi-quantitative information through visual colorimetric changes or through comparison with standard references. The majority of indicators have been developed to test package integrity. The most common cause of integrity damage in flexible plastic packages is associated with leaking seals (Hurme, 2003). Attachment of a leak indicator or sensor to a package ensures package integrity through the distribution chain.

A number of studies on package integrity in modified atmosphere packaged meat products (Ahvenainen, Eilamo, & Hurme, 1997; Eilamo, Ahvenainen, Hurme, Heiniö, & Mattila-Sandholm, 1995; Randell et al., 1995; Smolander, Hurme, & Ahvenainen, 1997) have established critical leak sizes and associated quality deterioration. Standard (destructive) manual methods for package integrity and leak testing are both laborious and can test only limited numbers of packs (Hurme, 2003). Currently available non-destructive detection systems have disadvantages such as requirements for specialised equipment, slow sampling time and an inability to detect leakages that are penetrable by pathogens (Hurme & Ahvenainen, 1998; Stauffer, 1988). Much of the research into integrity detection has focused on visual oxygen indicators for modified atmosphere packaged products. Many visual oxygen indicators have been patented and are based mainly on the use of redox dyes (Davies & Gardner, 1996; Krumhar & Karel, 1992; Mattila-Sandholm, Ahvenainen, Hurme, & Järvi-Kääriänen, 1995; Yoshikawa, Nawata, Goto, & Fujii, 1987). Testing and validation of such devices in modified atmosphere packaged minced steaks and minced meat pizzas have been reported (Ahvenainen et al., 1997; Eilamo et al., 1995). Disadvantages of such devices include high sensitivity (colour change as a result of low oxygen concentrations (0.1%)) and reversibility (leak-induced increases in oxygen consumed through subsequent microbial growth).

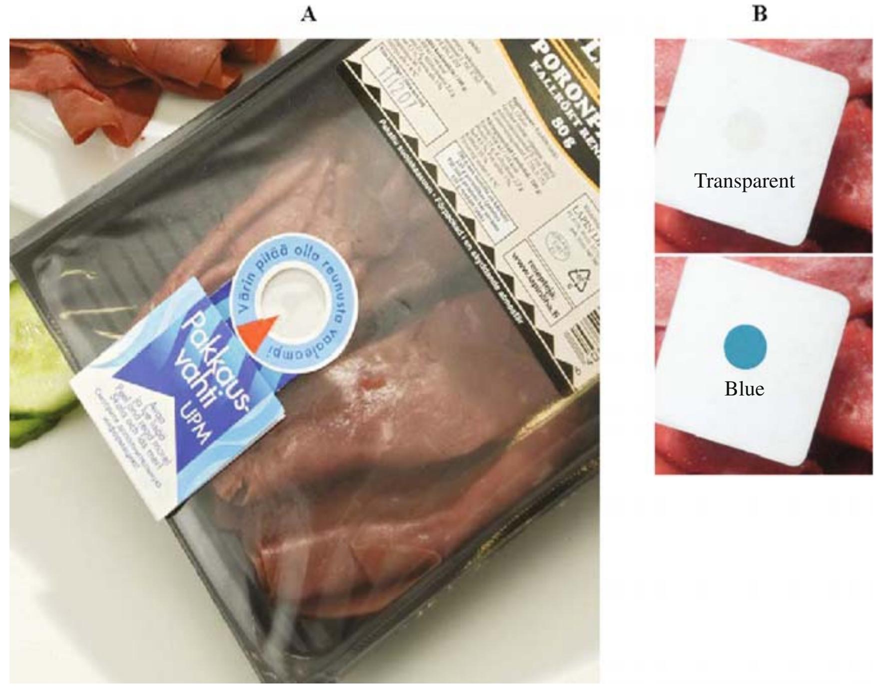

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Fig. 19.3 The UPM Shelf Life Guard (UPM, Helsinki, Finland)

