Chapter 8
Edible Films and Coatings for Meat and Poultry

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8.1 Introduction

Edible films and coatings are defined as continuous matrices that can be prepared from proteins, polysaccharides and/or lipids to alter the surface characteristics of a food. Although the terms films and coatings are used interchangeably, films in general are preformed and are freestanding, whereas, coatings are formed directly on the food product. Proteins used in edible films include wheat gluten, collagen, corn zein, casein and whey protein. Alginate, dextrin, pectin chitosan, starch and cellulose derivatives are commonly used in polysaccharide films. Suitable lipids for use in films and coatings include waxes, acylglycerol, and fatty acids (Kester and Fennema 1986). Composite films containing both lipid and hydrocolloid components have also been developed.

Plasticizers are often added to film-forming solutions to enhance the properties of the final film. These film additives are typically small molecules of low molecular weight and high boiling point which are highly compatible with the polymer. Common food-grade plasticizers such as sorbitol, glycerol, mannitol, sucrose and polyethylene glycol decrease brittleness and increase flexibility of the film, which are important attributes in packaging applications. Plasticizers used for protein-based edible films decrease protein interactions and increase both polymer chain mobility and intermolecular spacing (Lieberman and Guilbert 1973). The type and concentration of plasticizer influence properties of protein films (Cuq et al. 1997); mechanical strength, barrier properties, and elasticity decrease when high levels of plasticizers are used (Cherian et al.1995; Galietta et al. 1998; Gontard et al. 1993). Water is another important plasticizer for protein films (Krochta 2002). Similar to other plasticizers, water content impacts film properties.

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Common covalent cross-linking agents such as gluteraldehyde, calcium chloride, tannic acid, and lactic acid are used to improve water resistance, cohesiveness, rigidity, mechanical strength and barrier properties of edible films and coatings (Guilbert 1986; Marquie et al. 1995; Ustunol and Mert 2004). Exposure to UV light increases cohesiveness of protein films and coatings by promoting cross-linking (Brault et al. 1997). Alternatively, enzymatic cross-linking treatments with transglutaminases or peroxidases can be used to stabilize films.

Renewed interest in edible films and coatings in recent years has been due to concerns about the environment and a need to reduce the amount of disposable packaging, as well as consumer demand for higher quality food products and extended shelf life. Edible films and coatings are not intended to replace nonedible synthetic packaging materials or to be their biodegradable counterpart. Edible films are secondary packaging materials; they may offer protection to a food product after the primary packaging has been opened. They also provide food processors with a number of new unique opportunities for product processing, handling and development.

Edible films and coatings can provide protection to a food product by serving as barriers to moisture migration, and preventing diffusion of gases important in food deterioration, such as O_2 or CO_2. They can also enhance quality and appearance of a food product by preventing flavor and aroma migration and by providing structural integrity. Edible films and coatings can also serve as carriers for antimicrobials, antioxidants, nutrients, color, herbs and spices, and provide for localized or delayed activity if needed. Currently, edible films and coatings are used in a variety of food applications. Collagen films and sausage casings are probably the most successful commercial application of edible films in meat products. This chapter reviews application of edible films and coatings for meat and poultry products.

8.2 Historical Background

Edible films and protective coatings have been used for centuries to prevent quality loss such as shrinkage, oxidative off-flavors, microbial contamination, and discoloration in meat and poultry products. Yuba, the first freestanding edible film, was developed in Japan from soymilk during the fifteenth century, and was used for food preservation purposes. In sixteenth century England, cut meats were coated in fats to reduce moisture loss and, thus, shrinkage in a process called “larding” (Kester and Fennema 1986). Since then, a number of lipid coating formulations have been used to enhance quality of meat and meat products. Letney (1958) proposed coating meat with melted fat and letting it solidify to form a film to extend storage life of meat products during refrigerated storage and maintain “bloom” (a term used in the industry to signify the conversion from the purple state to the red state in the presence of oxygen). Carnauba wax, beeswax, and candelilla have been used to coat frozen meat to increase its shelf life (Daniels 1973). Use of acylated acylglycerol containing chlortetracycline (Ayers 1959), mixtures of mono-, di- and triacylglycerols in alcohol (Anderson 1960, 1961a, b), and acetylated mono- and diacylglycerol coatings have been suggested to reduce off-flavors and moisture loss, as well to maintain color and prevent freezer-burn in meat products. Applications of paraffinic acid mono-, di- and triacylglycerol with or without carboxylic acid have also been reported to improve meat quality and storage life (Schneide 1972). Other researchers have reported application of acetylated monoacylglycerol in vacuum-packed meats (Griffin et al. 1987; Leu et al. 1987). Emulsion coatings containing lipids have also been demonstrated to be useful in enhancing meat quality (Zabik and Dawson 1963; Bauer et al. 1968; Bauer and Neuser 1969; Kroger and Igoe 1971; Hernandez 1994; Baldwin et al. 1997). Films and coatings made from lipids alone, however, lack structural integrity and are brittle. Hirasa (1991) reported that highly saturated acetylated monoacyglycerol coatings tend to flake and crack during cold storage and have bitter aftertaste (Morgan 1971). Also, unsaturated acylglycerols are susceptible to oxidation. More recently, lipids have been incorporated in formation of composite protein or polysaccharide films to improve moisture barrier characteristics and provide flexibility to these films (Baldwin et al. 1995).

Various edible polysaccharide films and coatings such as starch and its derivatives, alginates, carrageenans, cellulose ethers and pectin also have been used to improve quality of meat and poultry products (Kester and Fennema 1986). Polysaccharide films are nongreasy and have visual appeal, which make them desirable for application as wraps in meat products (Labell 1991). They are good barriers to gases; however, because of their hydrophilic nature, they are poor barriers to moisture. Alginate coatings require a gelling agent, such as calcium chloride, which may impart bitterness (Earle 1968; Lazarus et al. 1976; Williams et al. 1978). Earle (1968) reported extending shelf life of meat products by coating them with an aqueous solution of algin and dextrose, followed by application of calcium solution. Carboxymethylcellulose (CMC) has been reported to improve adhesion of breading after baking when used in commercial breading mix (Suderman et al. 1981). Other derivatives of cellulose, methylcellulose (MC) or hydroxypropyl methylcellulose (HPMC) form reversible thermal gels, and have been used to produce glazed sauces for poultry and seafood. This treatment minimizes runoff during cooking, thereby reducing moisture loss (Baker et al. 1994).

