Meat Science 86 (2010) 138–150

Contents lists available at ScienceDirect

Meat Science

journal homepage: www.elsevier.com/locate/meatsci

Review

Quality and safety aspects of meat products as affected by various physical manipulations of packaging materials

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ARTICLE INFO

Article history:
Received 19 February 2010
Received in revised form 21 April 2010
Accepted 26 April 2010

Keywords:
Physical manipulation
Packaging material
Meat quality
Safety

ABSTRACT

This article explores the effects of physically manipulated packaging materials on the quality and safety of meat products. Recently, innovative measures for improving quality and extending the shelf-life of packaged meat products have been developed, utilizing technologies including barrier film, active packaging, nanotechnology, microperforation, irradiation, plasma and far-infrared ray (FIR) treatments. Despite these developments, each technology has peculiar drawbacks which will need to be addressed by meat scientists in the future. To develop successful meat packaging systems, key product characteristics affecting stability, environmental conditions during storage until consumption, and consumers' packaging expectations must all be taken into consideration. Furthermore, the safety issues related to packaging materials must also be taken into account when processing, packaging and storing meat products.

Contents

1. Introduction

In the modern food chain system, it is hardly conceivable to distribute foodstuffs without packaging. Traditionally, food packaging has been limited to preservation and protection of food from environmental factors including chemical, physical and biological

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doi:10.1016/j.meatsci.2010.04.035

influences up to the point of consumption. This emphasizes retarding spoilage, extending shelf-life, and preserving the quality of packaged food (Brody, Bugusu, Han, Koelsch, & McHugh, 2008). Modern packaging, however, should serve not only as an efficient tool for keeping quality of foodstuffs, but also for increasing product values, promoting sales and imparting information (Han, 2005). With consumers ageing, factors including price, safety, size of packaging and recyclability are most important, but design, convenience and utility must also be taken into account (Duizer, Robertson, & Han, 2009).

Traditional packaging technologies used for fresh meat and processed meat products have consisted chiefly of vacuum packaging, modified atmosphere packaging (MAP) and air-permeable packaging. In recent decades, technological advancements in materials, methodology and machinery have enhanced the efficiency and function of the packaging of meat products. In the future, innovative systems will be required to meet increasing expectations in terms of convenience and quality, and to fulfill our needs while meeting strict environmental and safety standards. Therefore, a review of the development of meat packaging technologies is in order, focusing on the pros and cons of physical manipulation of packaging materials, and associated quality and safety issues.

2. Manipulation of packaging materials

The quality of packaged foods is greatly influenced by the properties of packaging materials. These vary depending on factors including the type of material, use of additives and method of manufacture. For instance, the properties of plastic films are mainly dependent on their composition, crystallinity and morphology. Traditionally, the plastic films used for vacuum and MAP were developed to improve effectiveness in their gas and moisture barriers, shrinking properties, sealing characteristics, cook-in and retort capability and a variety of print and color options (Sebranek & Houser, 2006). The improvements in quality and shelf-life of food products have been achieved mainly by the control of gas or water vapor permeabilities (passive packaging) and partly by the application of bioactive agents into or onto the packaging materials (active packaging). New innovations in the manipulation of packaging materials, such as microperforation, which allows the control of gas or water vapor permeation, and shrinking, plasma/FIR treatments and nanotechnology, which improve function, all offer solutions. However, their implementation risks being compromised because of their potential effect on food characteristics and quality.

2.1. Barrier film

Among the physical properties of packaging materials, the control of gas permeability is very important for maintaining the quality of packaged meat products. Gas permeability can be reduced by combining the base materials with other gas barrier materials through laminating, coating, blending or metalizing. The quantity of gas transmission through a packaging material depends on various factors such as the type, area, thickness and gas permeability of the film, differences in the partial pressure on both sides of the film, and storage temperature and relative humidity (Lee, Yam, & Piergiovanni, 2008).

When the packaged meat is exposed to high O_2 concentration, growth of aerobic microorganisms, and oxidation of lipid and myoglobin are accelerated. Therefore, the use of gas barrier film to restrict the entry of O_2 through packaging material has been abundantly reported and widely commercialized in the industry (Griffin et al., 1982; Kotzekidou & Bloukas, 1996; Newton & Rigg, 1979; Rigg, Newton, Moore, & Harrison, 1978). For instance, it was reported the shelf-life of MA packaged meat increased by 10–15% when using a barrier film with an O_2 permeability below 2 cm^3/m^2/day/atm (Gill & Molin, 1991). The effect of gas barrier packaging materials on the growth of microflora may not necessarily be attributed to the reduction of O_2 in the package of meat because O_2 concentration was maintained consistently above 1%, while CO_2 concentration increased to 20% in vacuum packaged meat (Shaw & Nicol, 1969). Packaging meat in gas barrier film reduced both aerobic and anaerobic counts and favored the growth of *lactobacilli*, which markedly improved both the color and odour storage life (Roth & Clark, 1972). The color and odour of beef did not noticeably deteriorate in gas barrier film stored for 32 days at 5 °C. The color was acceptable for up to 5 days when subsequently packaged in permeable film, while meat in permeable film developed discoloration and putrid off-odours after 4 days (Roth & Clark, 1972). The use of gas barrier film was also effective to delay the off-odour development in pork chops stored for longer than 3 or 4 days (Vrana, Savell, Dill, Smith, Ehlers, & Vanderzant, 1986). The O_2 permeability has a significant influence on the color retention of processed meat products. Grini, Sørheim, and Nissen (1992) reported the surface color of sliced bologna was not affected by illuminated storage when the samples were packed in the films with an O_2 permeability lower than 10 cm^3/m^2/day/atm. The microflora on beef loin steaks packaged with gas barrier film consists mainly of *lactobacilli*, while *Pseudomonas* and *Brochothrix thermosphacta* were dominant in the samples packaged with permeable film (Vanderzant et al., 1982). When cooked sausages were packaged in a film with low O_2 permeability (19 cm^3/m^2/day/atm), the growth of *B. thermosphacta* matched the growth of lactic acid bacteria. However, when the films with higher O_2 permeability (70 and 150 cm^3/m^2/day/atm) were used, the growth of *B. thermosphacta* declined (Cayre, Garroa, & Vignolob, 2005).

Barrier films with O_2 permeability less than 100 cm^3/m^2/24 h/atm (at 23 °C and 0% rh) are generally being used for vacuum packaging or MAP of meat in the industry. Lee and Yoon (2001a) investigated the O_2 permeabilities of vacuum packaging materials used for fresh chilled meat in the Korean market. The average O_2 permeabilities of polyamide (PA)/polyethylene (PE) films and polyvinylidene (PVDC)/EVA (ethylene vinyl acetate) copolymer films were 48.8 and 14.0 cm^3/m^2/day/atm, respectively. In order to maintain the gas composition inside the MAP over the storage period as constantly as possible, sheet thickness for the MAP tray should be at least 1–2 mm, and CO_2 and water vapor permeabilities should be lower than 65 cm^3/m^2/day/atm and 645 g/m^2/day/atm, respectively (Smith, 2001). In plastic films, CO_2 has 4–5 times and 13 times greater permeability than O_2 and N_2, respectively, because the solubility coefficient of CO_2 is much greater than the other gases (Gill, 1992; Robertson, 2006; Stiles, 1990).

The chemical structures of high gas barrier films are generally represented as of linear, aromatic or polar features in high proportion and with high molecular weight (WHO, 1999). PA, PETP (polyethylene terephthalate) and PVC (polyvinyl chloride) have been commonly used as a barrier layer. Into these, EVOH (ethylene vinyl alcohol), PVOH (polyvinyl alcohol) or PVDC are embedded in the multilayered structure by lamination or coextrusion (Lange & Wyser, 2003) of which O_2 permeabilities are normally less than 1 cm^3/m^2/24 h/atm (Stiles, 1990). In order to get an absolute barrier, very thin vacuum metalized aluminum is coated to the PETP layer. These days, consumers and retailers are more likely to demand flexible transparent barrier materials. In this regard, the disadvantages of vacuum metalized aluminum film are its lack of transparency and its inability to be used for microwaving.