A commercial example, the UPM Shelf Life Guard (UPM, Helsinki, Finland) indicator label monitors the integrity of modified atmosphere packages (Fig. 19.3a). The label is attached to the inside of the packaging so that it can be viewed through the packages transparent outer shell. The presence of air in modified atmosphere packs reduces meat product shelf life. The label contains a redox dye, held between laminated layers, which react with oxygen. In modified atmosphere packages containing carbon dioxide, nitrogen or a mixture of both, the dye remains transparent. A colour change from transparent to blue (Fig. 19.3b) indicates that air has replaced the gases within the modified atmosphere pack i.e., the package is no longer intact and has been damaged, or a leak has occurred. The color change of the packaging label allows the consumer to make a personal assessment of the product based on his/her own sensory findings and consume the product well ahead of the best before date. UPM Shelf Life Guard has been successfully tested by Lapin Liha, a Finnish company who incorporated the labels into their packaged reindeer meat products in Tampere University Hospital in Finalnd and in Wigren 'siskonmakkara' traditional Finnish sausages. UPM also manufacture Freshness Guard where the indicator reacts to growing levels of nitrogen compounds in poultry or fish products stored in vacuum or modified atmosphere packages. Both UPM Shelf Life Guard and the Freshness Guard adhere to the European Union regulations (EU 1935/2004) with regard to food packaging.

An indicator system, specifically designed for modified atmosphere packaged foods, containing both an oxygen sensitive dye and an oxygen absorbing component exemplifies active and intelligent packaging in a single system (Mattila-Sandholm, Ahvenainen, Hurme, & Järvi-Kääriänen, 1998). A number of companies have manufactured oxygen indicators, the main application of which has been confirmation of the function of oxygen absorbers. Trade names for such devices include Vitalon®, Samso-Checker® and Ageless Eye® (Fig. 19.4). The Ageless Eye® is an in-package monitor which indicates the presence of oxygen at a glance.

A visual carbon dioxide indicator system consisting of calcium hydroxide (carbon dioxide absorber) and a redox indicator dye incorporated in polypropylene resin was described by Hong and Park (2000) and may be applicable to certain meat packaging applications.

Freshness Indicators

Freshness indicators provide direct product quality information resulting from microbial growth or chemical changes within a food product. Microbiological quality may be determined through reactions between indicators placed within the package and microbial growth metabolites (Smolander, 2003). The number of practical concepts of intelligent package indicators for freshness detection is limited; however, potential exists for the development of freshness indicators based on established knowledge of quality indicating metabolites. The improved detection of biochemical changes during storage and spoilage of foods (Dainty, 1996; Nychas, Drosinos, & Board, 1998) provide the basis by which freshness indicators may be

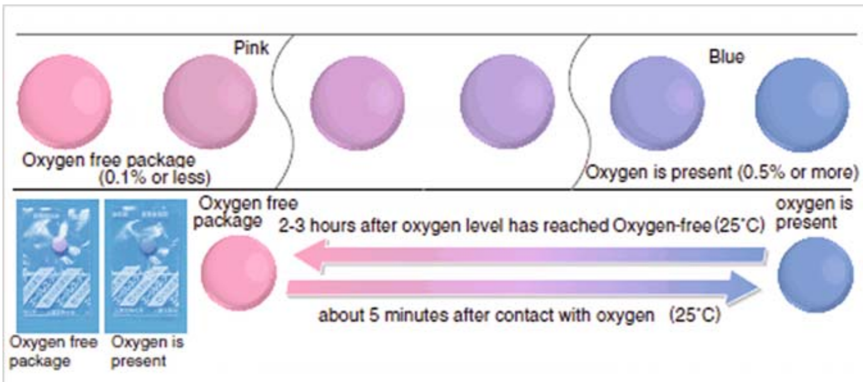

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Fig. 19.4 Ageless-Eye® oxygen indicator used for oxygen detection (Mitsubishi Gas Chemical Co., Japan) developed based on target metabolites associated with microbiologically-induced deterioration.

The formation of different potential indicator metabolites in meat products is dependent on the interaction between product type, associated spoilage flora, storage conditions and the packaging system.