Protein films and coatings have also been investigated throughout history to enhance quality of meat and poultry products. In the nineteenth century, use of gelatin films to preserve meat was proposed by Harvard and Harmony (1869) and Morris and Parker (1896). Patents as early as 1869 disclose gelatin-based films (Gennadios et al. 1997). Additional patents have been granted for acidic, aqueous solutions of gelatin and a metaphosphate polymer (Keil et al. 1960), and aqueous solutions of metal gelatinates (Keil 1961) as coatings on processed meats such as sausages, Canadian bacon, and boned hams to inhibit mold growth and lipid oxidation, and reduce handling damage. Incorporation of polyhydric alcohols (i.e., propylene glycol, ethylene glycol, glycerol, or sorbitol) into gelatin-film-forming solutions produce quick-setting, flexible films that exhibit good barrier properties (Whitman and Rosenthal 1971). Gelatin films have been applied to poultry products to prevent microbial growth and moisture loss and retard oil absorption during frying. Gelatin films also have been used as carriers of antioxidants for poultry products (Klose et al. 1952; Childs 1957; Gennadios et al. 1997). Villegas et al. (1999) reported on improved oxidative stability and color retention in frozen meat pieces used as pizza topping when they were gelatin-coated.

However, gelatin films lack the strength of those from collagen. Today, reconstituted or regenerated collagen films and sausage casings are probably the most successful commercial applications of edible films in the meat industry. Collagen films are used as wraps in hams and netted roast (Gennadios et al. 1997). Sausage casings are used in sausage production to hold meat batter together until it is heat-set to obtain the desired shape, form, and size (Wang 1986).

Natural casings have been the traditional sausage casings used throughout history. The collagen casing came about as a more sanitary and uniform alternative to gut casings. Compared to natural casings, they also have improved strength and flexibility and, therefore, better machinability. Collagen casings provide for more uniform products and better control of net product weight at high processing speeds. In addition, because of rapid uptake of smoke and smoke color by collagen, the smoking cycle may be shortened, thereby reducing product shrinkage due to smoking. Historical development of the collagen casing has been reviewed by Hood (1987). The coating of meat with gelatin obtained from partially hydrolyzed collagen is believed to be the origin of modern casing technology. However, a lack of collagen-like fibrillar structure within gelatin films has limited commercial development of gelatin-based casings, owing to their inelasticity and brittleness (Hood 1987).

The work of German scientist Oscar Becker during the 1920s and 1930s on synthetic collagen casings is believed to have led to manufacture of regenerated collagen casings, particularly those based on the dry extrusion principle (Becker 1936, 1938, 1939). Historically, industrial manufacture of collagen casings is divided into two distinct processes. Collagen casings have been produced from corium (the flesh side) of cattle hides using a "dry" process ("dry spinning technology") originally developed in Europe during the 1930s or the "wet" process ("wet spinning technology") developed in the 1960s in the United States.

The dry process involves alkaline treatment of hide coriums followed by acidification to pH 3. Acid-swollen coriums are then shredded to preserve maximum fiber structure of collagen, and are mixed to produce a dough high in solids (>12% solids). Plasticizers and cross-linking agents are added, and dough is pumped and extruded to form tubular casings followed by drying, conditioning, neutralizing, and/or providing for additional cross-linking. This process produces a tough casing, which was not acceptable to American sausage makers and therefore was not adopted by US casing manufacturers. In contrast, the wet process starts with acid- or alkaline-dehairing of cattle hides. The hide corium is decalcified, ground and mixed with acid to produce a swollen slurry of 4–5% solids using high shear homogenization. Cellulose and carboxymethylcellulose may be added to improve mechanical properties of the casing. The slurry is then homogenized and extruded, after which it passes through a coagulation bath of brine and shaped into a tubular casing. Casings are washed free of salts, and treated with plasticizing and cross-linking agents to provide for improved flexibility and strength, respectively. They are then shirred (or collapsed like an accordion) to fit over various-sized sausage stuffing horns, dried to 13–18% moisture, sealed in plastic bags and packaged (Hood 1987). Their shelf life depends upon maintaining favorable temperature and relative humidity conditions during storage.

Proper alignment of the collagen fibers is important in obtaining desirable properties for collagen casings. Orientation of the fibers in the direction of extrusion is undesirable because the casing can be readily split or torn lengthwise. Extrusion should realign collagen fibers as they exit the orifice of the extruder to produce a woven, crosshatched, fibrous collagen casing structure. The design of the extruder rotating disc and its action has a critical role in arrangement of collagen fibers, influencing strength and flexibility of the final collagen casings. The wet extrusion process typically produces shorter collagen fibers and provides for faster processing and larger production volumes. Dry extrusion technology produces thicker, longer collagen fibers and more expensive casings (Hood 1987).

A number of patents have been issued on improvements to collagen casings. Burke (1976) described a process for preparing collagen casings from limed bovine hide collagen that was soaked in an edible acid at pH < 5.5. Hides were then neutralized and washed, ground and formed into collagen slurry, and processed into collagen casings. Wilson and Burke (1977) reported that water and a mixture of partial fatty acid esters of glycerin and sorbitol could be used to coat the inside of unshirred collagen casings to improve the shirring process. Ziolko (1977, 1979) produced tubular collagen casing by extruding two gel "ropes" from collagen, with each individual rope consisting of several smaller ropes. The casing extruder was equipped with inner and outer orifices and extruded the ropes, orienting fibers in the direction of extrusion. Directing them outward in a radial and helical direction formed the first tubular layer; the second tubular layer was formed by directing inward in a radial and helical direction opposite from the first layer that was concentric to the first. The two layers were then united by a hardening step.

It is important that a sausage casing be able to stretch and shrink to withstand contraction and expansion of meat batter during various steps of processing (Schmidt 1986). Collagen casings must be strong enough to withstand the rigors of high-speed filling and linking, as well as to withstand high temperature and humidity conditions encountered during sausage manufacturing. Collagen fiber content, drying conditions, and extent of cross-linking influence the strength of collagen casings. Cross-linking agents, such as gluteraldehyde, provide for stronger and more coherent films of collagen fibrils that possess improved longitudinal and transverse strength, regardless of whether the casing is re-wetted or dry (Rose 1968). Glyceraldehyde (which lacks toxicity associated with other aldehydes used for cross-linking) also promotes cross-linking of fibrils and increases film strength and temperature resistance (Gennadios et al. 1994). Carboxymethylcellulose and salt treatments prevent disintegration of collagen casings during high-temperature cooking or frying (McKnight 1964a, b). UV irradiation of 180–420 nm increased collagen casing strength (Miller and Marder 1998).