Gas barrier packaging materials available on the market have some drawbacks in terms of their cost, water-sensitivity, opacity and mechanical resistance. For instance, some packaging materials which have polar groups in the chemical structure like –OH (EVOH and PVOH) or –CO (PA) are markedly affected by relative humidity surrounding the packaging material. Therefore, new efficient barrier solutions have been developed in recent years in terms of 1) new barrier polymers, 2) thin and transparent vacuum deposited coatings, 3) blends of barrier and standard polymers, 4) nanocomposites, and 5) organic barrier coatings or adhesives (Lange & Wyser, 2003).

The use of multilayered film including a barrier layer might not be desirable with respect to recycling issues, but a substantial gauge is needed when the PE or PP (polypropylene) film is used alone. For instance, approximately 2 cm PE is required to achieve the same O_2 barrier as EVOH at a gauge of 0.4 μm, which prohibits it as an eco-friendly solution (Cerny, 1991). Recent developments in transparent, eco-friendly and gas barrier films have been achieved by the incorporation of silica oxide (SiO_x) coated PETP films and trays (Lange & Wyser, 2003; Vangeneugden, 2007). SiO_x film can be obtained by vapor deposition methods either physically with SiO or chemically with gaseous organosilane and O_2 on PETP, PP or PA (Lange & Wyser, 2003). The advantages of SiOx films are transparency, microwaveability and barrier effectiveness comparable to metalized ones, while a lack of flexibility and crack resistance, and the high production cost are disadvantages. Composite films with inorganic fillers (clay, glass flakes and nanoparticles etc.) also increase barrier effectiveness.

2.2. Shrink film

Shrink wrap or shrink film, like stretch film, is apt to return to a smaller dimension due to a memory effect and cover the packaged product tightly when heated (Selke, 1997). Most of the shrink films are composed of POs (polyolefins including PE and PP), PVC and PVDC copolymer. It was reported that packaging with shrinking film after evacuation by passing through a hot air tunnel (around 150 °C) and hot water tank (80–90 °C) for several seconds could reduce the drip loss compared to the packaging with non-shrink film (Aspé, Roeckel, Martí, & Jiménez, 2008; Payne, Durham, Scott, & Devine 1998; Tändler, 1982). These effects might be attributed to the environment of shrunken film allowing less space for exudates, or the more flexible and soft nature of packaging (Payne et al., 1998). Stiebing and Karnitzschy (1997) observed similar effect of reduced drip loss by using their Pi–Vat system.

The use of heat-shrink film for small portioned retail meat cuts can be unattractive to consumers because the shrinking can cause wrinkles. Moreover, the heat-shrink film is more expensive than the normal vacuum packaging film. Therefore, this packaging is usually used for wholesale meat cuts. Vacuum packaged beef chops (bone-in *longissimus dorsi*) with shrink film had a better color (a^* value) stability than those with non-shrink film during storage. However, the microbial counts were not significantly different (Aspé et al., 2008). Gokalp, Ockerman, Plinptin, Parrett, and Cahill (1978) found shrink packaging contributed to maintaining meat color. With longer storage exudates accumulate in spaces in the package, creating turbidity. Moreover, O_2 ingress is increased which leads to progressive formation of metmyoglobin on the meat surfaces (Gill, 1992). However, the effect of the shrinking process on the exudates has been reported to be inconsistent. Yoon and Lee (2001) reported the drip losses in portioned beef cuts packaged with non-shrink PA/PE laminated film was not significantly different from those packaged with shrinkable PVDC/EVA copolymer. These inconsistent observations may be attributed to the fact that the experiments may have been carried out in different conditions where the drip losses are greatly influenced not only by film type but also by different packaging or evacuation methods. Other factors including the way the meat was cut, temperature fluctuations, and pressure on the products may also have influenced the results (Gill, 1996; McMillin, 2008; O'Keefe & Hood, 1980; Payne et al., 1998).

It has been claimed that PVDC and PVC films are not eco-friendly because they contain chloride which produces dioxin on combustion after disposal. However, PVDC is still widely used for packaging wholesale meat cuts as a shrink film in a composition of PVDC/EVA copolymer, and for shelf-stable retorted products in a rocket pack as a mono-layer or for fibrous casing as a barrier layer. PVC, the most common film for retail fresh meat packaging, is used as a plasticized cling film, and less frequently as a tray. Eco-friendly films and containers have been tested for meat products. For instance, a coextruded film of PA/EVOH/PE is a plausible alternative to PVDC/EVA for wholesale distribution of fresh chilled meat. Lee and Yoon (2001b) investigated the various quality characteristics of pork packaged with all-round adhering film made of 5-layer copolymer in a composition of LLDPE (linear low density polyethylene)/EVOH/LLDPE–VLDPE (very low density polyethylene) copolymer, and compared it with PVDC/EVA shrink film, during storage at 2 °C for 28 days. They found no significant differences between the two types of film with respect to quality characteristics in color retention and sensory attributes, even though the counts of total aerobes and lactic acid bacteria were lower in all-round adhering EVOH copolymer than in the PVDC/EVA shrink film. The development of biodegradable and/or edible films or containers for meat products is an area of research which will yield important new options and address significant problems in this field. Re-usable and recyclable materials must be developed to replace current materials.

2.3. Nanotechnology

Nanotechnology in food packaging is an emerging area in which packaging materials can be manipulated for improving the barrier properties, and mechanical and heat-resistance properties, biodegradability, and flame retardancy compared to normal polymer. It also promises options for developing active antimicrobial and antifungal surfaces and sensing as well as signaling microbiological and biochemical changes (ElAmin, 2005). The food packaging industry could potentially attract the largest share of the market for nanotechnology (EFSA, 2009). The most promising developments launched in the market to date are likely to improve the quality and shelf-life of meat products significantly, by improving barrier properties and incorporating bioactive nanocompounds into or onto the film (nanocomposite).

A nanocomposite is a type of multiphase solid material reinforced with nanometer (nm) scale particles, fibers, or platelets, which provide it with better mechanical and chemical properties than conventional composites (Ajayan, 2003; Pandey et al., 2005). Nanocomposites can be made by adding nanoparticulates to a ceramic-, metal- and polymer-matrix (Ajayan, 2003). For instance, polymer nanocomposites are made by mixing synthetic or natural polymer with nanoscale inorganic particles. Nanoclays like montmorillonite (MMT), hectorite and saponite, and cellulose nanowhiskers, carbon nanotubes, ultra fine layered titanates and nanosilver can be used as inorganic nanoscale fillers. Among the polymer/layered silicate nanocomposites, MMT and hectorite are the most widely used (Ray & Okamoto, 2003). In general, polymer/layered silicate nanocomposites fall into three differently structured categories of nanocomposites; 1) intercalated nanocomposites, 2) flocculated nanocomposites, and 3) exfoliated nanocomposites (Ray & Okamoto, 2003).

When small inorganic particles, typically 100 to 1000 × 1 nm in size, are incorporated in the polymer matrix, with a high aspect ratio, the O_2 and water vapor barrier properties are improved by increasing the tortuosity of the diffusion path through the package (Lange & Wyser, 2003). The appearance and transparency of nanocomposite films are dependent on the types of nanoclays added (Sothornvit, Rhim, & Hong, 2009). Nanocomposite films can provide optically similar clarity to platine film in visible light when nanoparticles are evenly distributed within the film (Ray & Okamoto, 2003). This is possible because the size of particle is smaller than the wavelength of visible light and therefore doesn't disturb the path of visible light. Even when the nanoparticles are intercalated or exfoliated in the polymer, the UV transmission through the film is decreased by strong scattering and/or absoption (Ray & Okamoto, 2003). Because of this mechanism, nanocomposite film has a potential to be used as a transparent gas barrier film for meat packaging.