A number of marker metabolites associated with muscle food products exist upon which indicator development may be based. Organic acids such as n-butyrate, L-lactic acid, D-lactate and acetic acid change concentration during storage and offer potential as indicator metabolites for a number of meat products (Shu, Håkanson, & Mattiason, 1993). Colour based pH indicators offer potential for use as indicators of these microbial metabolites. Ethanol is an important indicator of fermentative metabolism of lactic acid bacteria. Randell et al. (1995) reported an increase in the ethanol concentration of anaerobic modified atmosphere packaged marinated chicken as a function of storage time.

Biogenic amines, formed from the decarboxylation of amino acids, are an indicator of bacterial growth and spoilage. Given the toxicological concerns associated with these compounds and their lack of impact on sensory meat quality, the development of effective amine indicators would prove advantageous. Food Quality Sensor International (FQSI, Inc., Lexington, MA USA) has developed a revolutionary new smart sensor label which senses spoilage in fresh meat and poultry products (Fig. 19.5). The label functions by detecting volatile biogenic amines and is unaffected by modified atmosphere packaging gases. The SensorQ™ stick-on sensor label is applied by the meat packer to the inside wrap of meat and poultry packages to provide the consumer with a clear indication of product freshness. When the inside of the quality 'Q' on the label is tangerine orange, the product is fresh (Fig. 19.5a). When bacterial growth inside the package reaches a critical level, the

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FRESH NOT FRESH

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Fig. 19.5 SensorQ™ Smart Sensor Label (Food Quality Sensor International (FQSI), Inc., USA) orange colour turns to tan which indicates spoilage (Fig. 19.5b). The SensorQ label is made of food grade materials and is economical, costing less than 1% of the total value of the average package of meat or poultry it labels. Market research indicated that over 95% of consumers would opt to purchase a product with a freshness indicator attached. FSQI are currently in the final stages of testing and validating SensorQ and expect to launch the product in late 2008.

Hydrogen sulphide, a breakdown product of cysteine, with intense off-flavours and low threshold levels, is produced during the spoilage of meat and poultry by a number of bacterial species. It forms a green pigment when bound to myoglobin and this pigment formed the basis for the development of an agarose-immobilised, myoglobin-based freshness indicator in un-marinated broiler pieces (Smolander et al., 2002). The indicator was not affected by the presence of nitrogen or carbon dioxide.

Freshness indicators based on broad spectrum colour changes have a number of disadvantages which need to be resolved before widespread commercial uptake is likely. A lack of specificity means that colour changes indicating contamination can occur in products free from any significant sensory or quality deterioration. The presence of certain target metabolites is not necessarily an indication of poor quality. More exact correlations need to be established between target metabolite, product type and organo-leptic quality and safety. The possibilities of false-negatives are likely to dissuade producers from adopting indicators unless specific indication of actual spoilage can be guaranteed (Kerry et al., 2006).

Time-Temperature Indicators

A time-temperature indicator (or integrator) (TTI) is defined as a device (small tag or label) used to show a measurable, time-temperature dependent change that reflects the full or partial temperature history of a food product to which it is attached (Taoukis & Labuza, 1989). Operation of TTIs is based on mechanical, chemical, electrochemical, enzymatic or microbiological change, usually expressed as a visible response in the form of a mechanical deformation, colour development or colour movement (Taoukis & Labuza, 2003). Therefore, the visible response gives a cumulative indication of the storage temperature to which the TTI has been exposed. TTIs are classified as either partial history or full history indicators, depending on their response mechanism.

Effective TTIs are required to indicate clear, continuous, irreversible reaction to changes in temperature. TTIs should also be small, reliable, low cost, easily integrated into food packaging, have a long pre- and post-activation shelf life and be unaffected by ambient conditions other than temperature. TTIs should also be flexible to a range of temperatures, robust, pose no toxicological or safety hazard and convey information in a clear manner.

A large number of TTI types have been developed and patented, the principles and applications of which have been reviewed previously (Taoukis & Labuza, 2003). TTIs currently commercially available include a number of diffusion, enzymatic and polymer-based systems.