Tsuzuki and Lieberman (1972) reported that enzymatic treatments employed in manufacture resulted in collagen casings with a more uniform diameter, greater thickness, and increased tenderness. Addition of protease from *Aspergillus niger* var. *macroporous* to collagen batter partially solubilized collagen prior to the extrusion step. Similarly, Miller (1983) reported that the wet process could be improved by incorporating proteases such as papain, bromolain, ficin, fungal protease, trypsin, chymotrypsin, or pepsin into the collagen batter prior to extrusion. Boni (1988) reported that mechanical properties of collagen casings at low temperatures were improved by incorporating an alkyl diol into the collagen batter to reduce intermolecular hydrogen bonding and increase molecular spacing. More recently, coating of sausage batter with a thin layer of collagen material has been accomplished by co-extruding sausage batter and collagen (Deacon and Kindleysides 1973; Hood 1987; Smits 1985; Waldman 1985; Kobussen et al. 1999).

In addition to collagen, other proteins such as casein, whey proteins, soy protein, wheat gluten, corn zein and egg albumin have also been investigated in the production of edible films and coatings for meat applications (Ben and Kurth 1995). Such films are good barriers to gases such as oxygen and carbon dioxide, and adhere well to hydrophilic surfaces. But being hydrophilic in nature, these coatings are typically poor barriers to moisture, limiting their application in meat products (Gennadios and Weller 1990; Baldwin et al. 1995). Also, there has been some concern regarding their potential allergenicity, especially in the use of milk, egg, peanut, soybean and rice proteins in films and coatings.

8.3 Technical Developments

8.3.1 Protein-Based Films and Coatings

Co-extrusion technology is an alternative to the conventional method of stuffing sausage batter into a preformed collagen casing for manufacture of sausage (Deacon and Kindleysides 1973). Smits (1985) further refined the process. This process involves simultaneous co-extrusion of collagen and sausage emulsion to create a thin layer of collagen coating at the meat batter surface. The end of the extruder barrel is equipped with a nozzle through which sausage batter flows out. A thin layer of collagen suspension is extruded directly onto the surface of the sausage as it is pumped through the extruder. Counter-rotating concentric cones are employed to orient the collagen fibers in a woven structure. MC is incorporated to provide additional strength to the casing and reduce its disintegration during cooking (Hood 1987). The collagen-coated sausage is then immersed in a brine bath to further set the collagen casing. Smoking and drying of sausages in subsequent steps allow further interactions between the collagen fibers and meat proteins. Co-extrusion produces a casing that is more tender than preformed or reconstituted collagen casings (Waldman 1985). Smits (1985) has described a continuous co-extrusion process that is capable of large production volumes. Over the years, various modifications to the co-extrusion process have been reported. Kobussen et al. (1999) developed a modified extrusion attachment for sausage stuffing machines. This attachment consists of three passageways, where meat emulsion is extruded from two passageways and is coated with a thin layer of extruded collagen pumped through the third passageway. The collagen coating is set with liquid smoke and a dehydrating agent (i.e., alkali or salt solution) to produce a casing that is strong enough that it can be twisted to produce sausage links.

The "hybrid technology" for manufacture of collagen casings was described by Osburn (2002). This technology combines fundamentals of dry and wet processing technologies described previously for collagen-casing manufacture. In the hybrid process, collagen slurry (no more than 5% collagen) is prepared similar to wet processing (dehairing of cattle hides by acid or alkaline, decalcification, grinding and mixing with acid to produce swollen slurry, high shear homogenization). The tubular collagen casing is extruded, and inflated with an ammonia–air mixture to prevent the collapse of the casing. In the next steps, the casing tube is flattened, washed and plasticized in sequence in a manner similar to the wet extrusion process. Then, the casings are re-inflated, dried, and shirred. The hybrid process produces collagen casings with improved tensile strength and smaller diameter. They are usually straight and suitable for manufacture of small sausage casings. But this process is limited in the manufacturing of larger diameter and longer sausage casings and where curved casings may be needed.

Collagen is also used for production of sheet films (cut to the dimensions required by the customer) and in rolls (continuous film reeled on a cylindrical core; typical film length: 50 m or 100 m; typical film widths between 380 and 620 mm), which are used as wraps for netted meats, such as hams or roasts, to prevent the elastic net from sticking to the meat product (Gennadios et al. 1997). In the course of the cooking and smoking process, the collagen film becomes an integral component of the meat, allowing the elastic net to be easily removed from finished product without doing harm to the meat surface, providing for an attractive appearance. Collagen films are also reported to reduce shrink loss and increase juiciness in these netted products. Farouk et al. (1990) studied Coffi®, an edible collagen film (Breechteen Co.) widely used in specialty smoked meats and roasted meat products, which are heat-processed in elastic stretch netting or coarse stockinette. They observed significant reduction in exudation of meat products, including beef round steaks, upon wrapping in Coffi® compared to unwrapped controls. However, wraps had no significant effect on color or lipid oxidation of the meats.

Over the years, the growing US processed-meat industry has relied heavily on imported collagen to meet the needs of production. Since the late 1990s, the safety of imported collagen has become a concern owing to the link between bovine spongiform encephalopathy (BSE or "mad cow" disease) and Creutzfeldt–Jacob disease, a highly fatal disease in humans. On May 20, 2003, the USDA placed an import restriction on ruminant material coming from Canada because of possible risk of BSE. Whey protein-based films and casings have been proposed as alternatives to collagen films and sausage casings (Kim and Ustunol 2001a–c; Simelane and

Ustunol 2005; Amin and Ustunol 2007). Kim and Ustunol (2001a) developed whey protein/lipid emulsion edible films that were heat-sealable, and could be formed into tubular casing. They reported increased hydrogen and covalent bonding (involving C–O–H and N–C) as the main forces responsible for the sealed joint formation of the films. These films were further modified through heat-curing to make them more closely resemble collagen films that would be amenable to hot dog manufacture (Amin and Ustunol 2007). Heat-cured films were further tested under various combinations of time, temperature and relative humidity typically encountered in meat processing. Manufacture of whey protein-based sausage casings is viable because of the high film degradation temperatures (>130°C) and heat sealability of these whey-based films. Furthermore, the ability of these films to withstand temperature/time/relative humidity conditions that would be typically encountered during sausage manufacturing has confirmed their suitability (Simelane and Ustunol 2005).

The same research group subsequently developed heat-sealable whey protein–based casings containing sorbic acid, *p*-aminobenzoic acid, or sorbic acid–*p*-aminobenzoic acid (1:1) for use in hot dog manufacture, and compared these casings to commercial collagen and natural casings (Cagri et al. 2002, 2003). Antimicrobial properties of these casings are further discussed in Sect. 8.3.5.

