33
Nonmeat Ingredients and Additives

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33.1 Introduction

“Food additives” is a general term referring to anything added to food to achieve specific functions, for example, to aid in food processing, to increase the product’s nutritive value, to enhance the product’s palatability through regulating its physicochemical properties, and to extend the product’s storage stability. In muscle food processing, both synthetic and natural, generally recognized as safe (GRAS) chemical compounds and ingredients are used as functional nonmeat additives to assure quality and safety of finished products.

The main ingredients in a typical meat product are raw muscle and fat. Nonmeat ingredients include a variety of additives that are small molecules (salt, phosphate, antioxidant, and antimicrobial compounds present in plant-derived spices and seasoning, etc.) or large molecules (starch, gums, nonmuscle proteins, etc.). All these additives can be referred to as chemical ingredients (Table 33.1). Nonmuscle proteins and protein hydrolysates (peptides), such as, soy protein, soy protein hydrolysate, and sodium caseinate, are used in meat processing to improve textural characteristics and water-binding capacity in finished products. Common small ingredients influence meat product quality through interaction with proteins and lipids in meat processing. Examples include monobasic salts (NaCl, KCl, etc.), divalent cationic salts (CaCl$_2$, MgCl$_2$, etc.), various alkali and acid compounds, and different phosphates. Lipid and nonlipid free radicals, which are commonly generated in meat processing, can also have a profound impact on the quality of meats because they not only cause off-flavors but also impair products’ texture by reducing muscle protein functionality. To control oxidation, antioxidant compounds are widely used. Moreover, the cross-linking enzyme microbial transglutaminase (MTGase) is beneficial in improving gelling properties of muscle proteins under both low- and high-salt conditions and has been used in the manufacture of restructured meatloaves, meatballs, steaks, and nuggets. Overall, the intended roles of many of the
large- and small-molecular chemical ingredients are affected by the specific meat processing conditions.

In this chapter, the roles of different ingredients used in the processing of comminuted as well as whole-muscle meat products, particularly those with a low- or reduced-fat content, are discussed. Emphasis is placed on the fundamental mechanisms by which different ingredients affect the physicochemical characteristics of cooked products as related to palatability, for example, gelling, emulsifying, texture-forming, water-binding, and hydration properties. For additional reading, authors are referred to several excellent reviews (Keeton 1996; Rogers 2001) and a comprehensive book edited by Tarté (2009) on similar or related topics.

### 33.2 Salts

Salt can be defined as any compound that results from replacement of part or all of the hydrogen atoms of an acid by a metal ion(s). Thus, salts are ionic compounds composed of cations (positively charged) and anions (negatively charged). Although salts are electrically neutral compounds, in aqueous solutions, such as the aqueous phase of meat products, cations and anions in many salts are dissociable, making them chemically active substances that can react with proteins and other muscle constituents.

The most commonly used salt in meat products is NaCl. The main functions of NaCl, other than providing flavor, are to solubilize proteins thereby eliciting their functionalities, to improve meat dehydration, and to alter osmotic pressure so as to inhibit bacterial growth and subsequent spoilage. Salt can be applied to meat directly in its dry crystal form or dissolved in solution (pickle or marinade) before incorporation into meat. The exploitation of meat protein functionality by the use of NaCl is accomplished through two distinct mechanisms: aiding in myofibrillar protein extraction and modifying protein–protein interactions. When used as a protein extraction agent, NaCl at an application level of ~2% or higher raises the ionic strength of the sarcoplasm to above 0.5, enabling myosin filaments to depolymerize and myofibrils to swell resulting in improved hydration and water-holding capacity (Hamm 1986). When salted raw meat is finely chopped in the presence of NaCl, myofibrils disintegrate and dissociate, leading to the extraction of solubilized actomyosin, myosin, actin, and most other myofibrillar proteins (Offer and Trinick 1983; Xiong and others 2000), a process known as “salting-in.” Solubilization is achieved through ionic interactions of cations (Na+) and anions (Cl-) with oppositely charged side-chain groups of proteins (COO− and NH+) to enhance electrostatic repulsions between proteins and promote protein–water interaction. The concentration of NaCl affects the thickness of the hydration layer, which is closely related to the electric double layer surrounding a protein, hence, solubility of the protein (Figure 33.1).