Hong and Rhim (2008) investigated antimicrobial activity of whey protein isolate/clay composite films which include naturally obtained montmorillonite nanoclays (Cloisite Na^+), and two organically modified ones (Cloisite 20A and Cloisite 30B) against pathogenic bacteria such as *Staphylococcus aureus*, *Listeria monocytogenes*, *Salmonella typhimurium* and *E. coli* O157:H7. The results showed Cloisite 30B had the highest antibacterial activity followed by Cloisite 20A, while no significant antibacterial activities were observed with the unmodified montmorillonite (Cloisite Na^+). Antimicrobial activity of nanocomposites depends largely on the microbial species, organoclay types and polymer matrix used for nanocomposite formation. The antimicrobial activity of organically modified nanocomposites is attributed to the quarternary ammonium contained in the clays (Hong & Rhim, 2008).

The new concept of edible coating or edible film made possible through nanotechnology has been introduced to incorporate food additives and other bioactive substances for controlled release of engineered nanomaterials (ENMs) (Sorrentino, Gorrasi, & Vittoria, 2007). These nanolaminate coatings must consist of food-grade ingredients (proteins, polysaccharides, lipids etc.) to which various functional agents including antimicrobials, anti-browning agents, antioxidants, enzymes, flavourings and colorants can be added (Weiss, Takhistov, & McClements, 2006). The edible coating with nanoencapsulated active compounds can efficiently control their release and protect the products from moisture, heat or other influences, making them a good option for maintaining quality, especially for long-term storage of foods (López-Rubio, Gavara, & Lagarón, 2006; Sorrentino et al., 2007). Even though much has been reported about the potential advantages of utilizing nanotechnologies for the food industry, little practical application for meat products has been developed to date.

2.4. Microporous film

The increase of the permeability of plastic films has been principally achieved by adding inorganic fillers to create pores, by attaching a porous patch or label and by mechanical perforations (Robertson, 2006). The plastic films can be mixed with inorganic materials such as $CaCO_3$ and SiO_2 to generate microporous films (Romig & Mir, 2004). By adjusting the filler content, particle size of the filler and degree of stretching, the permeabilities can be controlled, with the average pore size ranging from 0.14 to 1.4 µm (Mizutani, 1989). The effects of microporous films have been initially tested in a range of fresh produce, controlling the respiration rate, and these effects are now well recognized (Ibaraki, Ishii, Ikematsu, Ikeda, & Ohta, 2000; Rodov, Fishman, De la Asuncion, Peretz, & Ben-Yehoshua, 1997). Gas and water vapor permeabilities of normal films are too low even at very thin gauges for fresh produce. The optimum concentration range of CO_2 and O_2 within packaging must be maintained to allow respiration and prevent decay during storage (Robertson, 2006).

The mechanical perforating technique of plastics was first introduced in the 1940s (Wilsey & Neumann, 1945). These days, microperforation can be done by using hot or cold needles and pins, electrostatic discharge, high pressure air, open flame or high pressure water jet, and corona, laser or plasma treatments. Among these, the most simple and cost effective microperforation can be done by a pinned rotary tooling method. However, for more flexibility, consistency and productivity in the microperforation process, laser perforation, particularly using the beam compression technique, is the preferred option (Chow, 2003). Depending on the size and number of pores, the permeability of film can be controlled and a passive MAP environment can be created within the package to meet the product's requirements. The diameter of mechanical microperforation is usually in the range of 40–200 µm (Romig & Mir, 2004). Smaller pores down to less than 1 µm in size can also be created using a synthetic diamond perforator. The device perforates the film or membrane by pressing, sintering, or using a powder metallurgy process involving diamond sand particles with pointed tips or protrusions (Fan, 2009). This allows air through the holes but prevents water from passing through the film.

Quenching extruded film at a very low temperature gives it a lamellar structure, enabling it to be stretched further in mechanical and transverse directions. The direction and temperature of stretching determines the structure and size of the pores (crystalline/amorphous ratio). The pores will be between 0.01 and 0.2 µm in size, making it difficult for bacteria (ranging from 0.2 to 2 µm in diameter and from 2 to 8 µm in length in most cases) to pass through (Tortora, Funke, & Case, 2002). The film is effectively impermeable to water while allowing the passage of O_2 or CO_2 as required. This highly gas-permeable film can be attached onto a die-cut hole as an adhesive label. The pores inside the film layer make it opaque, which may constitute a problem. Glancing angle deposition (GLAD) technology is another option for fabricating highly functional, thin, porous films with columnar structures whose cross-sectional dimensions are typically around 100 nm (Steele & Brett, 2007). Such porous films can be manufactured using GLAD technique to create a columnar microstructure from obliquely incident flux and limited diffusion of vapor (Hawkeye & Brett, 2007).

The amount of water vapor within package can be controlled during storage by using a microperforated film, which prevents saturation and condensation. Lee, Choi, and Yoon (2004) reported that microperforated film was effective in preserving the quality of pork, reducing weight loss and microbial growth rate. This was compared with samples packaged with non-perforated PP film and control samples without any packaging at all. They suggested microperforated film could be effectively used for preserving the meat cuts in a chilled room or cabinet environment by maintaining the relative humidity at an optimum level to prevent the meat surface from excessively drying-out or to minimize microbial growth. These microperforated films may also have an application in the master packaging of fresh meat. Beggan, Allen, and Butler (2005) tested various beef steaks MA packed under low O_2 conditions (mother packs and barrier trays) using microperforated lid film (with/without O_2 scavengers). They found the steaks could be successfully stored in barrier packaging material together with microperforated film and scavengers. Furthermore, microperforated film can be used in the microwave heating of ready-to-eat or ready-to-cook meat products to facilitate the ventilation of steam from inside the package.

2.5. Plasma treatment

Surface modification offers a high-quality, eco-friendly and cost-effective way of extending the application of plastics. To improve the functional properties of packaging film, different surface modification treatments can be applied. Wet chemical modification treatments using strong acids and bases have been used industrially in some parts, but the disposal of hazardous waste leads to environmental and safety problems. Because of this, physical surface modification methods are preferred these days. These include flame and corona treatments, UV, γ-ray, electron beam irradiations, ion beam, plasma and laser treatments. Among these, the relatively low-cost options of flame and corona discharge treatments are the mostly widely used, even though their use is characterized as non-specific and short-term functionalization (Lee, Goddard, & Hotchkiss, 2009).

Plasma treatment focused on the specific modification of plastic surfaces has become increasingly significant in recent decades. Plasma treatment has been used to improve the wettability, sealability, printability, adhesion property and surface cleaning of packaging materials. Surface functionalization by plasma treatment is of particular interest to the food packaging industry to improve barrier characteristics and to impart films with antimicrobial properties (Ozdemir & Sadikoglu, 1998; Ozdemir, Yurteri, & Sadikoglu, 1999a). Compared to chemical modification methods, plasma treatment is a promising alternative, being eco-friendly. It is an advantage of plasma treatment that surface modification is limited to the surface layer to a depth of approximately 0.05–0.005 µm and so maintains bulk properties (Ozdemir, Yurteri, & Sadikoglu, 1999b). The drawback of plasma treatment is its higher investment cost and lower rate of functionalization than the wet chemical treatments. Therefore, various plasma treatment techniques to improve the functionality of film were examined, including varying pressure and time, using repeated treatment and determining optimum storage (Lee et al., 2009).