Limited information exists on use cereal and oilseed proteins (i.e., soy protein, wheat gluten, corn zein) as edible films in meat and poultry applications. Corn zein and corn zein–tocopherol coatings were reported to reduce lipid oxidation in precooked pork chops, but did not retard shrinkage (Hargens-Madsen et al. 1995). Herald et al. (1996) reported that addition of an antioxidant, emulsifier and plasticizer to corn zein films reduced rancidity in cooked turkey breast slices; however, they also reported production of off-flavors. Kunte (1996) reported that a 7S soy protein fraction-based coating was not effective in preventing warmed-over flavor (WOF) formation in pre-cooked chicken breast, compared to phosphates. Soy protein and wheat gluten coatings were shown to be as effective as polyvinyl chloride films in reducing moisture loss on coated precooked beef patties during 3 days of refrigerated storage (Wu et al. 2000). Furthermore, both soy protein and wheat gluten coatings reduced lipid oxidation, as indicated by decreased thiobarbituric acid and hexanal values, for coated meat samples relative to those that were not coated. Rhim et al. (2000) reported that wheat gluten and soy protein coatings were as effective as polyvinyl chloride films in reducing moisture loss. Wheat gluten coatings were also effective in reducing lipid oxidation.

8.3.2 Lipid Films and Coatings

Lipids suitable for use in edible films and coatings include waxes (i.e, candelilla, carnauba, beeswax), acylglycerol (vegetable or animal origin), as well as fatty acids and derivates (Kester and Fennema 1986). Lipids, because of their hydrophobicity and tightly packed crystalline structure, are good barriers to moisture and gas migration. Their effectiveness, however, is dependent on lipid type, chemical structure, chemical arrangement, polarity/hydrophobicity and physical state (solid or liquid), and on its interactions with other components (i.e., proteins and polysaccharides). Lipid films and coatings lack structural integrity, and do not adhere well to hydrophilic surfaces (Ben and Kurth 1995). Lipids are also used with proteins and polysaccharides in production of composite films and coatings to improve moisture barrier characteristics and provide flexibility (Baldwin et al. 1995). They can also serve as "release agents" or lubricants to prevent coated foods from sticking together or from sticking to other surfaces such as packaging material (Baldwin et al. 1995).

"Larding" is a process of coating meats with fat to extend shelf life, and was practiced in sixteenth century England. Fats are still used today to coat a variety of foods, including fresh and frozen meat and poultry (Hernandez 1994). McGarth (1955) reported that a coating of wax eliminated downgrading of fresh meats due to discoloration. The wax provided a transparent, attractive coating that also afforded ease in handling product at the supermarket by minimizing mechanical damage. Since then, carnauba wax, beeswax, and candelilla, have been used successfully to coat frozen meat pieces to reduce dehydration during frozen storage (Daniels 1973). Letney (1958) used molten fats as coatings by allowing them to solidify over fresh meat surfaces to form a film/coating to lengthen storage life at refrigerated temperatures, lessen surface hydration and maintain "bloom." Ayers (1959) reported that an acetylated acylglycerol coating with incorporated chlortetracycline was effective in reducing off-flavors and retaining moisture; however, it produced an unappealing meat color. Three patents for lipid-based coatings were issued to Anderson (1960, 1961a, b). Coating solutions, containing 40% mono-, di- and tri-acylglycerol in alcohol, were heated to 50°C, and sprayed directly on the meat surface or applied to meat products in the molten state by dipping. Although initial studies with fresh lamb were not successful, application of coatings to other fresh meats prior to freezing improved color and texture. Schneide (1972) coated beef, veal, pork steaks and fish fillets with different compositions of mono-, di- and triacylglycerols of paraffinic and/or carboxylic acids to improve keeping quality of meat and maintain its desirable sensory properties. Stemmler and Stemmler (1976) described coating formulations containing cellulose proprionate and acetylated monoacyglycerol (obtained from lard) used to prolong freshness, color, aroma, tenderness and microbiological stability of fresh beef and pork cuts. Heine et al. (1979) reported that an acetylated mixture of fatty acid mono-, di-, and triacylglycerols applied to fresh beef and pork pieces helped retain desirable color and reduced moisture loss during 14 days of refrigerated storage. A product called Myvacet® (Eastman Chemical Products, Inc., Kingsport, TN), a distilled acetylated monoacylglycerol, has been marketed as a protective coating for frozen poultry. It is applied as a dip or spray prior to the freezing of meat; the coating is then left on product during cooking (Hernandez 1994). Griffin et al. (1987) and Leu et al. (1987) coated vacuum-packaged strips of loins and top rounds with an acetylated monoacylglycerol coating. They observed no differences in microbial counts, color, or odor of vacuum-packaged steaks or roasts after 4 and 7 weeks of refrigerated storage, respectively. Acetostearin films have also been reported to provide oxidative stability when used on meat surfaces, whereas acetoolein films were less resistant to oxidation (Feuge 1955; Baldwin 1994).

Water-in-oil emulsions from animal fats or vegetable oils have been used as protective coatings and as flavor carriers for meat and poultry products (Bauer et al. 1968; Hernandez 1994; Baldwin et al. 1997). Emulsion coatings were effective in protecting frozen chicken pieces and pork chops from dehydration. Increased meat yield, decreased moisture loss and flavor, and improved tenderness were observed when these meats were coated (Zabik and Dawson 1963; Kroger and Igoe 1971; Baldwin et al. 1997). Addition of MC to water-in-oil emulsion coatings provided for more stable coatings at lower temperatures and prevented excessive moisture loss during cooking for pork, beef, chicken, comminuted meat, sausages, fish and seafood (Bauer and Neuser 1969).

8.3.3 Polysaccharide Films and Coatings

Starch, alginate, dextrins, pectin, chitosan and carrageenans are used in polysaccharide films and coatings. Water-soluble polysaccharides are long-chain polymers that are typically used in foods for thickening and/or gelling abilities (Glicksman 1983; Whistler and Daniel 1990; Nisperos-Carriedo 1994). Polysaccharide films are good barriers to gases, and possess resistance to fats and oils; however, their hydrophilic nature makes them poor water vapor barriers (Ben and Kurth 1995). They have been used to extend shelf life of meat and poultry products by retarding dehydration, oxidative rancidity and surface browning. The ability of some polysaccharides (e.g., methylcellulose) to form thermally induced gelatinous coatings has also made them desirable for reducing oil absorption during frying (Nisperos-Carriedo 1994).