| TABLE 33.1 |
| Common Ingredients Utilized in Meat Processing |
| Ingredient | Example | Main Function |
| Salts | NaCl, KCl, LiCl, CaCl₂, MgCl₂ | Flavor; protein solubility; protein functionality; meat hydration |
| Phosphates | Na₂PO₄ (ortho-), Na₃P₂O₇ (pyro-), Na₅P₃O₁₀ (tripoly-), (NaPO₄)₅ (hexameta-) | pH stability; protein extraction; water-holding; meat hydration |
| Alkalis | NaHCO₃, alkali phosphates | Protein extraction; meat hydration |
| Acids | Citric acids, malic acid, lactic acid, acetic acid | Protein extraction; meat hydration |
| Curing agents | Nitrate, nitrite, erythorbate | Cured meat color (pinkish-red); flavor; antimicrobial |
| Nonmuscle proteins | Soy protein, sodium caseinate, protein hydrolysates | Extender; filler; texture; water-binding |
| Polysaccharides | Carrageenan, xanthan, Konjac flour, starch | Water-binding; emulsification |
| Enzymes | Bromelain, papain, ficin, transglutaminase | Meat tenderness; meat-binding; texture of restructured meats |
| Seasoning | Paprika, black pepper, fennel, cumin, garlic | Flavor; antioxidant; antimicrobial |
| Health ingredients | Vegetable oils, protein hydrolysates, rice bran | Nutrition; health |
Because an excess dietary intake of sodium is linked to hypertension, there has been considerable effort to partially replace NaCl with nonsodium salts in meat products. Gordon and Barbut (1992) compared four chloride salts (KCl, LiCl, MgCl$_2$, and CaCl$_2$) as potential substitutes for NaCl in reduced-sodium meat emulsion products. A similar protein extraction pattern was noted between NaCl, KCl, and LiCl (1.5%) treatments. CaCl$_2$ and MgCl$_2$ were less capable of stabilizing fat and binding water, which was evidenced by the porous structure in cooked batters as revealed by the electron microscopy and excessive amount of water released. This was probably due to the amount of the divalent cation salts used being too high (ionic strength 0.43), because at a much reduced concentration (<5 mM), both CaCl$_2$ and MgCl$_2$ promoted the extraction of myofibrillar proteins, including myosin (Xiong and Brekke 1991). In fact, low concentrations (<5 mM) of divalent cations, notably Ca$^{2+}$, enhance the gel-forming properties of chicken muscle myofibrillar proteins (Xiong and Brekke 1991). Similar cation effects have been reported for turkey muscle protein extraction (Nayak and others 1996). The efficacy of cations varies depending on muscle fiber types. As shown by Xiong and Brekke (1991), while the extractability of chicken breast myofibrillar proteins (white) was enhanced by <5 mM CaCl$_2$ or MgCl$_2$, it was lowered at >10 mM CaCl$_2$. However, the extractability of red muscle myofibrillar proteins (red) increased 40–70% upon treatment with 10 mM CaCl$_2$ or MgCl$_2$ and remained unchanged within the 10–100 mM concentrations. The presence of <10 mM Ca$^{2+}$ promoted protein–protein interaction, leading to a more rigid gel with a stronger water-holding capacity. However, when the Ca$^{2+}$ concentration exceeded 10 mM, gelation was suppressed for white myofibrillar proteins. It appears that subtle structural differences in myosin isoforms (Pette and Staron 1990) affect carboxyl-Ca$^{2+}$ association.

### 33.3 Phosphates

Phosphates are common functional ingredients in meat processing due to their unique capability to interact with myofibrils to enhance water-binding and extract myosin. In the United States, the amount of phosphates added to meat cannot exceed 0.5% of the product. The most widely used phosphates are pyrophosphate (PP), tripolyphosphate (TPP), and hexametaphosphate (HMP). Monophosphate (ororphosphate) is rarely used except when a buffering agent is needed. The chemical structures of these phosphates...
are displayed in Figure 33.2. PP is a diphosphate; it exists in acidic, neutral, or basic forms, depending on the number of metal ions (Na\(^+\) or K\(^+\)) attached to the molecule. TPP has three phosphorus atoms; it, too, varies in the number of bound metal ions to form acidic, neutral, or basic compounds. On the other hand, ring-structured phosphates, generally referred to as metaphosphates, are condensed phosphates. They are composed of up to 15 or more orthophosphate units connected via oxygen atoms to form bulky cyclic compounds. Among them, sodium HMP is commonly used in meat products. Commercial HMP usually is a mixture of metaphosphates with different numbers of phosphate units.

Open-chain phosphates can readily react with divalent cations; hence, they have a tendency to precipitate in aqueous solutions containing high amounts of calcium, for example, hard water. Even in the absence of calcium, PP has a relatively low solubility when compared with TPP. Thus, PP is often used in conjunction with TPP or HMP, which are more tolerant of Ca\(^{2+}\), in injection or marination brines. Possible mechanisms by which phosphates enhance water-binding ability and meat hydration in marinated muscle foods include the ionic effect and pH alteration contributed by phosphates and the ability to sequester Ca\(^{2+}\), thereby reducing myosin aggregation. For PP and TPP, the ability to dissociate the actomyosin complex also contributes to water-binding in meat. The dissociation of actomyosin enables myofibril lattices to expand, thereby allowing increased water entrapment (Offer and Trinick 1983).