Diffusion-Based TTIs

The 3M Monitor Mark® (3M Company, St. Paul, Minnesota, USA) is a non-reversible indicator, dependent on the diffusion of a coloured fatty acid ester along a porous wick made of high quality blotting paper. The measurable response is the distance of the advancing diffusion front from the origin. The useful range of temperatures and the response life of the TTI are determined by the type and concentration of ester. FreshnessCheck® (3M Company) incorporates a visco-elastic material which migrates into a diffusively light-reflective porous matrix at a temperature dependent rate. This results in a progressive change in light transmission of the porous matrix and provides a visual response.

Enzymatic TTIs

The VITSAB® TTI (VITSAB A.B., Malmö, Sweden) is based on a pH induced colour change resulting from controlled enzymatic hydrolysis of a lipid substrate. The indicator consists of two separate compartments containing an aqueous solution of lipolytic enzymes, the lipid substrate suspended in an aqueous medium and a pH indicator mix. Different enzyme–substrate combinations are available to give a variety of response lives and temperature dependencies. Activation of the TTI is brought about by mechanical breakage of the seal separating the two compartments. Hydrolysis of the substrate decreases the pH and results in a colour change from dark green to bright yellow. Visual evaluation of the colour change is made by reference to a five-point colour scale. CheckPoint® labels are the latest TTIs developed by VITSAB, which comprise a label type designed to create a better subjective reading response for users and offer direct application to poultry and ground beef products.

The Cryolog (Gentilly, France) (eO)® adhesive TTI label is in the form of a small gel pad, shaped like the petals of a flower, which changes from green (good) to red (not good). The pH induced colour change is due to a microbial growth within the gel itself. The TRACEO® (Cryolog) transparent adhesive label is designed for use on refrigerated products and placed over the barcode. The colour of the transparent adhesive label changes from colourless to red when the product is no longer fit for consumption.

Polymer-Based TTIs

The Fresh-Check® TTI (TEMPTIME Corporation, NJ, USA) is a self-adhesive device specifically formulated to match the shelf life of food products to which it is affixed (Fig. 19.6). The reactive centre circle portion of the Fresh-Check® label, based on solid-state polymerization of substituted monomers, darkens irreversibly in response to specific time and temperature. The colour change is faster at higher temperatures and slower at lower temperatures. When the centre circle is lighter than the reference colour, the product is safe to use assuming it is within its expiration date. When the centre circle has the same colour as the reference colour, the endpoint

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Fig. 19.6 The Fresh-Check indicator label (TEMPTIME Corporation, NJ, USA)

has been reached and the product should not be used. When the centre circle is darker than the reference colour, the endpoint has been exceeded and the product should not be used. Fresh-Check indicators act as a warning device to show if the product has been exposed to excessive heat at any time during storage, distribution and through final use. Warning is through a visual indicator that a time temperature profile, as specified by the manufacturer has been exceeded. Commercially, Fresh-Check® labels are currently used in modified atmosphere packaged ground beef (Fig. 19.6).

The OnVu™ TTI labels (Ciba Specialty Chemicals Inc., Switzerland) are based on organic pigments which change colour with time at rates determined by temperature (Fig. 19.7). The TTI label consists of a heart shaped 'apple' motif containing an inner heart shape. The image is stable until activated by UV light from an LED lamp, when the inner heart changes to a deep blue colour. A filter is then added over

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Fig. 19.7 The OnVu^{TM} time-temperature indicator (Ciba Speciality Chemicals Inc., Switzerland and Freshpoint Holdings SA, Switzerland) the label to prevent it from being recharged. The blue inner heart changes to white as a function of time and temperature (Fig. 19.7). The system can be applied as a label or printed directly onto the package.

The Food Sentinel System™ from SIRA Technologies, USA uses a modified barcode containing a proprietary thermo-chromic printing ink which is printed in a non-scannable colour. On encountering product abuse, the thermo-chromic ink changes to an irreversible deep magenta colour which is visible and detectable during scanning (Fig. 19.8). Therefore it is possible to add a temperature and shelf life monitor to any product barcode, thus preventing the sale of contaminated food and archiving of the incident.

A number of TTI systems have their histories read by RFID readers (see Sect. 'Radio Frequency Identification') rather than by visual means. These include Bioett®, Timestrip®, KSW Microtec® and TempTime®. The use of electronic readers allows storage of information and subsequent downloading to local networks and databases.