Starch, being one of the largest component biomasses produced on earth, is abundant and readily available for use in edible films and coatings. Starch is available from different botanical sources, including wheat, corn, rice, potato, cassava, yam, and barley, among others; corn represents the major commercial source (Riaz 1999). There are also several genetic mutant varieties of corn created to alter starch content and the ratio of amylose to amylopectin, the two main polymers of starch. Starch-based films are similar to plastic films in their properties; they are odorless, tasteless and colorless. They are nontoxic, biologically absorbable and semipermeable to carbon dioxide and are good barriers to oxygen (Nisperos-Carriedo 1994). Ediflex®, an extruded hydroxypropylated high-amylose starch film, was developed and used as a wrap for frozen meats and poultry in the late 1960s (Anonymous 1967; Kroger and Igoe 1971; Morgan 1971; Sacharow 1972). Ediflex® was flexible, a good oxygen barrier, oil-resistant and heat-sealable, and therefore was effective in protecting meat products during frozen storage. The coating also dissolved during thawing and cooking (Kroger and Igoe 1971; Morgan 1971; Sacharow 1972).

Alginates are derived from brown seaweed and, in the presence of divalent cations, produce films that are particularly useful for applications that enhance quality of meat and poultry products (Kester and Fennema 1986; Nisperos-Carriedo 1994). Calcium is the most common and effective divalent cation in gelling alginates, though magnesium, manganese, aluminum, ferrous, or ferric ions are also used (Kester and Fennema 1986). At levels of 5 M or greater, calcium chloride may provide a bitter taste to foods, so other calcium salts may be substituted or lower levels used (Baker et al. 1994). Alginate film strength may further be improved in the presence of modified starches, oligosaccharides or simple sugars (Gennadios et al. 1997).

Allen et al. (1963) coated beefsteaks, pork chops and chicken drumsticks in alginate or cornstarch by dipping them first in coating solution and then in calcium chloride solution. Coatings were effective in reducing moisture loss and, therefore, shrinkage during 1 week of refrigerated storage. They also provided improved juiciness, texture, color and odor within the meats. However, calcium chloride contributed a bitter taste. Calcium gluconate, nitrate, or proprionate provides more acceptable flavor; however, due to their weak ionizing properties, the coatings are not as strong as those formed with calcium chloride (Allen et al. 1963; Hartal 1966). Lazarus et al. (1976) reported that alginate coatings gelled by calcium chloride reduced weight loss of lamb carcasses during refrigerated storage. Although the alginate coatings were not as effective as plastic films in preventing weight loss, bacterial counts were significantly reduced in the alginate-coated carcasses. In other studies, alginate coatings were not reported to affect cooking loss, flavor, odor, or overall acceptability of coated beef (Mountney and Winter 1961), pork (Nisperos-Carriedo 1994) and poultry products (Williams et al. 1978). Alginate coatings also did not decrease weight loss, off-odor and drip of beef cuts compared to noncoated controls (Williams et al. 1978). The coated meats were acceptable in flavor, tenderness, appearance and cooking loss. However, after 4.5 months of refrigerated storage, drying of the coating was noted.

As consumer demand for more convenient foods has increased, considerable research effort has been focused on improving quality of precooked meat products. Precooked meat products are susceptible to lipid oxidation, which results in a rancid or warmed-over flavor (WOF) during refrigerated storage (Tims and Watts 1958; St. Angelo et al. 1987; Love 1988). Moisture loss is also a critical factor affecting quality and shelf life of precooked meats. Among the many techniques used, edible films and coatings have also been studied as a means for controlling quality of precooked meats. Wanstedt et al. (1981) observed that alginate-coated precooked, frozen and stored pork patties had reduced oxidative off-flavors (thus, WOF), better sensory properties and greater desirability than the uncoated controls. Coatings of starch–alginate, starch–alginate–tocopherol and starch–alginate–rosemary have been reported to reduce WOF in precooked, refrigerated pork chops and beef patties (Hargens-Madsen et al. 1995; Ma-Edmonds et al. 1995; Handley et al. 1996). Starch–alginate–stearic acid composite films were effective in controlling lipid oxidation, WOF and moisture loss in precooked ground beef patties (Wu et al. 2001). Tocopherol-treated films were more effective than the non-tocopherol controls;

however, none of the films was as effective as polyester vacuum bags in retarding moisture loss and lipid oxidation.

Cellulose and its derivatives also produce edible films and coatings that are water-soluble, tough, flexible and resistant to fats and oils (Krumel and Lindsay 1976; Baldwin et al. 1995). However, their application to meat and poultry products has been limited. Ayers (1959) reported that application of methylcellulose (MC)–lipid coatings prevented desiccation and extended shelf life of beefsteaks. These coatings were transparent and peeled easily. MC and HPMC coatings on meats and poultry are used during deep fat frying to reduce oil uptake and moisture loss (Balasubramaniam et al. 1997; Meyers 1990), and extend shelf life of the frying oil (Balasubramaniam et al. 1997; Holownia et al. 2000). They can also help maintain integrity of the breading or batter during frying. Specifically, CMC has been shown to improve breading adhesion (Suderman et al. 1981).

Carrageenan is a complex mixture of polysaccharides extracted from red seaweed (Nisperos-Carriedo 1994). Carrageenan-based coatings have been reported to extend shelf life of poultry (Pearce and Lavers 1949; Meyers et al. 1959). Carrageenan and agar (another seaweed-derived polysaccharide) coatings containing antibiotics were shown to extend shelf life of coated poultry (Meyers et al. 1959) and beef (Ayers 1959), though coatings did not reduce moisture loss. More recently, incorporation of nisin (a bacteriocin) into agar coatings together with food-grade chelators (EDTA, citric acid, or polyoxyethylene sorbitan monolaureate) effectively reduced levels of *Salmonella typhimurium* on poultry products (Natrajan and Sheldon 1995).

Limited reports are available on application of chitosan and pectin films and coatings to meat and poultry products. Stubbs and Cornforth (1980) showed that calcium pectinate gel coatings significantly reduced shrinkage and bacterial growth for beef patties.