The mechanism underlying the action of PP and TPP to promote hydration and water-binding in fresh meat has been elucidated using myofibrils as a model. Significant hydration of salt-marinated meat begins at ~0.6 M (i.e., 2.1% in meat) NaCl, which parallels significant enlargements of the myofibril diameter. When 10 mM (0.3% in meat) PP is also added, the required level of NaCl for meat hydration is reduced to ~0.4 M (1.6% in meat). This effect is of importance for reduced-salt meat products. Because of its actomyosin dissociation capability, the presence of PP facilitates the extraction of myosin, which occurs preferably at both ends of the A-band of the sarcomere, namely, the A–I junction (Xiong and others 2000). Interestingly, marination in the presence of orthophosphate or metaphosphate does not induce the above extraction pattern, which is similar to that of NaCl-only marination. In general, the ability of sodium phosphates to facilitate water-binding in meat follows the order of PP ≥ TPP > HMP > orthophosphate. The improvement in protein extraction by the presence of phosphates leads to better protein functionalities, including gelation and emulsification, which, in turn, improves the textural properties of comminuted, cooked meat, such as sliceability and smoothness.

The efficacy of phosphates is sensitive to pH and ionic strength. In general, phosphates improve water-binding and meat product texture only if the NaCl concentration is <2% (equivalent to an ionic strength of ~0.5) under the typical meat pH condition (pH 5.50–6.0). If the salt content exceeds 2% or the pH of the meat product is sufficiently high (>6.3), the effect of phosphates tends to diminish. With the combination of high levels of salt and pH, NaCl alone is capable of causing myofibrils to swell and myosin to solubilize.
Thus, the exact efficacy of phosphates in modifying protein functionality is directly related to the solubility status of myofibrillar proteins, which is influenced by the processing conditions as indicated above.

### 33.4 Alkalis

Because phosphates at elevated concentrations can produce off-flavors and pose health concerns to some individuals who are sensitive to phosphorous compounds, there have been attempts in recent years to use alkali and acids to replace phosphates as water-binding agents in meats. Sodium bicarbonate (NaHCO$_3$) has been used to enhance the textural quality of meat products through alterations of physiochemical properties of muscle. Chicken, beef, and pork treated with sodium bicarbonate showed increased juiciness and overall palatability (Sheard and others 1999; Sen and others 2005). Sodium bicarbonate has also been used to alleviate the inferior-water-binding problem associated with pale, soft, exudative pork (Kauffman and others 1998).

The efficacy of bicarbonate is attributed to the ability to partially solubilize myofibrillar proteins and enhance their electrostatic repulsion through raising the pH. Sodium bicarbonate lowers the hydrogen ion concentration and shifts the pH of the intramuscular aqueous phase away from the isoelectric point of myosin (pH ~ 5.2). This leads to transverse expansion of myofibrils, allowing more water pickup and retention. Because the expansion increases the protein surface, it further promotes hydrogen bonding and electrostatic interactions between water and individual muscle proteins. Thus, swelling of the myofibrils leads to an osmotic compression of water molecules, thereby enhancing juiciness of cooked products and increasing consumer acceptance. At comparable application levels, sodium bicarbonate has been found to be at least as effective as sodium PP in increasing hydration and reducing cooking loss in marinated fresh pork meat (Bertram and others 2008). In fact, bicarbonate-marinated pork has more extensive myofibrill swelling, and consequently, reduced space between the myofibrils than samples treated with PP.

Moreover, the addition of sodium carbonates to meat and meat emulsions can decrease drip loss. Dolata and others (1999) reported that sausage produced with carbonate additives (0.075–1.7%) had an increased cooking yield when compared with control sausage. The addition of the carbonate preparation OPREN (0.075%) yielded the highest pH value and lowest thermal drip loss, indicating an inverse relationship between the two factors. A 0.5 U increase in pH would lead to markedly enhanced water-holding capacity of meat batters. Sen and others (2005) showed that chicken breast meat marinated with 3% bicarbonate had a reduced cooking loss than the control (treated with 2% NaCl) or breast meat marinated with 3% TPP.

### 33.5 Acids

Weak acids are also used in meat processing, for example, in marination. Acid marination is especially desirable for lower-grade meat cuts. The marination creates a tenderized meat by affecting muscle proteins and fiber structures through a variety of processes. When the pH is lowered to a level far below the isoelectric point of myosin, muscle fibers and connective tissue will swell due to charge repulsion. Ke and others (2009) reported a significant increase in water-binding capacity of bovine muscle at pH 3.52 upon the addition of citric acid (0.2 M). Burke and Monahan (2003) noted increased moisture uptake, fiber swelling, and collagen solubility along with a reduced cooking loss of shin beef upon marination treatments with 31% citric juices (orange and lemon). The substantial reduction in the pH (from 5.7 to 3.1) was thought to be responsible for the improved water-binding capacity in the muscle tissue.