Plasma treatments can be used to destroy microorganisms. Compared to conventional sterilizing methods using autoclave and ethylene dioxide or irradiation, plasma treatments must be recognized as one of the most promising alternatives, particularly for packaged foodstuffs which need to be kept sterile after processing (Lerouge, Wertheimer, & Yahia, 2001). Surface modification treatment has traditionally involved coating the polymer surface with antimicrobial substances, but these substances can migrate into the foodstuffs, posing a safety problem for consumers. Therefore, plasma treatment is an attractive option because it provides non-migratory antimicrobial packaging or in-package processing by a solid covalent immobilization of active compounds in the packaging (Vartiainen, Rättö, & Paulussen, 2005; Zhang et al., 2006). Using plasma treatments extensive attempts were made to attach and immobilize bioactive functional compounds including lysozyme, nicin, sodium benzoate and glucose oxidase and antimicrobial peptides to the film. These effectively suppressed microbial growth and extended the shelf-life of packaged foodstuffs (Appendini & Hotchkiss, 2002; Buonocore et al., 2004; Ghanem & Ghaly, 2004). Various antimicrobial substances were immobilized on film by plasma treatment, including chitosan, silver and trichlosan, which all showed certain antimicrobial activities (Joerger, Sabesan, Visioli, Urian, & Joerger, 2009; del Nobile et al., 2004; Vartiainen et al., 2005). However, the true value of plasma-treated packaging materials for improving the quality and shelf-life of meat products has not been fully assessed to date.

Plasma treatments have been used to alter the barrier properties of plastic polymers (Chapman, Bhattacharyya, Eberharta, Timmons, & Chuonga, 2008; Friedrich et al., 1995; Rossi, Incarnato, Tagliaferri, & Acierno, 1995). Rossi et al. (1995) found that the O_2, CO_2 and N_2 permeabilities of LDPE and HDPE films could be considerably reduced by Ar-plasma treatment. The plasma treatment induced cross-linking of polymer chains which results in improved barrier properties (Ozdemir & Sadikoglu, 1998). Plasma-assisted coating treatments have been used to improve the barrier properties of film. For instance, SiO_x coating on PETP films by means of low pressure microwave plasma improved the barrier property more than 65 times for one-sided coating (Delimann, Grabowski, Theiß, Bibinov, & Awakowicz, 2008).

2.6. Far-infrared ray (FIR)

Since the 1970s, scientists have begun to recognize the potential of FIR in medical and health care. From the 1980s onwards, the health benefits and preservation capabilities of FIR have drawn much attention, particularly in Japan, spawning a huge FIR-related market. FIR has been applied to health and medical care, kitchen utensils, textiles, construction materials, bath supplies, food processing, packaging materials and other fields. However, not much has been published on the biological activities of FIR treatments.

FIR has a long wavelength spectrum (3–1000 μm) compared to visible light and UV, therefore it can penetrate through the skin to the subcutaneous tissues and transform light energy to heat energy. The wavelength of FIR is similar to water and organic materials, the main components of food, so it can be easily absorbed by them (Van Zuilichem, Van't Reit, & Stolp, 1986). Ceramics, including the metal oxides are widely used as radiation materials because of their high emissivity (about 70–90%) in the infrared region, which endows them with the capacity to transfer energy. The FIR emissivity of ceramics composed of the combinations of CaO, TiCb, ZnO, P_2O_5, TiO_2, Fe_2O_3, Cr_2O_3, Y_2O_3, MgO, ZrO_2, SbO_2, CoO and SiC is greater than 80% (Wei, 2008). The FIR-emitting ceramics have a wavelength around 10 μm encouraging antibiosis and deodourization and potentially extending shelf-life (Lee et al., 2008).

The application of FIR to food packaging materials to maintain freshness of foodstuffs has not yet been comprehensively tested. The antimicrobial effects of radiation-emitting materials were examined using alumina silicate added paperboards (Lee, Kim, et al., 2008) and muscovite added film (Kim, 2005). An FIR-emitting agent was used to produce functional paperboards able to keep mandarin oranges fresh (Lee, Kim, et al., 2008). Silver ion and FIR-emitting bio-active ceramic compounds were added to film's sealant layer, giving an excellent FIR emitting ratio of more than 90%, and tested for maintaining the freshness of raw meat and meat products (Youlchon Chem., 2004). FIR treatment has been proven to activate covalently bound phenolic compounds and increase the contents showing antioxidant effects in various foods including rice hulls (Lee, Kim, Jeong, & Kim, 2003), green tea leaves (Lee, Kim, Jeong, & Park, 2006) and licorice root (Lee & Lee, 2010). Lee, Kim, Nam, and Ahn (2003) examined the effect of FIR treated rice hull (FRH) extracts on irradiated turkey meat. They found the 0.1% FRH addition showed an equivalent antioxidant effect with 0.1% sesamol or 0.1% commercial rosemary oleoresin. FIR as well as near infrared (NIR) treatment have been effectively used for surface pasteurization prior to final packaging, alone or in combination with hot water immersion heating in ready-to-eat meat products (Huang, 2004; Huang & Sites, in press). However, the exact mechanism and efficacy of FIR on food quality have not yet been thoroughly investigated.

2.7. Active packaging

Meat quality and shelf-life can be determined by either passive or active packaging. In passive packaging, permeability for gases and water vapor is recognized to be the most significant factor. Active packaging technologies have also been developed, in which specific bioactive substances are incorporated into the packaging material or within the package or container in order to positively affect the quality and to extend the shelf-life of meat products. Recently, a number of comprehensive examinations of active food packaging have been published (Coma, 2008; Joerger, 2007; Kerry, O'Grady, & Hogan, 2006).

According to Cooksey (2001) active packaging systems aimed at quality improvement and shelf-life extension of foods can be categorized by three concepts, firstly direct incorporation of active substances into the packaging film, secondly edible films and coating with bioactive substances, and thirdly incorporation of the active substances into a sachet, patch or tablet. Most common and promising are antimicrobial packaging systems, O_2 scavenging systems, and moisture-control systems, which offer significant benefits to the meat industry and consumers, and for which exist a large potential market (Han & Floros, 2007).

2.7.1. Direct incorporation of the active substances into the packaging film

2.7.1.1. Antimicrobial agents. The shelf-life of fresh chilled meat has been extended by vacuum packaging or MAP. In spite of these developments, however, there is still concern about the growth of psychrotrophic pathogens (Skandamis & Nychas, 2002). The meat industry has tried to use different preservative systems to minimize the risk of poisoning and spoilage. Since microbial contamination on the meat surface occurs primarily during and following the process of slaughtering, various antibacterial spraying or dipping decontamination methods have been tested to improve safety and delay spoilage (Aymerich, Picouet, & Monfort, 2008; Kerry et al., 2006). Antimicrobial packaging can delay microbial spoilage on meat surfaces between packaging and consumption. This may prove a key to providing consumers with safe and healthy meat products in future. Recently, antimicrobial packaging has attracted increasing attention, reflecting increasing interest in preservative-free meat products. Consumers dislike products containing additives. Packaging containing antimicrobial additives may prove more acceptable to consumers as no labeling is required, working to the advantage of producers.

There are two types of antimicrobial packaging systems, those containing an antimicrobial agent which migrates to the food surface, and those that offer an antimicrobial effect without migration of active agents to the food (Hotchkiss, 1995; Kerry et al., 2006). In contrast with traditional packaging technologies which are focused on the barrier system or work by mixing chemical additives into the meat matrix, active packaging implies a system facilitating the direct release or reaction of the antimicrobial substances onto the food surface. The effect of traditional application of antimicrobial agents directly on the food surface could be limited due to the diffusion or dilution of active components into foods (Min & Krochta, 2005). In the active antimicrobial packaging system, the antimicrobial substances may either migrate into the food by diffusion or partition or be released through evaporation in the headspace of the packaging. In the case of meat products, antimicrobial substances migrate from the surface slowly, improving their effectiveness and allowing concentrations to be maintained higher than if they were applied directly onto product surfaces (Coma, 2008). However, further investigation is required into biologically derived antimicrobial materials for incorporation into films, which won't migrate to the food and thus pose a hazard (Han & Floros, 2007). Several factors are essential for this technology to become commercially viable, including the stable immobilization of enzymes in the supporting films, cost-effectiveness and legislative approval of antimicrobial substances for use in contact with food (Kerry et al., 2006).