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Fig. 19.8 The Food Sentinel System™ (Sira Technologies, CA, USA)

The use of TTIs, applied to packaged food products, has been reported previously (Riva, Piergiovanni, & Schiraldi, 2001; Shimoni, Anderson, & Labuza, 2001; Welt, Sage, & Berger, 2003). In frozen pork, Yoon, Lee, Kim, Kim, & Park (1994) demonstrated a positive correlation between oxidative stability and TTI colour change using a phospholipid/phospholipase-based TTI. Smolander, Alakomi, Ritvanen, Vainionpää, and Ahvenainen (2004) determined the applicability of VITSAB®, Fresh-Check® and 3M Monitor® TTIs for monitoring the quality of modified atmosphere packaged broiler cuts at different temperatures. Further details on the suitability for, and projected uptake of TTIs by the food industry are reviewed by Kerry et al. (2006).

Radio Frequency Identification

Radio Frequency Identification (RFID) is an electronic, information-based form of intelligent packaging. RFID uses tags to capture, store and transmit accurate real-time information about assets (cattle, containers, bins etc) to a user's information system (Townsend & Mennecke, 2008). RFID is one of the many automatic-identification technologies (a group which includes barcodes) 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, Sarhadi, Lenk, & Fawcett, 2002).

RFID systems include two basic components: the interrogator (transmitter and receiver), and the transponder (the tag itself) (Townsend & Mennecke, 2008). While tags are relatively simple, better inventory information than barcode or human entry systems can be gained through tracking software. RFID tags have an advantage over barcoding, as the tags can be embedded within a container or package without adversely affecting the data. RFID tags also provide a non-contact, non-line-of-sight ability to gather real-time data and can penetrate non-metallic materials including bio-matter (Mennecke & Townsend, 2005). Tags can hold simple information (such as identification numbers) for tracking or can carry more complex information (with storage capacity at present up to about 1MB) such as temperature and relative humidity data, nutritional information, cooking instructions. Read-only and read/write tags are also available depending on the requirements of the application in question.

Tags are classified into two types: active tags function with battery power, broadcast a signal to the RFID reader and operate at a distance of up to 50 metres. Passive tags have a shorter reading range (up to about 5 metres) and are powered by the energy supplied by the reader. Common RFID frequencies range from low ($\sim$ 125 KHz) to UHF (850–900 MHz) and microwave frequencies ($\sim$ 2.45 GHz). Low frequency tags are cheaper, use less power and are better able to penetrate non-metallic objects (Townsend & Mennecke, 2008).

At present, Canada and Australia have mandated live-animal traceability from birth to slaughter using RFID-based systems. The key to individual animal traceability lies in the ability to transfer animal information sequentially and accurately to subparts of the animal during production. RFID-based tracking systems provide