In addition, a reduced pH level can activate cathepsins, thereby promoting proteolytic degradation of myofibrils and increasing the solubility of collagen fibrils (Berge and others 2001; Aktas and others 2003). The type of acids is important in the overall pH reduction, moisture retention, and cooking yield of final meat products. For example, lactic acid yields a lower pH value compared to citric acid in marinades and can produce greater moisture uptake. This difference is attributed to the buffering properties of citric acid, a weak organic acid with three ionizable carboxyl groups ($pK_{a1} = 3.06$; $pK_{a2} = 4.74$; $pK_{a3} = 5.40$), compared with only one ionizable group ($pK_a = 3.86$) for lactic acid that gives rise to stronger acidification of the muscle fibers.
33.6 Nitrate, Nitrite, and Cure Adjuncts

Nitrate (NO$_3^-$) and nitrite (NO$_2^-$) are used exclusively in the meat-curing process to develop desirable red/pinkish color of cooked meats. Sodium nitrate was originally approved for color fixation in cured meats but now is largely replaced by nitrite. This is because nitrate is reduced to nitrite either by organisms or reducing compounds before curing reactions take place, and direct application of nitrite can be more easily controlled. Nitrate is now used only in a few products, such as country-cured hams and dry sausage.

Nitrite is a multifunctional compound: it induces and stabilizes the pinkish color of lean meat, contributes to the characteristic flavor of cured meat, inhibits the growth of spoilage microorganisms, and retards development of oxidative rancidity. No other compounds that we know can uniquely serve all these functions simultaneously. Another benefit of using nitrite in cured meats is its ability to prevent the growth of Clostridium botulinum, a pathogen that produces neurotoxins. The chemistry of nitrite curing has to do with the binding of nitric oxide (NO), converted from NO$_2^-$ through reduction, to heme iron (Fe$^{2+}$), forming nitrosylmyoglobin that appears pinkish red (Figure 33.3). Upon cooking, nitrosyl myoglobin changes into nitrosylhemochrome or dinitrosylhemochrome due to the denaturation of the protein moiety (globin) or displacement of protein by NO at one of the coordination sites of heme iron. To facilitate the conversion of NO$_2^-$ to NO, and ferric ion to ferrous ion, erythorbic acid or sodium erythorbate, which has a strong reducing power, is commonly used as a cure adjunct. Erythorbate also functions as an antioxidant to stabilize both cured color and flavor and decrease the formation of nitrosamines. Other cure adjuncts are sugar, salt (NaCl), and phosphates. Salt is needed to impart taste and to enhance firmness of meat through dehydration, and sugar is used to mainly counter hardness of meat caused by NaCl. On the other hand, phosphates are used to balance the water-binding and dehydration of cured meats.

The level of nitrite or nitrate allowed in cured meats, both going and residual, is strictly regulated by the United States Department of Agriculture (USDA). For instance, the maximum level of ingoing NaNO$_2$ in pumped bacon is 120 ppm, and the residual level (in the finished product) shall not exceed 40 ppm. The restriction of nitrite levels is based on the concern that nitrite can form carcinogenic nitrosamines by reacting with secondary amines in cooked-cured meat as well as in the intestines of the human body. Amine compounds are degradation products from proteins that can be formed in meat and in the gastrointestinal tract. The formation of nitrosamines is greatly facilitated at high temperatures. For this reason, less nitrite is permitted in cured meats that are normally cooked at high temperatures, bacon (≤120 ppm nitrite), for example, than products cooked at relatively low temperatures, ham (≤200 ppm nitrite). Nitrosamines are known to be carcinogenic based on animal testing, but their carcinogenicity is quite variable among species. For an average meat consumer, the amount of nitrite ingested from cured meats is extremely low and should not be a concern.

In fact, many nonmeat products, including a variety of leafy vegetables, are excellent sources of nitrite or nitrate compounds. For example, the nitrate content is 2400–3000 ppm in radishes, 1600–2600 ppm in celery, 1000–1400 ppm in lettuce, and 600 ppm in zucchini. Other nitrate-rich fresh produce include cabbages, potatoes, and spinach. These vegetables contribute much more nitrite to the human body than do cured meats, but they have been known to be safe for hundreds of years. In fact, total dietary intake

\[
\begin{align*}
\text{NaNO}_2 + H_2O & \rightarrow HNO_2 + NaOH \\
3\text{HNO}_2 & \rightarrow HNO_2 + 2\text{NO} + H_2O
\end{align*}
\]
of nitrite or nitrate from cured meats is only about 2–4% of the nitrite entering the human body. The vast majority is produced by the human body itself in the intestine (80–130 mg per day) and during salivation (8 mg per day) (Romans and others 1994).