8.3.4 Composite Films

A single-component film generally has either good barrier or good mechanical properties, but typically not both. Thus, multiple components are often combined to form composite films with desired properties. Polysaccharides and proteins, owing to their intermolecular interactions, form films and coatings that have good structural integrity and mechanical properties; but they are generally not effective barriers to moisture because of their hydrophilic nature. Lipids, on the contrary, are good barriers to moisture as a result of their hydrophobic character, though their films lack structural integrity, are brittle, and do not adhere well to hydrophilic surfaces. In formation of composite films and coatings, two or more components are combined to improve mechanical properties, gas exchange, adherence to surfaces and/or moisture barrier properties (Baldwin et al. 1995). They may be applied as emulsions or bi-layers. Plasticizers, such as glycerol, polyethylene glycol, or sorbitol, may be added to modify film mechanical properties and provide increased flexibility (Ben and Kurth 1995). Cross-linking of proteins with enzymes (e.g., transglutaminase) or polysaccharides with polyvalent ions (e.g., calcium cations) may be employed during the film-forming process, and various additives to improve specific film attributes may also be incorporated. Ben and Kurth (1995) reported that clarity of caseinate–lipid composite films could be improved by addition of three enzymes to cross-link sodium caseinate molecules. Resulting films had improved appearance, and meat was juicier because of reduced drip loss. Packaging waste and handling was also reduced owing to the elimination of an absorbent pad (Ben and Kurth 1995).

8.3.5 Antimicrobial Films and Coatings

Edible films and coatings can serve as carriers for a wide range of food additives, including antimicrobials, which can reduce microbial growth at meat and poultry surfaces to improve product safety and extend product shelf life. The primary advantage of antimicrobial edible films and coatings is that inhibitory agents in these films can be specifically targeted to postprocessing contaminants on the food surface, with diffusion rates of antimicrobials into the food product being partially controlled by properties of the antimicrobial agent itself, as well as the properties of the film.

As consumer demand for convenience continues to increase, demand for ready-to-eat (RTE) foods will also continue to grow. Quality, safety and shelf life of RTE foods is often dictated by the type and numbers of pathogenic and spoilage bacteria present on the food surface. Approximately two-thirds of all microbiologically related class I recalls in the United States result from postprocessing contamination during subsequent handling and packaging, as opposed to processing itself. Most of these recalls are prompted by contamination with *Listeria monocytogenes,* for which the United States has maintained a policy of zero tolerance since 1985. From January 1998 to February 2003, over 130 *Listeria*-related class I recalls involving more than 80 million pounds of cooked RTE meats have been issued (CDC 2000). More than 35 million pounds of hot dogs and luncheon meats were voluntarily recalled in 1998 by one Michigan manufacturer in response to an outbreak that resulted in 101 cases of listeriosis (including 21 fatalities) spread across 22 states. Two years later, another listeriosis outbreak involving 29 cases and ten states (including seven fatalities) prompted recall of approximately 14.5 million pounds of turkey and chicken delicatessen meat; again, the product became contaminated with *L. monocytogenes* after processing (USDA-FSIS 2001). More recently, the largest product recall ever issued, 27.4 million pounds of fresh and frozen RTE turkey and chicken products, was linked to another major outbreak of listeriosis emanating from a manufacturer in Pennsylvania. Each year, approximately 2,300 cases of foodborne listeriosis are reported in the United States at an estimated cost of \$2.33 billion (~\$1 million per case), making *L. monocytogenes* the second costliest foodborne pathogen after *Salmonella* (2.38 billion) (USDA-FSIS 2001).

Product slicing and packaging operations are points at which both pathogenic and spoilage organisms can be introduced to cooked RTE foods. In commercial manufacturing facilities, slicing of RTE meat products can easily increase microbial population 100-fold or greater (Cagri et al. 2004). Heightened consumer demand for enhanced keeping quality and freshness of RTE foods has given rise to the concept of active packaging – a type of packaging that alters conditions surrounding the food to maintain product quality and freshness, improve sensory properties, or enhance product safety and shelf life. A specific function of active packaging includes restriction of antimicrobial activity through controlled diffusion of one or more antimicrobial agents from packaging material into the product. Antimicrobial edible films and coatings can potentially serve as active food packaging materials by altering permeability of a product to water vapor and oxygen, as well as by minimizing growth of surface contaminants during refrigerated storage, providing an alternative to postprocess pasteurization for inactivation of surface contaminants.

Some of the more commonly used preservatives and antimicrobials in edible films and coatings include benzoates, proprionates, sorbates, parabens, acidifying agents (e.g., acetic and lactic acids), curing agents (e.g., sodium chloride and sodium nitrite) bacteriocins, and natural preservatives (e.g., natural oils, lysozyme, liquid smoke) (Cagri et al. 2004). Antifungal compounds, organic acids, potassium sorbate, or the bacteriocin, nisin, were reported to be more effective in reducing levels of foodborne microorganisms when immobilized or incorporated into edible gels (i.e. starch, carrageenan, waxes, cellulose ethers, or alginate) and applied to meat surfaces than when these agents were used alone (Cutter and Sumner 2002).

Incorporation of antibiotic and antifungal compounds into carrageenan films was reported by Meyers et al. (1959), who showed a two log reduction in bacterial counts at the surfaces of coated poultry products. Hotchkiss (1995) reported incorporating antimycotics into wax and cellulose-based coatings. Siragusa and Dickson (1993) reported that organic acids were more effective in reducing *L. monocytogenes*, *S. typhimurium* and *E. coli* O157:H7 levels on beef carcasses when they were immobilized in calcium alginate gels (and applied), compared to when they were applied alone. Baron (1993) verified that potassium sorbate and lactic acid incorporated into an edible cornstarch film inhibited growth of *S. typhimurium* and *E. coli* O157:H7 on surfaces of poultry. Incorporation of the bacteriocin, nisin, into calcium alginate gels was investigated by Cutter and Siragusa (1996, 1997). They showed greater reductions in bacterial populations and greater retention of nisin activity on both lean and adipose beef surfaces when nisin was immobilized in an alginate gel matrix, compared to controls that were treated with only nisin. Natrajan and Sheldon (2000) reported that incorporation of nisin and chelators into protein- and polysaccharide-based films inhibited growth of *Salmonella* on poultry skin. Control of *L. monocytogenes* at the surface of refrigerated RTE chicken was achieved with edible zein film coatings containing nisin and/or calcium propionate (Janes et al. 2002). McCormick et al. (2005) reported that wheat gluten films containing nisin were effective in reducing populations of *L. monocytogenes*, but were not effective against *S. typhimurium*. Inhibition of *L. monocytogenes* was demonstrated on turkey frankfurters coated with soy protein films containing nisin combined with grape seed and green tea extracts (Theivendran et al. 2006). Miller and Cutter (2000) incorporated nisin into collagen-based films to provide protection against pathogenic and spoilage organisms. A sausage casing containing sorbate and glycol was commercially marketed by Union Carbide (Labuza and Breene 1989).