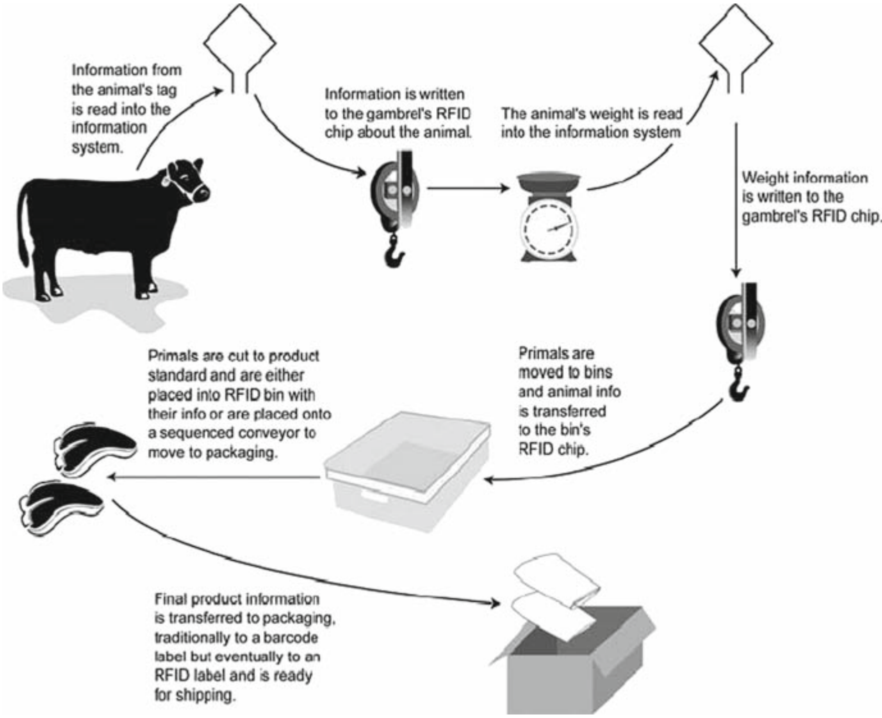

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Fig. 19.9 Illustration of a fundamental RFID tracking process (Townsend & Mennecke, 2008)

an automated method of contributing significantly to that information exchange (Mennecke & Townsend, 2005). Currently, individually RFID tagged meat products are not available to the consumer, although the use of RFID tagging of meat cuts has been extended to the pig processing industry (Dalehead Foods, Cambridge, UK), where tracking occurs from the individual pig to its subsequent primal pieces i.e. hams. Although the purpose of this tracking scheme is for quality control, employee accountability and precision cutting, and does not extend beyond the cutting room floor or provide information about the individual animal with the final product, it does exemplify the developing use of RFID technology within the meat industry. An illustration of a fundamental RFID tracking process is outlined in Fig. 19.9. Future aspects and costs associated with RFID technology are reviewed by Kerry et al. (2006).

Convenience Smart Packaging Applications in Meat Products

Changes in consumer type, attitudes and preferences, has increased the popularity of convenience-orientated ready-prepared meals. As a result, the demand for food packaging has increased prompting further development and growth in smart packaging technologies. In response to demands and growth in the 'Heat n' Serve' convenience food category, the Kepak Group (Ireland) developed the 'Global Cuisine' range (Fig. 19.10) consisting of pre-cooked meat joints (beef, pork, chicken and turkey) combined with natural gravy and vacuum skin packaged in pre-formed trays. Cryovac Darfresh® vacuum skin packaging technology enables products to be cooked, shipped, stored, displayed, sold, re-heated and served all in the same package. From a manufacturing perspective, vacuum skin packaging results in fewer processing steps and eliminates secondary product handling. Products can be cooked (re-heated) by the consumer in a microwave in approximately 7 minutes, and have a shelf life of up to 21 days when stored between 0 and 4°C. The package does not require ventilation holes to be punctured in the package before microwave heating. During product heating, the vacuum-skin film forms a bubble (Fig. 19.11a–d), trapping moisture and flavour, subsequently self-vents and relaxes over the product. The 'stay cool' side handles reduce the risk of burns as the tray is removed from the microwave and eliminates handling messy hot pouches associated with current 'Heat n' Serve' microwavable meals. The package contains an easy-open feature which enables consumers to peel away the cover film and serve after heating.