The antimicrobial agents used for active packaging can be categorized depending on the material base as either 1) organic or inorganic or 2) chemical agents or natural agents or probiotics. The following food-grade antimicrobial agents can be used for antimicrobial food packaging systems; organic acids and their salts (acetic acid, benzoic acid, potassium sorbate, sodium benzoate, sorbic anhydride, benzoic anhydride, alkyl (ethyl, methyl, propyl) paraben, fatty acids (lauric acid, palmitoleic acid, glycerol mono-laurate), chelating agent (EDTA), metals (silver, copper, zirconium, titanium oxide), enzymes (lysozyme, peroxidase, glucose oxidase), polypeptide (lactoferrin), bacteriocin (nisin, pediocin, lacticins), chitosan, antioxidants, antibiotics, fungicides, sanitizing gas, sanitizers, phenolics, plant volatiles, plant spice/spice extracts, plant essential oils (EOs) (cinnamon, oregano, lemongrass), nitrites and sulphites, and probiotics (Franssen & Krochta, 2003; Han & Floros, 2007; Lee, Kim, et al., 2008; Lee, Lee, et al., 2008; Lee, Yam, et al., 2008; Quintavalla & Vicini, 2002). Nisin produced by *Lactococcus lactis* has a narrow spectrum of antibacterial activity, especially inhibiting only gram-positive bacteria including *Clostridium* spp., *B. thermosphacta*, *Enterococcus*, *Listeria monocytogenes* and *lactic acid bacteria etc*. A combined use of nisin with 2% lactate was proven to be more effective to suppress the growth of total aerobes, *S. aureus* and *Salmonella* Kentucky in fresh pork sausage than nisin alone during chilled storage for 10 days (Scannell, Hill, Buckley, & Arendt, 1997). In addition, nisin is heat-stable, non-toxic and sensitive to digestive proteases (Guerra & Pastrana, 2002).

Similar effects on the reduction of total plate counts were observed by packaging with film containing bacteriocins (Ming, Weber, Ayres, & Sandine, 1997; Scannel et al., 2000). Scannel et al. (2000) found lactic acid bacteria in ham packaged in MAP (60% N_2:40% CO_2) declined in covalently immobilized PA/PE film with nisin. Antimicrobial enzymes such as glucose oxidase, which forms hydrogen peroxide, can also be bound to the inner surface of food contact films. In Japan, however, Ag-substituted zeolite is the most common antimicrobial agent incorporated into plastics. Ag-ions inhibit a wide range of metabolic enzymes and

Table 1
Examples of application of antimicrobial films incorporated with antimicrobial agents for preserving fresh meat and processed meat products.

Antimicrobial substances	Products	Carrier film	Effects	Reference
Bacteriocins, nisin	Beef	PE	*Reduction of B. thermosphacta*	Siragusa, Cutter, and Willett (1999)
Nisin, lacticin	Beef	LDPE, PA	Inhibition of total aerobes and coliform bacteria	Kim, Paik, and Lee (2002)
Nisin, EDTA	Beef	PE	Inhibition of *B. thermosphacta*	Cutter, Willett, and Siragusa (2001)
Nisin, EDTA, citrate	Chicken	Acrylics, PVA/PE	Inhibition of many gram-pos. bacteria, and also gram-neg bacteria like *Salmonella spp.*	Natrajan & Sheldon (2000)
Nisin, lauric acid	Turkey bologna	Soy protein	Inhibition of *L. monocytogenes*	Dawson, Carl, Acton, and Han (2002)
Bacteriocin, pediocin	Poultry and meat products	Casings, plastic bag	Inhibition of *L. monocytogenes*	Ming et al. (1997)
Bacteriocins, nisin and lacticin	Ham stored in MAP(60% N_2:40% CO_2)	PE/PA (70:30)	Reduction of *L. innocua*	Scannel et al. (2000)
Nisin	Fresh poultry (broiler skin and drum stick)	PVC, LLDPE and Nylon	Inhibition of *S. typhimurium*	Natrajan & Sheldon (1995)
	Cooked ham	HPMC	Reduction of *L. monocytogenes*	Geornaras et al. (2006)
Pediocin	Sliced ham	Cellulose	Reduction of *Salmonella* and *L. innocua*	Santiago-Silva et al. (2009)
Nisin, sakacin, potassium lactate	Cooked ham	PET/PE	Inhibition of *Salmonella*	Anna, Teresa, Josep, and Margarita (2008)
Organic acid	Beef carcass	Alginate	Reduction of *L. monocytogenes*, *S. typhimurium* and *E. coli* O157:H7	Gregory and James (1993)
Organic acid/ cinnamaldehyde	Processed meat	Chitosan	Inhibition of *Enterobacteriaceae* and *Serratia liquefaciens*	Ouattara, Simard, Piette, Bégina and Holley (2000)
Tocopherol	Beef	LDPE	Inhibition of *L. monocytogenes*	Moore, Stanley, Smithson, O'Malley, and Murphy (2000)
Amino polysaccharide	Meat products	Chitosan based film	Inhibition of *S. aureus* and *E. coli*	Wang et al. (2007)
Chitosan	Turkey breast	Ethylene copolymer film (corona-treated surface)	Inhibition of *L. monocytogenes*, and *E. coli* O157:H7	Joerger, Sartori and Kniel (2009)
	Grilled pork	Chitosan coated film	Shelf-life extension up to 4 wks at 2 °C	Yingyuad et al. (2006)
Trichlosan	Sliced ham	PE	1.5 log reduction of *E. coli* and *S. aureus*	Camilloto, Soares, Pires, and Paula (2009)
	Refrigerated vacuum packaged chicken breast	Film	Inhibition of *L. monocytogenes*	Vermeiren, Devlieghere, and Debevere (2002)
	Food-borne pathogenic bacteria associated with meat surface	Plastic matrix	Inhibition of *S. aureus*, *Shigella*, and *S. Typhimurium*	Cutter (1999)
Horseradish extract, probiotics	Ground beef	PE/EVOH/PET	Inhibition of *E. coli* O157:H7	Muthukumarasamy, Han and Holley (2003)
Grape fruit seed extract	Fresh minced meat	Multilayered PE films	Inhibition of spoilage bacteria	Ha, Kim, and Lee (2001)

antimicrobes (Vermeiren, Devlieghere, Van Beest, de Kruijf, & Debevere, 1999). The zeolites by which sodium ions are substituted with Ag-ions are incorporated into plastics in a concentration of 1–3% (Brody, Strupinsky, & Kline, 2001). Table 1 shows some examples of antimicrobial packaging tested for the fresh meat and processed meat products.

In spite of this research and development into active packaging during the last two decades, however, antimicrobial packaging has found relatively a few commercial applications. In terms of the availability of bacteriocins, for instance, nisin is presently the only one commercially available and approved by USFDA and WHO (Joerger, 2007). The greatest restriction to the use of natural antimicrobial agents is cost. For this reason, the most appropriate enzymes which are commercially available at a cost for preservation of food products are lysozyme and glucose oxidase (Fuglsang, Johansen, Christgau, & Adler-Nissen, 1995). Besides, it must be taken into consideration that certain antimicrobial agents in active packaging have the potential to be harmful if the release from the packaging material is not properly controlled.

2.7.1.2. Antioxidants. Antioxidants incorporated into film migrate and retard the oxidative process of meat products during storage. Moore et al. (2003) investigated the effect on the color stability of fresh beef, of incorporating various antioxidants into the packaging film, including BHA, BHT, rosemary extract and α-tocopherol. After 7 days of storage, the control samples had lower redness values than the treated ones, with BHA-impregnated films providing the most promising result for preserving meat color. They concluded that additives incorporated in packaging can be more effective than additives placed directly on the meat surface.

2.7.2. Edible films and coating with bio-active substances

In edible films, diverse food additives such as preservatives, antioxidants and seasoning can be used to improve the quality and shelf-life of foods. Edible coatings can be applied to the food surface to increase the gas, moisture, solute and oil barrier properties as well as to improve the mechanical and organoleptic quality (Nussinovitch, 2009). Edible films and surface coatings with bioactive substances are likely to be used to enhance preservation and add value to products in future.