The consumer concern with the potential toxicity and carcinogenicity of nitrite and its derivatives has promoted the meat industry to develop alternative curing methods. For example, “No-Nitrate/Nitrite Added” cured meats are produced by some meat processors. Instead of using pure nitrate or nitrite, vegetable extracts such as radish juice, cabbage juice, celery powder, and spinach extract, which contain up to 2000 ppm nitrite, are used to develop cured meat color and flavor (Sebranek and Bacus 2007). These products must be labeled with the statement “No nitrate or nitrite added except that found in radish juices or (other).” Another alternative method to produce pink, cured color is through microbial conversion of myoglobin. Several lactic acid bacteria have the ability to reduce \( \text{Mb(Fe}^3+) \) to \( \text{Mb(Fe}^2+) \) and change the muscle color from brown to bright red. Among them, \textit{Kurthia} spp. and some strains of \textit{Lactobacillus fermentum} are capable of converting \( \text{Mb(Fe}^3+) \) to cured meat pigment \( \text{NO-Mb(Fe}^2+) \) (Arihara and others 1993).

### 33.7 Nonmeat Proteins

A variety of nonmeat proteins are used as fillers, extenders, or water-binding agents in processed muscle foods, of which, soy proteins and dairy proteins (nonfat dry milk, sodium caseinate, whey protein concentrate, etc.) are most widely used. A general application level of up to 2% for protein isolates and 3.5% for protein concentrates is allowed. Meat products containing these proteins have improved texture and sliceability as well as reduced formulation costs in most cases. A technical challenge for using these nonmeat proteins is their thermoincompatibility with muscle proteins. Processed meats are usually cooked to a final temperature of 65–73°C for palatability. However, these final temperatures are not sufficient to denature main constituents of most plant proteins intended as meat binders or extenders. Consequently, interactions are limited between plant and animal proteins needed for the production of a viscoelastic composite product structure upon cooking. For example, 7S and 11S soy globulins denature around 75°C and 90°C, respectively (Scilingo and Anon 1996). High-salt concentrations (2–3.5% NaCl), which are usually present in processed meats, shift the denaturation of these soy proteins to even higher temperatures (Nagano and others 1996). This explains why native soy protein does not contribute to meat batter gelling properties (McCord and others 1998). For this reason, commercial soy proteins for meat product applications are usually subjected to preheat treatment in order to dissociate protein subunits as well as induce partial structural unfolding. Preheat treatments of plant proteins would enhance their performance in meats, including meat batter emulsion stability and bind strength (Feng and Xiong 2003). When slightly destabilized by brief heat treatment, soy globulins can promote muscle protein gelation and water-holding capacity.

Similarly, partially denatured whey proteins through brief heating can promote myofibrillar protein gelation and emulsification, thereby improving the textural properties of comminuted meats (Hung and Zayas 1992). As much as 50% denatured protein can be found in commercial whey protein ingredients intended for meat processing. Partially destabilized whey proteins, notably \( \beta \)-lactoglobulin, can synergistically interact with myosin when a meat batter is cooked to 65–70°C. The ensuing hydrophobic aggregation and disulfide cross-linking lead to the formation of a composite gel system of high rigidity and binding strength (Beuschel and others 1992). It is also possible that heat-denatured whey proteins can act as active fillers in comminuted products, that is, they can interact with surrounding meat proteins to reinforce the gel matrix (Barbut 2006).

Exposures of nonmeat proteins to extremely low or high pH conditions can also enhance the functional performance of proteins. For example, when subjected to pH 1.5 or 12 to induce structural unfolding, followed by pH 7 to refold (a process known as “pH-shifting”), a native soy protein isolate (SPI) exhibits drastically improved emulsifying activity (Jiang and others 2009) (Figure 33.4). The pH-shifting process has a larger influence on 11S globulins than on 7S. In addition to structural changes in protein monomers, the dissociation of native soy protein complexes contributes to the emulsifying property enhancements. Because pH-shifting treatments greatly increase the solubility of proteins at pH 6, the process seems to promote the overall functionality of soy proteins (Jiang and others 2010; Wagner and Guéguen 1999).
Various plant-derived polysaccharides are used in meat processing to bind water and modify texture in low- and reduced-fat products, such as sausage, bologna, and deli-type boneless hams. Polysaccharides are long-chain carbohydrates possessing polyhydroxyl groups. Some of them contain carboxylic and sulfate groups, hence, are negatively charged when dissolved in water. Because of their high affinity for water molecules, polysaccharides exhibit hydrocolloid characteristics, that is, they can absorb moisture rather efficiently and will swell, thicken, or gel in aqueous solutions. Many polysaccharides when applied to comminuted meats also have the ability to emulsify fat, encapsulate fat particles, and stabilize emulsions. Polysaccharides used in low-fat and restructured meats include alginate, carrageenan, locust bean gum, guar gum, gellan gum, xanthan gum, konjac flour, curdlan, cellulose derivatives, and starches. Excluding starches, these polysaccharides are nondigestible. They are generally applied at a level <0.5% to avoid excessive slippage and gastrointestinal upset.