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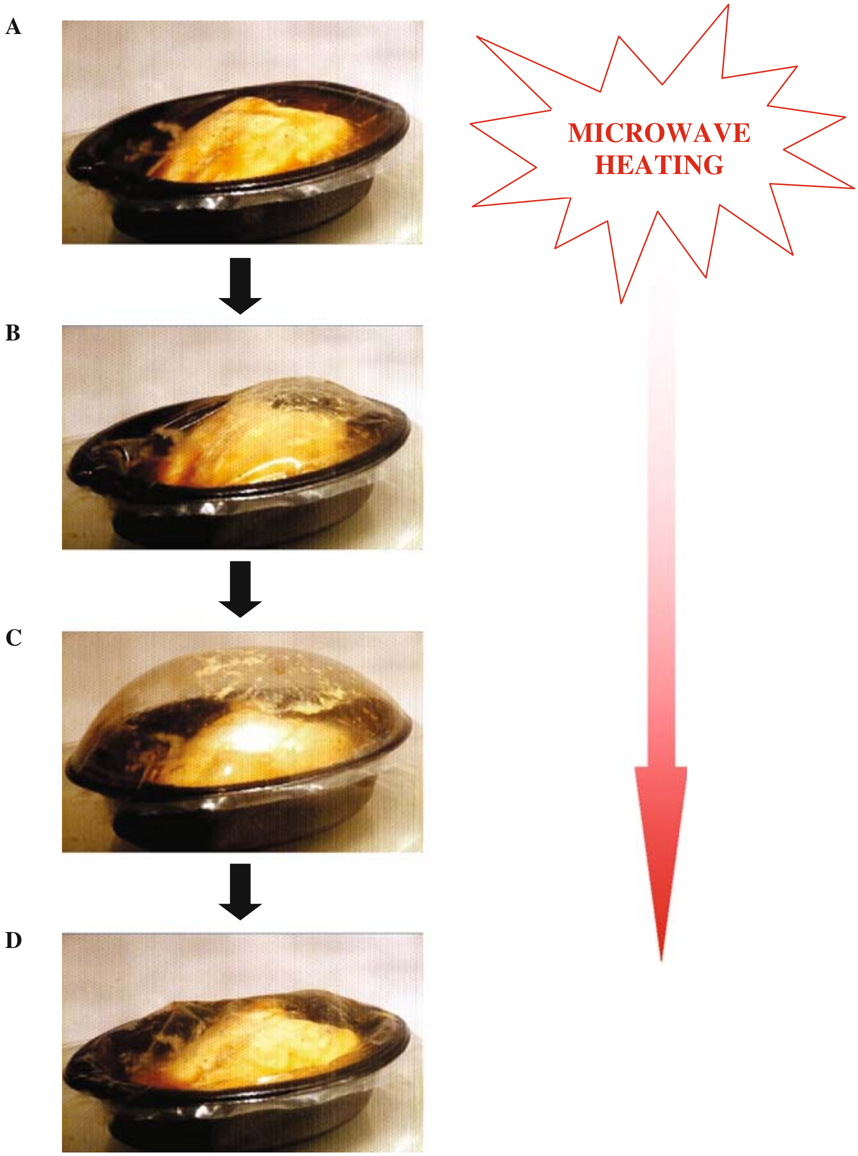
Fig. 19.10 Global Cuisine 'Heat n' Serve' range (Kepak Group, Ireland)



©*Food Packaging Group, UCC.*

Fig. 19.11 Schematic representation (a–d) of the bubble formed by the vacuum-skin film during microwave re-heating of a Global Cuisine 'Heat n' Serve' meat product

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Fig. 19.12 Ready meal packaging (Marks and Spencer plc) containing a SmartCode for use with a Smart Oven

Smart cooking is a new cooking innovation combining the cooking capabilities of a convection oven with microwave and grill cooking. The Smart cooking process is made possible through the innovation of Smart ovens (e.g. Samsung BCE 1197) which read special SmartCodes (2Dimentional barcodes). The SmartCode is scanned by the oven scanner and the Smart oven converts the code into a cooking instruction. Every SmartCode (Fig. 19.12) contains a unique set of instructions which provide the Smart oven with the correct temperature, microwave power and time to cook the food to perfection. SmartCodes cook meals to the same quality each time delivering consistent oven cooked results.

Conclusions

Interest in the use of smart packaging (active and intelligent) technologies has increased in recent years. The most highly developed and widely used form of active packaging is oxygen absorption or scavenging systems. Additional active packaging technologies include carbon dioxide scavengers and emitters, moisture control agents and antimicrobial packaging technologies. Intelligent packaging technologies are systems which monitor the condition of packaged foods to give information regarding the quality of the packaged food during transport and storage. Sensor technology, indicators (integrity, freshness and time-temperature (TTI) indicators) and radio frequency identification (RFID) all have potential applications in smart packaging of meat and meat products; however, further research is necessary. The increased demand for ready prepared meals will serve to further advance smart packaging research and technologies, for use in the convenience food sector. The recognition of the benefits of smart packaging by the meat industry, development of economically viable packaging systems and increased consumer acceptance are necessary for commercial realization of smart packaging technologies for use with meat and meat products in the future.

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