The spray application of a bovine gelatin coat to beef tenderloins, pork loins and chicken breasts extended the shelf-life of products stored at 4 °C in a modified atmosphere of 80% O_2 and 20% CO_2 and exposed to fluorescent light, due to the reduction of drip loss for all products and color preservation for beef (Antoniewski, Barringer, Knipe, & Zerby, 2007). Antimicrobial edible films and coatings may inhibit spoilage and pathogenic bacteria by maintaining effective concentrations of the active compounds on the food surfaces (Gennadios & Kurth, 1997). For instance, calcium alginate-based films were found to be effective in restricting contamination by microorganisms on the surface of beef (Williams, Oblinger, & West, 1978). The specific antimicrobial activity of calcium alginate coatings might be partly attributed to the activity of calcium chloride (Cuq, Gontard, & Guilbert, 1995). Among the materials used to form edible films, chitosan is regarded as one of the most promising due to its ability to form film, biodegradability, biocompatibility and non-toxicity (Ravi Kumar, Muzzarelli, Muzzarelli, Sashiwa, & Domb, 2004).

2.7.3. Incorporation of the active substances into a sachet, patch or tablet

The atmosphere milieu within packaging can be changed by incorporating active substances into the package using a sachet, patch or tablet, allowing non-contact mechanisms like evaporation and absorption processes to exert antimicrobial activity. Prime technologies for improving the quality and shelf-life of meat products include O_2 scavengers, CO_2 generators and moisture controllers. Some antimicrobial agents like ethanol and chlorine dioxide may be incorporated into the packages.

The oxidative degradation in the meat is due to O_2 within the package. The final O_2 concentration in the package and packaged meat product itself depends upon the level of microorganism, the degree of enzymatic reaction, the permeation rate of packaging material, the residual content inside of packaging and the meat's structure after packaging. The O_2 scavenging system has several advantages over vacuum and gas flushed packaging. The use of O_2 scavengers is faster than vacuum and gas flushing systems, and better at removing the residual O_2 in the package and the product during extended storage. For ground products like meat patties it is better for reducing O_2 concentration within the package, because of the problems associated with removal of O_2 totally from corners and from between particles. If O_2 is not properly removed or back-flushed with N_2 from the package, there may be a greater risk of metmyoglobin formation. Meat will deteriorate during storage if O_2 remains, causing mould or oxidation. In this case, the use of O_2 scavengers can eliminate the trace amount of O_2 within both vacuum and N_2-flushed packs. Tewari, Jayas, Jeremiah, and Holley (2001) reported the prevention of transient discoloration of MAP by using an O_2 scavenger. Moreover, a combination of O_2 scavenger with MAP is effective in suppressing mould growth and oxidation in meat products. However, under certain circumstances, the use of O_2 scavenger system can promote the growth of facultative or anaerobic microorganism, which may be worse from the safety point of view than the growth of aerobic microorganism. Therefore, the direct approach of inhibiting the microbial growth by applying antimicrobial agents via the package is a better option.

Commercially available O_2 scavengers include radical acceptors, O_2 interceptors or reducing agents, O_2 absorbers and others. O_2 scavenging is accomplished by the oxidative reaction of iron powder, ascorbic acid, photo-sensitive dye, catechol, some nylons, unsaturated hydrocarbons, ligands and enzymes (Brody et al., 2008). O_2 scavenging capacity depends on the product. Commercial O_2 scavengers containing active iron oxide can reduce the internal O_2 content to less than 0.05% within 9 h (Ooraikul, 1991). The use of an O_2 scavenger with gas barrier packaging could maintain the residual O_2 concentration level below 0.01% in sliced ham, retarding the growth of moulds, aerobic and facultatively anaerobic bacteria, insects and oxidative changes (Andersen & Rasmussen, 1992). These scavengers are usually inserted into the package as a form of sachet, cartridge and tablet or attached to the film as a patch. Unlike the Asian countries, sachet-type O_2 scavengers are not widely commercially applicable in Europe and North America. Furthermore, there is a risk that they can be accidentally ingested. The risk of sachet leakage and the limited applicability for dried products also present disadvantages. Moreover, when the packaged meat product is substantially composed of liquid or has to pass a metal detector after fabrication, enzymatic scavenger systems are a better option than the iron-containing scavenger. Therefore, new technologies for the direct incorporation of O_2 scavenging agents into packaging film by mixing them into the master batch or laminated onto film are proving viable commercial options. For example, immobilized enzymes such as glucose oxidase/catalase can remove O_2 within the package by a process of catalytic reaction. The use of an O_2 scavenger system needs a gas barrier packaging material for which gas barrier films of at least the standard of PA and PETP, but EVOH, PVOH or PVDC layers could be incorporated to achieve a more effective barrier.

CO_2 can also be used to suppress the microbial growth, therefore CO_2 emitting chemicals like bicarbonate, which is activated by moisture, can be incorporated in the form of sachets and absorbent pads (Brody et al., 2008). In the case of other foods like bakery items, cheese, semi-dried fresh products and grapes, sachets made of polymer films with silica, which use ethanol and sodium metabisulfite to generate sulfur dioxide have been shown to prevent the growth of mould (Labuza, 1996). Chlorine dioxide has a broad bactericide spectrum but it has an adverse effect on meat quality including color darkening (Brody et al., 2008). It should be noted that the excessive sulfur dioxide produced and absorbed by foods is potentially harmful (Ozdemir & Sadikoglu, 1998).

For moisture-sensitive meat products such as beef jerky or dry fermented products, moisture inside packaging can be controlled by means of desiccants such as silica gels, natural clays and calcium oxide (Brody et al., 2008). These can be delivered using internal porous sachets or perforated water-barrier plastic cartridges containing desiccants, or directly incorporated into the packaging material.

2.7.4. Regulations for active packaging

Regulations related to active packaging differ from country to country. For instance, O_2 scavengers and ethanol emitters have been widely accepted in Asian countries including Korea and Japan. However, in the USA and EU where different social concerns prevail and governments wield stricter regulations, the implementation of active packaging is restricted (Lee, Kim, et al., 2008; Lee, Lee, et al., 2008; Lee, Yam, et al., 2008).

2.7.4.1. EU. EU countries regulate substances added to or used in packaging separately from food additives unlike the USA. The definition and basic rules for active packaging in the EU are defined in Framework Regulation (EC) No. 1935/2004. Guidelines specifically for marketing active and intelligent materials and articles intended for contact with food were published on May 29, 2009 (Regulation No. 450/2009) in the Official Journal of the EU and came into effect on June 18, 2009. These provisions were based on the general requirements established in 2004 in Framework Regulation (Regulation (EC) No 1935/2004) for the safe use of active and intelligent packaging materials. According to this regulation, 'active materials and articles' are defined as "materials and articles that 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 the environment surrounding the food."

2.7.4.2. US FDA. Unlike the EU, no specified regulation on active packaging exists in the USA. However, substances contained in packaging materials as a food additive, which are intended to migrate to food, or if they otherwise affect the characteristics of food are regulated according to Section 201(s) of the FFDCA (Federal Food, Drug and Cosmetic Act). Food additive means any substance expected to become a component of (or otherwise affect) the characteristics of food. Like food additives, general provisions for indirect additives stipulate that the quantity of food additive added to food, as a result of its use in packaging must not exceed that necessary to achieve the intended technical effect in the food article.

Since active packaging affects food, substances contained in the package should be regulated on a similar basis to food additives. When an antimicrobial additive is used in packaging material, affecting the food due to migration or some other type of time-release mechanism, it should be approved through the food additive petition process. Food-contact substances and materials with no direct technical effect, which won't migrate into the food, including diffusion barriers and O_2 scavengers, are only subject to notification requirements (Song & Hepp, 2005).