Incorporation of essential oils has also been investigated in production of antimicrobial edible films and coatings. Although antimicrobial properties of essential oils have been recognized for centuries, there has been renewed interest in their use because of consumer demand for natural ingredients and additives. Essential oils are responsible for odor, aroma and flavor of spices and herbs. These compounds are added to edible films to modify flavor, aroma and odor, as well as to impart antioxidant and antimicrobial properties. Films containing these ethanol-soluble compounds show activity against both Gram-positive and Gram-negative bacteria. Essential oils of angelica, anise, carrot, cardamom, cinnamon, cloves, coriander, dill weed, fennel, fenugreek, garlic, nutmeg, oregano, parsley, rosemary, sage and thymol are inhibitory to various spoilage and/or pathogenic bacteria, as well as molds. Oussalah et al. (2004) produced milk protein-based edible films containing oregano, pimiento and oregano-pimiento mixtures. The oregano-containing films provided the greatest antimicrobial activity against *E. coli* O157:H7 and *Pseudomonas* spp. on beef muscle slices, whereas pimiento-containing films were least effective against these two bacteria. More recently, Zivanovic et al. (2005) reported that chitosan films enriched with essential oils (anise, basil, coriander and oregano) had strong antimicrobial effects on *L. monocytogenes* when applied to inoculated bologna samples.

Other antimicrobial films based on whey protein isolate (WPI) containing sorbic acid or *p*-aminobenzoic acid were developed by Cagri et al. (2001). Both films reportedly inhibited *L. monocytogenes, E. coli* O157:H7 and *typhimurium* DT104 on a nonselective plating medium. Subsequently, these films were tested with beef bologna and summer sausage slices that were surface-inoculated with these same pathogens at levels of 10^6 CFU/g (Cagri et al. 2002). WPI films containing sorbic or *p*-aminobenzoic acid decreased *L. monocytogenes*, *E. coli* O157:H7 and *S. typhimurium* DT 104 populations by 3.4–4.1, 3.1–3.6 and 3.1–4.1 log, respectively, on bologna and sausage slices after 21 days of aerobic storage at refrigerated temperature. Growth of mesophilic aerobic bacteria, lactic acid bacteria, mold, and yeast on meat slices was also inhibited by the same antimicrobial WPI films, compared to those coated with antimicrobial-free control films.

The same research group subsequently developed heat-sealable WPI casings containing sorbic acid, *p*-aminobenzoic acid, or sorbic acid–*p*-aminobenzoic acid (1:1 ratio) for hot dog manufacture (Cagri et al. 2003). WPI casings containing *p*-aminobenzoic acid inhibited *L. monocytogenes* on hot dogs for 42 days of refrigerated storage; however, films containing sorbic acid or sorbic acid–*p*-aminobenzoic acid were less effective. Sensory (texture, flavor, juiciness, overall acceptability), chemical (thiobarbituric acid; pH; moisture, fat, and protein contents), physical (purge, color) and mechanical (shear force) characteristics of hot dogs processed within WPI casings containing *p*-aminobenzoic acid were comparable to those prepared with collagen and natural casings. Thus, WPI casings containing *p*-aminobenzoic acid may eventually provide a viable alternative to postprocess pasteurization of hot dogs for minimization of *Listeria* risk.

Incorporation of other antimicrobials into edible films and coatings such as liquid smoke, sodium chloride and nitrites, has not been extensively studied. Liquid smoke, which contributes antimicrobial, antioxidant, color and flavor attributes, is also a potentially attractive film additive. Liquid smoke has been studied in conjunction with edible collagen casings, where liquid smoke is introduced into the acid-swollen collagen mass before extrusion as a casing or film (Miller 1975). Because liquid smoke is generally very acidic (pH 2.5 or less), it is compatible with the gel system, and can replace a portion of acid normally added to induce swelling of collagen. Sodium chloride (common salt) has been recognized as a food preservative since ancient times, and can be used alone or in combination with other preservation techniques, such as pasteurization or fermentation. Most bacterial foodborne pathogens are susceptible to elevated concentrations of salt, particularly in the presence other preservatives. Incorporation of salt into protein-based films (e.g., whey protein) as an antimicrobial agent is of limited use, since physical properties of protein films are altered with increasing ionic strength. At high ionic strength, proteins aggregate to form turbid, opaque gels with high water-holding capacity (Smith and Culbertson 2000). Nitrite has not yet been studied as an edible film additive, although it appears to be suitable for production of antimicrobial edible films. Application of films containing nitrite to RTE meat products may not only help prevent growth of *L. monocytogenes* and spoilage bacteria that can contaminate such products after processing, but might also improve meat surface color.

Release of antimicrobial agents from an edible film and controlling the conditions for release are very important considerations for effectiveness of antimicrobial films and coatings. Release of antimicrobial substances from edible films is dependent on many factors, including electrostatic interactions between the antimicrobial agent and polymer chains, ionic osmosis and structural changes induced by the presence of the antimicrobial and environmental conditions. Diffusion of antimicrobials through the edible film is also influenced by film (type, manufacturing procedures), food (pH, water activity), hydrophilic characteristics and storage conditions (temperature, relative humidity, duration).

8.3.6 Incorporation of Other Additives

Many potential benefits of edible films as carriers of other additives (e.g., flavors, antioxidants, coloring agents, vitamins, probiotics and nutraceuticals) justify continued research in the field of active packaging. However, only antioxidants have been investigated extensively. Although oxygen-barrier properties of edible films and coatings may reduce need for oxidative stabilization, antioxidants have been used in edible coatings to provide further protection to meat and poultry products.

Incorporation of antioxidants such as gallic or ascorbic acids into carrageenan coatings to extend shelf life of poultry products has been reported as early as 1948 (Stoloff et al. 1948; Allingham 1949). Antioxidants were incorporated into a mixture of lard and tallow coating containing lactic acid–fatty acid triacylglycerol, which was used to coat freeze-dried and fresh meats, including beef steaks, pork chops and beef cubes (Sleeth and Furgal 1965). Thiobarbituric acid levels were significantly reduced in meats to which antioxidant-containing coatings were applied, compared to those of non-coated controls (Sleeth and Furgal 1965). Pork chops treated with alginate–starch coatings containing tocopherol were reported to be juicier and less susceptible to lipid oxidation, compared to the untreated controls. However, they still developed off-flavors (Hargens-Madsen et al. 1995). Herald et al. (1996) reported that turkey breasts wrapped in corn zein films containing butylated hydroxyanisole (BHA) had a lower hexanal content than samples packaged in polyvinylidene chloride (PVDC).