Alginic acid (β-D-mannuronic acid and α-L-guluronic acid) forms irreversible gels in cold water in the presence of calcium, and hence, is used in the formation of restructured fresh meat steaks (Means and Schmidt 1986). The heat stability of the gel makes alginate useful in low-fat meat products that will be reheated. Carrageenan (sulfur-containing polygalactose) consists of three major types: κ-carrageenan, ι-carrageenan, and λ-carrageenan. κ-Carrageenan forms firm gels that can undergo syneresis, while ι-carrageenan forms weak gels that are not subject to syneresis. Both gels are thermally reversible. To control syneresis and firmness of gels, blends of κ- and ι-carrageenan are often used. κ-Carrageenan has been used in restructured turkey rolls, ham, and sausage, and ι-carrageenan is used in low-fat beef patties. When used in low-fat sausage, κ-carrageenan not only improves water-binding, but also textural characteristics when compared with other polysaccharides (Xiong and others 1999). κ-Carrageenan also shows a high efficacy in increasing water-binding and texture and reducing cooking loss in structured beef rolls (Shand and others 1994). λ-Carrageenan does not form a gel and is not normally used in meat products. Carrageenan solubilizes as meat products are heated. A gel is formed when the cooked product is chilled to below 60°C. Carrageenan interacts with proteins to stabilize fat particles, bind water, improve sliceability, and increase tenderness of finished products. In addition, it reacts synergistically with starches, konjac flour, and locust bean gum, and therefore, can be used in conjunction with these polysaccharides in low-fat sausage.
Locust bean gum (polygalactomannan) is used in canned meat, low-fat bologna, and salami. It is insoluble in cold water but soluble when heated. It is added to meat to impart a smooth texture, reduce syneresis, and provide a fat-like mouthfeel. Locust bean gum does not gel by itself, but when mixed with xanthan or carrageenan, they form cogels and improve meat-cooking yield. Guar gum, another polygalactomannan, is soluble in cold solutions. Its use in low-fat meat is mainly to increase viscosity and cream-like mouthfeel of the product. Xanthan gum, which is a fermentation product by the bacterium *Xanthomonas campestris*, is a heteropolysaccharide consisting of glucose, mannose, and glucuronic acid. It does not gel in aqueous solutions. However, its remarkable thickening effect enables it to function as an excellent water-binding agent in comminuted meats, such as frankfurters (Fox and others 1983). Konjac flour, which contains water-soluble glucomannan polymers, can form thermostable gels. This gelling ability allows Konjac flour to complement the texture- or gel-formation by proteins in meat products (Chin and others 2009). Furthermore, because Konjac gels are firm, they can be used to physically mimic ground fat, which is removed from meat product formulation.

Different starches, generally at up to 3.5% application levels, are used to improve texture and water-binding capacity in meat emulsion products, low-fat sausage, and other water-added meats. Starches suited for cooked meat should have a gelatinization temperature (i.e., swelling and dissolution of starch granules) within the range of meat products’ final cooking temperatures (65–75°C). However, due to their susceptibility to freeze-thaw conditions, instability to shear and acids, and potential retrogradation when meat products are refrigerated, native starches are of limited use in meat products. Therefore, starches intended for meat processing are usually modified, for example, through cross-linking, to minimize negative impacts associated with excessive swelling of starch granules, unwanted gelatinization, or other problems as indicated above.

Skrede (1989) compared different types of starch (potato flour, wheat starch, corn starch, tapioca starch, and modified potato starch with acetylated distarch phosphate) for their effects on textural and sensory properties of sausage. Total quality index, defined as sensory quality index (firmness, juiciness, etc.) minus percent cooking loss and liquid exudation, and long-term storage stability were found to be the highest for sausage with modified potato starch cooked to 75°C. This sausage also had a relatively large freeze–thaw tolerance. Pietrasik (1999) also noted reduced cooking loss and increased hardness of sausage formulated with 3–5% modified potato starch when compared with untreated sausage. Joly and Anderstein (2009) evaluated five modified starches for their influence on cooking yield, purge, and firmness of chicken rolls injected with 45% brine. The results showed that modified waxy corn starch was most effective in increasing the cooking yield while modified potato starch produced the greatest firmness in cooked products.