2.8. Irradiation treatment

The contamination level of packaged materials is usually very low compared to raw food materials because of their exposure to high temperature during manufacture, and is also negligible when the packaged foods are to undergo heat treatment. Sometimes, packaging materials are irradiated before use in the factory (Haji-Saeida, Sampa, & Chmielewski, 2007). Microorganisms can cause contamination during the packaging process as a result of contact with the material itself, or contact with the environment via the operator, machinery, or surrounding air etc. Contamination of pasteurized meat products during the packaging process can detrimentally affect the shelf-life and quality of packaged foods. Foods to be preserved by irradiation are therefore usually prepackaged to avoid subsequent microbial recontamination. Irradiation of packaged foods has been recognized worldwide as a promising preservation technology, and a potential alternative to the heat sterilization techniques recently gathering interest for use in the development of space meals and military rations.

For the irradiation treatment of foodstuffs, packaging serves as a protective barrier from recontamination thus maintaining quality up to the point of consumption. In this regard, it is important to ensure the safety of irradiated packaging materials used for food with respect to the risk of migration of hazardous substances from the packaging material into the food (WHO, 1999). The Section 179.45, 21 Code of Federal Regulations of US FDA, defines the kinds of packaging materials allowed to be processed using irradiation treatment, and prescribes all requirements and specifications. In this document, the maximum dose of irradiation for treatment of packaging materials is generally restricted to 10 kGy (US FDA, 2006).

Commercialization of the irradiation process is hampered by the limited number of packaging materials approved for food irradiation and the physical and sensory changes associated with the irradiation. Radiation of packaging materials can alter the mechanical, thermal and barrier properties of packaging materials due to chain scission, cross-linking, free radical formation, and discoloration, and the migration behavior can change (Buchalla, Schuttler, & Bogl, 1993; Demertzis, Franz, & Welle, 1999; Haji-Saeida et al., 2007). γ-irradiation doses between 2.5 and 10.0 kGy on PP-based retortable food packaging materials reduced the mechanical properties, while O_2 permeability was not affected significantly (George et al., 2007). However, the mechanical properties influenced by irradiation were reported inconsistently depending on the film's composition and the dose or type of irradiation (Hassan, El-kelesh, & Dessouki, 2008; Oliviera, Angel, DelMastro, & Moura, 2009). Antimicrobial compounds coated on LDPE/PA film continued to act after they were exposed to an electron beam with doses of 1–3 kGy. In this case, tensile strength and toughness were not affected by the presence of the active compound or dose, while films became more ductile. The moisture barrier property was increased while O_2 permeability was not affected (Han, Castell-Perez, & Moreira, 2007). However, changes in the mechanical and physical properties of packaging materials by irradiation are insignificant in light of the advantages in transport durability and sustained shelf-life (Haji-Saeida et al., 2007). In the case of radiation-sterilized food, barrier changes in the plastic layers are not so important, because the packaging film usually incorporates an aluminum barrier layer in the middle. In the quest for highly radiation-durable polymers, especially for space applications, PETP and aromatic polyimide were determined to be the best (WHO, 1999). Recent technical advances and developments in packaging for radiated foods have improved the sensory attributes and overall reliability of packaged foods.

3. Safety issues related to packaging materials

3.1. Migration from general food-contact materials (FCMs)

FCMs including packaging film, containers, utensils, food processing machines and pipes, papers and paperboards, metal cans and gaskets can transfer some low-molecular weight compounds (LMWCs) to foodstuffs by migration kinetics. Potential migrants from packaging materials include residual monomers, oligomers, solvents, decomposition by-products and environmental contaminants from raw materials etc. In addition, various additives such as antioxidants, stabilizers, plasticizers, catalysts, adhesives and slip agents can migrate from packaging materials, most frequently from plastic FCMs. Some of them, which belong to the group of endocrine disrupting substances or are suspected as carcinogenic, can have detrimental hazardous effects on human health. For instance, carcinogenic vinyl chloride monomer can migrate from PVC film and containers, even though the actual migration concentration is usually restricted far below the limitation value of 10 µg/kg (EEC, 1978). Furthermore, some migrants can affect the organoleptic quality (e.g. flavour and odour) of packaged foods when the concentration exceeds the threshold value. Most developed countries have therefore established appropriate food-contact legislation to regulate quantities in packaging material and the consequent migration of substances to foodstuffs or food simulants.

The migration to food demonstrates a kinetic behavior by LMWCs from FCMs through diffusion, solution and partition processes. Plastic films are the most common FCMs being used for fresh meat and processed meat products, followed by metal cans, glass, and paper and paperboard. Among the FCMs, glass itself is an inert material, and paper and paperboard are usually not often in direct contact with foods. The food-contact inner layer of metal cans is coated with plastic material such as epoxy resin. Therefore, the LMWCs contained in plastic FCMs are of particular interest in relation to migration and safety evaluation. In the case of plastic packaging films, the contact layer is most commonly composed of POs, EVA or ionomer to facilitate sealing. The concentration of residual LMWCs in those layers and their migration rates to foods or food simulants have been extensively investigated (Ashraf-Khorassani & Levy, 1990; Castle, Mercer, & Gilbert, 1995; Lickly, Bell, & Lehr, 1990). However, migration can also occur from the adhesives used for laminating films and the labels attached to the films. That means the substances can diffuse through the thin stretch or wrap film, or the laminated/coextruded flexible films and vice versa (Petersen, 2001). Recently, concerns have been raised about migration following reaction of isocyanate, when used as a monomer of polyurethane adhesives in a laminated film, with food moisture that ultimately forms a carcinogenic, primary aromatic amine (Brede, Skjevrak, Hellstrøm, & Færden, 2001).

It is well known that migration contents from FCMs increase with the increase of fat content, the extension of storage time and temperature in storage or during heating of packaged meat products (Baner, Bieber, & Figge, 1992; Castle, Jickells, Gilbert, & Harrison, 1990). For instance, diethylhexyl adipate (DEHA) is a plasticizer which is usually added to produce a PVC wrap film at a level of 20–25% (w/w). The packaging of fatty meat and processed meat products with PVC wrap films containing plasticizer often causes an exaggerated migration which results in exceeding EFSA (European Food Safety Authority) limits of 3 mg/kg. Petersen and Naamansen (1998) reported DEHA migrated from ground pork with 8.8% and 19.4% fat contents, which was previously packaged with plasticized PVC wrap film and stored for 1 day at 5 °C, at 6.2 and 18.0 mg/kg, respectively. Hong and Lee (2003) investigated the effect on the migration of DEHA of fat content, thickness, storage temperature and storage duration of fresh pork and beef. They found the migration of DEHA was only limited to a depth of 2 cm under the meat surface when the pork and beef portioned meats were wrapped with plasticized PVC films and stored at 5 °C for 2 days. Migration values measured in different storage conditions, for instance, to examine the effect of different fat contents from 5.9% to 29.6%, the storage time from 1 to 7 days, and wrapping once or twice, exceeded in most cases the EFSA limit (Hong & Lee, 2003). Therefore, it is recommended that direct contact of PVC wrap film with fresh meat and processed meat products, particularly with fatty products and even at refrigerated temperature, should be avoided if possible.

Since the early 1980s, alternatives to plasticized PVC film have been developed including PO and EVA copolymer films. In Denmark, plasticized PVC films have been partly substituted with non-PVC stretch films for packaging fresh meats (Petersen et al., 2004). However, the exclusive use of non-PVC films to replace plasticized PVC film for the packaging of fresh meats is unlikely in near future. That's because plasticized PVC film has various superior physical properties including flatness, transparency, smoothness, and can be produced at a cheaper cost than other options (Eilert, 2005; Lee & Yoon, 2001a; McMillin 2008).

Gaskets in glass bottle caps have been found to use different plasticizers, most frequently diisododecyl phthalate, epoxidized soybean oil (ESBO) or diethylhexyl phthalate (DEHP) (Hirayama, Tanako, Kawana, Tani, & Nakazawa, 2001; Lee et al., 2003; Lee & Lee, 2009). However, migration of these plasticizers into foods were not found to exceed the detection limit (Lee & Lee, 2009). ESBO was detected at between 3.2 and 10.6 mg/kg in various foodstuffs wrapped with PVC wrap film and stored at 20 °C for up to 5 days (Lee, Hong, et al., 2003; Lee, Kim, Jeong, et al., 2003; Lee, Kim, Nam, et al., 2003). Lee, Lee, and Lee (2008) examined the overall migration values from 28 vacuum packaging materials used for meat packaging including PA/PE or PA/LLDPE, PETP/PE, and PVDC films, which were 7.6, 6.9 and 14.1 mg/L, respectively. These values were far below the limit prescribed by Korean or Japanese regulations (150 mg/L for PE and 30 mg/L for PVDC film, when judged on the basis of the food contact layer of tested films).