Essential oils from oregano, sage rosemary, thyme and pimiento are reported to possess antioxidant properties comparable to or greater than BHA or butylated hydroxytoluene (BHT) (Wu et al. 1982; Shelef 1983; Howard et al. 2000; Bendini et al. 2002). Oussalah et al. (2004) have reported on antioxidant properties of milk protein-based edible films containing oregano, pimiento and oregano-pimiento mix. Pimiento-containing films provided the highest antioxidant activity on beef muscle slices; oregano-based films were also able to inhibit lipid oxidation in beef muscle samples. Armitage et al. (2002) evaluated egg albumen coatings with natural antioxidants, fenugreek, rosemary and vitamin E, for antioxidant activities in diced raw and diced cooked poultry breast meat. In both raw and cooked experiments, coatings with no added antioxidant showed greatest inhibition of lipid oxidation as monitored by thiobarbituric acid reactive substances (TBARS).

Although some edible films have received consumer acceptance, further research is needed to develop cost-effective production and application methods for continuous extrusion and application of films and coatings as flat sheets or casings.

8.4 Film-forming Techniques and Application

Several different techniques, including solvent removal, thermal gelation and solidification of melt, have been developed for forming edible films and coatings. Solvent removal has been used to produce hydrocolloid edible films. In this process a continuous structure is formed and stabilized by chemical and physical interactions between polymer molecules. Macromolecules in film-forming solution are dissolved in a solvent, such as water, ethanol or acetic acid, which contains other functional additives (plasticizers, cross-linking agents, solutes). Film-forming solution is then cast in a thin layer, dried and peeled from the surface. Freestanding films are formed by a casting technique in which film-forming solutions are poured onto a smooth, flat, level surface, and allowed to dry, usually within a defined surface (Donhowe and Fennema 1994).

In preparing some types of protein films (e.g., whey protein, casein, soy protein, wheat gluten), solution is heated to promote protein gelation and coagulation, which involves denaturation, gelation, or precipitation, followed by rapid cooling. Intramolecular and intermolecular disulfide bonds in the native protein complex are cleaved and reduced to sulfhydryl groups during protein denaturation (Okamoto 1978). When film-forming solution is cast, disulfide bonds re-form to link polypeptide chains together to produce the film structure, which is further stabilized by hydrogen and hydrophobic bonding.

Melting followed by solidification is a means for producing lipid-based films. Casting molten wax on dried methylcellulose films followed by solubilization of the methylcellulose can also be used to form wax films (Donhowe and Fennema 1993).

Edible films and coatings may be applied to meat and poultry products by foaming, dipping, spraying, casting, brushing, individual wrapping, or rolling (Donhowe and Fennema 1994; Grant and Burns 1994). Foam application is used for emulsion coatings, where a foaming agent is added to the coating or foam is created by compressed air; meat may be coated with protective foam as it moves over rollers. Flaps or brushes may also be used to distribute coating over the product (Grant and Burns 1994). Irregular surfaces of food products present particular challenges to uniform application of coatings. Thus, several applications may be needed to obtain a uniform coating on a food surface. Emulsions may work in case of multiple applications where the coating will need to set (or solidify). This is done typically after dipping product that is being coated, letting the coating drain and set prior to application of the next coating layer (Donhowe and Fennema 1994). Spraying is most suitable where thinner films are needed, or when a coating is applied to only one side of a product. Spraying is also used when dual applications are used to promote cross-linking (e.g., with alginate–Ca^{2+} coatings) (Donhowe and Fennema 1994). Early procedures for coating meat and poultry products involved spraying materials onto rollers or brushes, and allowing meat to be coated by the tumbling action of the product (Grant and Burns 1994). Brushing and/or rolling the coating directly onto meat surfaces may also be used to apply edible coatings. Edible films and coatings applied to food products will need to set or solidify at the food surface. This requirement can be accomplished at ambient temperatures or with the use of heat. Shorter drying times tend to provide for more uniformly distributed coatings (Grant and Burns 1994).

Other than on collagen films and casings, only limited information is available on continuous extrusion of freestanding films for meat applications.

8.5 Regulatory Aspects

The process of determining acceptability of most ingredients used in edible films and coatings is similar to that used for food formulations (Heckman and Heller 1986). If the edible film or coating is made from materials that have been generally recognized as safe (GRAS) and its use in the film or coating is in accordance with good manufacturing practices, it will be considered GRAS. If materials are not GRAS, but safety of the film or coating can be demonstrated, the manufacturer may file a GRAS Affirmation Petition with FDA or proceed without FDA concurrence on the basis of self-determination. The manufacturer may not need to establish that materials used are GRAS if the film or coating materials have received a pre-1958 FDA clearance or "prior sanction". If materials used in films and coatings are not GRAS or have not received prior sanction, then a food additive petition to the FDA must be filed (Krochta and De Mulder-Johnston 1997).

With the exception of chitosan, polysaccharides including cellulose and its approved derivatives (CMC, MC, HPMC), starches and their approved derivatives, and seaweed extracts (agar, alginates, carrageenan), are either approved food additives or GRAS substances. Regulations regarding their specific use are described in the Code of Federal Regulations (CFR) Title 21 (Nisperos-Carriedo 1994). Many of the lipid compounds used are classified either as GRAS or food additives (FDA 1991). Beeswax, carnauba wax, candelilla wax, carnauba wax, mono-, di-, and triacylglycerols, glyceryl monooleate, glyceryl monostearate and steric acid are GRAS substances. Acetylated monoacylglycerol is classified as a multipurpose additive; fatty acids are approved as lubricants and defoamers (CFR Title 21; Baldwin et al. 1997). Proteins that are most commonly used for edible films and coatings, such as corn zein, wheat gluten, soy protein and milk proteins, have GRAS status. However, some concerns have been raised due to allergenicity or intolerance some consumers have to wheat proteins or lactose. Since edible films and coatings become part of the food to be consumed, all materials used in these products must be appropriately declared on the label. Regulations regarding incorporation of antimicrobials, antioxidants, essential oils, color and other additives are the same as those that will be applicable to food formulations.

8.6 Conclusions

Edible films and coatings provide numerous opportunities to meat processors as well as to consumers. Alternatives to collagen casings are feasible. Incorporation of antimicrobials, antioxidants, flavors and colors provide for additional opportunities. Once thermoplastic processing of other proteins and materials are refined, large-scale production of these films will be viable. Development and application of these materials should improve quality and safety of meat products.

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