### 33.9 Enzymes

Several enzymes are used to improve palatability of fresh meat or textural characteristics of processed meat products. Bromelain, papain, and ficin are three proteases widely used to tenderize meat. They are extracted from the fruits of, pineapples, papayas, and figs, respectively. These plant protease extracts are commonly used in a marinade or directly sprinkled on uncooked meat prepared in restaurant and institutional settings. The enzyme will penetrate the meat and hydrolyze both myofibrillar and connective tissue (collagen) proteins, tendering meat upon cooking. Plant proteases are particularly useful for tenderizing tough muscles, such as beef chuck, and meat from mature animals in general. However, because these proteases are activated at cooking temperatures (50–70°C), the texture may become too “mushy” for slowly cooked meat due to overwork of the enzymes. Hence, care must be taken to avoid excessive proteolysis, for example, through controlling the marination and cooking times.

Other enzymes that have been approved for use to tenderize meat include those from fungi (*Aspergillus oryzae* and *Aspergillus niger*) and bacteria (*Bacillus subtilis*). Actinidin, a main protease present in kiwi fruit extracts, shows considerable activity against myofibrillar and connective proteins (Christensen and others 2009). The enzyme is activated at a lower temperature than is bromelain, ficin, or papain, making it easier to control the tenderization reaction in a marinade even at refrigerator temperatures. Ginger extracts also contain protease activity that is useful for tenderizing tough meat. Like bromelain,
ginger rhizome protease degrades collagen more than myofibrillar proteins and has an optimum temperature of about 60°C (Lee and others 1986).

Transglutaminase, an enzyme that catalyzes an acyl transfer reaction (Gln ε Lys) to form ε-(γ-Glu)-Lys isopeptide bonds within and between proteins (Figure 33.5), is used to promote protein functionality and bind meat particles in restructured products (Kuraishi and others 2001). The enzyme also catalyzes the hydrolysis of the γ-carboxyamide group in glutaminyl residues, resulting in deamidation. In muscle foods, where protein lysine residues (acyl acceptors) are abundant, the Gln-Lys cross-linking reaction prevails. While the enzyme can be extracted from a variety of natural sources, MTGase produced from Streptomyces mobaraensis has attracted the most attention. MTGase was introduced initially by Ajinomoto Co. to meat processing to facilitate the production of muscle protein gels and the “bind” in restructured raw meat, including fish fillets and nuggets. MTGase suits processed meats well as it maintains high activity over a broad pH, temperature, and salt concentration range.

A soft gel that can bind meat particles in raw, restructured meat can be formed by incubation of myofibrillar proteins with MTGase at refrigerator temperatures. To obtain a stronger gel, a small amount of caseinate (an excellent MTGase substrate) is generally added to aid in meat particle binding (Kuraishi and others 1997). When heated to 30–50°C, MTGase becomes highly activated. Therefore, for cooked meat products, nonmeat protein additives are generally unnecessary as long as a small amount of salt is added to ensure a minimal amount of soluble proteins (substrate) is available for the enzyme. With MTGase, myofibrillar protein thermal gels can reach an overall rigidity of as much as 10 times that of control (MTGase-free) gels (Ramirez-Suarez and others 2005) or MTGase-treated cold-set gels. This is true to both low- and high-salt protein or meat gels (Chin and others 2009). The enhanced gel rigidity (storage modulus) can be explained by the formation of thread-like cross-linking in MTGase-treated protein samples (Ahmed and others 2009). MTGase-treated myofibrillar protein and meat batter gels also exhibit improved water-holding capacity. Moreover, emulsifying activity of myofibrillar proteins, emulsion characteristics, and emulsion stability are markedly enhanced following MTGase treatment (Ramirez-Suarez and others 2005). This would explain why MTGase treatments in situ improve meat emulsion firmness and stability (Kawahara and others 2007).

33.10 Seasonings

Seasonings are ingredients that impart flavor to food and food products. Seasonings used in meat products, besides salt, include various spices (usually seeds) and herbs, for example, fennel seeds, paprika, cumin, nutmeg, oregano, mace, clove, garlic powder, onion, ginger, rosemary, sage, parsley, and white, black, and red pepper. Fresh sausage is the main user of seasonings, but the specific application depends heavily on the type of sausage, which varies between countries, regions, and cultures. For example, Italian fresh sausage is seasoned with red pepper to give it a hot, spicy taste, and Chinese winter sausage is seasoned with soy sauce to give it a umami savory taste. Spice and herb extracts are also used in many processed meats, as is liquid smoke.
Studies have shown that many spices and herbs possess antioxidant and antimicrobial activity, which is largely attributed to phenolic compounds. Kong and others (2010) compared 13 common spice extracts for their antioxidant activity, of which clove, rosemary, and cassia bark, which had the greatest total phenolic content, were strongly inhibitory of lipid oxidation in fresh pork during storage. Rosemary and licorice extracts were also shown to inhibit *Listeria monocytogenes* in fresh pork, cooked ham (Zhang and others 2009), and Swedish-style meatballs (Fernandez-Lopez and others 2005). Eugenol (from clove) was reportedly effective against *L. monocytogenes* on beef slices (Hao and others 1998). Spoilage microbes, particularly Gram-positive species, are also susceptible to antimicrobial spice and herb extracts. Therefore, spice and herb extracts can be used as alternatives to synthetic antioxidants due to their equivalent or greater effect on the inhibition of lipid oxidation as well as microbial growth in meat and meat products.