Recent reports have warned of potential migration of hazardous substances from the FCMs used for packaging foods containing fresh meat and processed meat products during processing, distribution or preparation as seen commonly in the market. For instance, 2-ethylhexanoic acid, a known teratogenic substance, was detected in 80% of the baby foods which were packed in glass jars with PVC gaskets (Elss, Grünewald, Richling, & Schreier, 2004). This constitutes a significant health risk, particularly for children. Trimellitic acid and its esters, components of the epoxyanhydride coatings used in the production of metal cans and recognized to cause mild skin irritation and severe eye irritation, were determined in canned foods. The migration into food was 900 μg/kg in average which far exceeds the Swiss limit of 50 μg/kg (Fankhauser-Noti & Grob, 2004). Various endocrine disruptors such as DEHP, dibutyl phthalate and bis-phenol A were detected in 77.5%, 67.5% and 47.5% of paper and paperboard containers used for take-away food. Other potentially harmful substances were found from paper and paperboard including benzophenone and isopropylthioxanthone (residues of UV-cured inks and lacquers), diisopropyl naphthalenes (residues of carbonless paper) and anthracene (Anderson & Castle, 2003; Eom et al., 2007; López-Espinosa et al., 2007; Mariani, Chiacchierini, & Gesumundo, 1999).

Most of the safety evaluation results showed that migration from various FCMs used for foods including fresh meat and processed meat products can occur, but frequently it doesn't exceed the limitation values. Nevertheless, in order to avoid an unnecessarily increased migration, it is advisable for consumers that the FCMs should not come into direct contact with fatty foods, and should only be exposed to high temperature, as in the case of microwave or oven cooking, as briefly as possible if needed (Castle et al., 1990; Galotto & Guarda, 1999; Lickly et al., 1990).

3.2. Migration from irradiated packaging materials

Packaging materials should not transfer radiation-induced by-products or additives to food because it affects the safety and sensory aspects of packaged products. The ionization treatment of packaging materials is known to decompose the polymer structure resulting in the formation of volatile migration products (Komolprasert, McNeal, Agrawal, Adhikari, & Thayer, 2001; Stoffers, Linssen, Franz, & Welle, 2004). The main volatile compounds causing off-odour problems in electron-beam irradiated packaging materials were identified as hydrocarbons (C_3–C_{13}), alcohols (C_2–C_3), aldehydes (C_2–C_5), ketones (C_4–C_8) and carboxylic acids (C_2–C_5) (Tyapkova, Czerny, & Buettner, 2009). Polymer additives like antioxidant Irganox 168 can produce 1,3-di-tert-butylbenzene and 2,4-di-tert-butyl-phenol by radiolysis as decomposition products (Welle, Mauer, & Franz, 2002). In the case of waxy plastics, slightly pungent and sweet odours can be detected after sensory evaluation of irradiated LDPE and PETP packaging materials (Welle et al., 2002). Irradiation treatment induced the decomposition of polymer sheets of PS (polystyrene), PC (polycarbonate), PA-6 and PVC sheets and resulted in the increase of residual monomers after γ-irradiation with doses between 5 and 200 kGy (Park et al., 2006).

Total extracted amounts from various plastic packaging materials were lower than the overall migration limits set by EU legislation (Marque, Feigenbaum, & Riquet, 1996). Overall migration values measured with LDPE, HDPE and PS by using 95% ethanol simulant did not differ with irradiation doses between 0 and 54 kGy. This observation challenges the assumption that irradiation increases overall migration. It might be attributed to the loss of volatile substances during the evaporation step in sample preparation (Stoffers et al., 2004). However, results are inconsistent for migrated amounts of specific substances as affected by irradiation dose, depending on the type of substance and film. No significant differences in the amount of migrated plasticizer (DEHA) in PVC wrap film were found in chicken between non-irradiated and irradiated samples which were irradiated with γ-radiation at doses of 4 or 9 kGy and stored at 4–5 °C (Goulas & Kontominas, 1996). Carprolactam monomer levels contained in most of the PA-6 films, which is commonly used as a vacuum packaging film for meat products increased as irradiation doses increase (Araüjo, Felix, Manzoli, Padula, & Monteiro, 2008). The migration effects caused by irradiation treatment on packaged meat products have not yet been studied in depth.

3.3. Safety of nanocomposites

Despite the advantageous properties of nanocomposites, the use of nanotechnology for foods and FCMs has been a concern owing to the potential hazard of ENMs which could be harmful when they are inhaled or ingested (Geiser et al., 2005; Oberdörster, Oberdörster, & Oberdörster, 2005). However, there remain uncertainties regarding the risk assessment of ENMs due to the insufficient database and information on the toxicity of ENMs and their exposure to consumers etc. (EFSA, 2009). With regard to the migration data from nanocomposite packages, a study conducted at Central Science Laboratory in the UK reported no detectable migration of nanoclay components from PETP bottles nanocomposited with nanoclay. Very low levels of silver migration (less than the limit of quantification) from food containers made of PP-nanosilver composite were reported (Chaudhry, 2009). Avella et al. (2005) examined the mineral levels which migrated from nanoclay composite films with potato-starch and potato starch-PETP blend to vegetables (lettuce and spinach). The migrated levels of Fe and Mg were insignificant while Si showed a 3–5-fold higher migration level. They concluded the migration from clay nanocomposites complied with current EU regulations. However, more studies are needed to assure the safety of FCMs made by nanotechnology because the relevant data are limited and the physico-chemical properties and migration behavior of ENMs can be different from the non-nanoforms (Chaudhry, 2009; EFSA, 2009).

To date, the regulations specifically referring to the production and application of ENMs have not been established anywhere in the world. When products containing ENMs are subject to a pre-market control or pre-market notification, the risk assessment can be verified by authorities before approving them for the market (EFSA, 2009). Even though cases of human toxicity have not been associated with the approximately 2000 types of ENMs currently being used or developed, those risks can't be ignored (Schmidt, 2009). Despite all these uncertainties, however, many food products containing invisible and un-labeled ENMs are already on market (Brody, 2006; Mazzola, 2003; Sorrentino et al., 2007). Therefore, more knowledge about the safety of ENMs and nanoproducts affecting human health is necessary in the future to ensure adequate regulation and their useful application for FCMs.

4. Conclusion

A large variety of packaging materials and methodologies are currently available for preserving fresh meat and processed meat products. The quality of meat products is significantly affected by the properties of packaging materials. The selection of appropriate packaging systems must be based on characteristics influencing product quality, shelf-life and safety from the time of processing or production, through distribution and storage until consumption, as well as the environmental impact on disposal. Recently, there have been attempts to improve the quality and shelf-life of packaged foods by manipulation of packaging materials. In particular, various physical manipulation technologies of packaging materials have been developed and commercialized partly in the meat industry, including barrier film, shrink film, nanocomposites, microperforated film, active packaging, plasma and FIR treatments. Each of these treatments has advantages and drawbacks in application. Most innovative packaging systems have the potential to increase packaging costs, and so restrict options for commercialization, especially for small and medium-sized businesses. However, these cost increases are counterbalanced by reductions in wastage due to the improved quality and shelf-life of products. Therefore, a comprehensive assessment of specific costs and benefits is the essential next step in establishing the commercial application of innovative packaging technology. An additional and no less important factor in developing new packaging systems is the safety of packaging material, which can detrimentally affect the final quality and brand image of the packaged product, rendering useless all the benefits achieved by innovative technology.

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