33.11 Nutritional and Health Ingredients

33.11.1 Vegetable Oils

Vegetable oils have been used as partial substitutes for animal fat in frankfurters and other comminuted meats to produce cooked products with nutritionally balanced fatty acid profiles and reduced cholesterol content. Ambrosiadis and others (1996) replaced fat (20% of product weight) in beef frankfurters with vegetable oils (soy, sunflower, cotton, corn, or palmine), reporting acceptable sensory properties in finished products. Youssef and Barbut (2010) indicated that for such formulated products, the stability of meat emulsion was critically influenced by fat/oil type and the level of soluble proteins. Unlike animal fat, vegetable oils are fluids, thus, difficult to immobilize. A common approach to producing a stable meat batter is to add preemulsified oils. Bloukas and others (1997) demonstrated that up to 20% of pork backfat could be replaced by olive oil in the form of an emulsion without negatively affecting the processing and quality characteristics of dry-fermented sausage. Muguerza and others (2001) also succeeded in manufacturing traditional Spanish sausage by substitution of preemulsified olive oil for up to 25% of pork backfat. The sensory characteristics, including texture and color, were comparable with those of traditional products. Rheologically, preemulsified vegetable oils, stabilized with a protein membrane, can be readily incorporated into the gel matrix in comminuted meats where the oil droplets are stabilized through protein–protein interactions and function as fillers to enhance the viscoelastic properties of cooked products (Wu and others 2009).

33.11.2 Natural Antioxidants

Because meat products are susceptible to lipid and protein oxidation due to the high-fat and prooxidant (heme, free iron, copper, etc.) contents, antioxidants have long been used in meat product formulations. Traditionally, butylated hydroxyanisole, butylated hydroxytoluene, propyl gallate, and tertiary butyl hydroquinone (TBHQ), at an application level not exceeding 0.01% of fat content when used individually or 0.02% if used in combination, have been used in sausage and other meats. However, the increasing concern with the safety of synthetic compounds has prompted the meat industry to replace synthetic antioxidants with those of natural origins. Of different plant-derived antioxidants, mixed tocopherols and rosemary extracts are the most widely used, and a myriad of basic and applied studies that consistently illustrate oxidative protection of sausage and meat emulsions by these natural ingredients have been published in scientific literature. In addition, as discussed earlier, antioxidative compounds present in many spices contribute to the oxidative stability and shelf life of cooked pork, beef, chicken, and turkey meat products.

Many peptides and protein hydrolysates have also exhibited antioxidant activity, hence, have been applied to muscle foods to improve oxidative stability. Carnosine, a dipeptide with the sequence of β-alanyl-histidine, and its related dipeptides anserine (β-alanyl-1-methylhistidine) were shown to strongly inhibit lipid oxidation and preserve the red color of fresh, salted ground pork (Decker and Crum 1991). Hydrolyzed casein (Diaz and Decker 2004) and potato protein (Wang and Xiong 2005)
were excellent inhibitors of lipid oxidation in raw and cooked beef patties. Similarly, when applied to cooked pork meat emulsions containing 15% or 30% fat, hydrolyzed potato protein at a 2.5% application level reduced lipid oxidation in the products by two- to four-fold (Figure 33.6). Because peptides and protein hydrolysates are water soluble, they can complement fat-soluble antioxidants, such as tocopherols and phenolic extracts from spices, to improve the oxidative stability of meat emulsion products.

### 33.11.3 Dietary Fibers

Plant ingredients rich in dietary fibers have been used in cooked meat products to improve textural properties and impart health benefits. Rice bran, rye bran, wheat bran, and oat bran added to comminuted and emulsified meat products have the ability to bind water and stabilize fat particles (Fernandez-Gines and others 2005). These cereal fibers are composed primarily of cellulose, hemicellulose, and lignin, which are insoluble polysaccharides. Claus and Hunt (1991) reported that oat fiber-containing bolognas were grainy and somewhat dry, but they had reduced purge when compared with nonfiber control. In addition, by-products of fruit juice processing, for example, citrus peel, and apple, peach, and orange pomaces, which are rich in pectin-type soluble fibers, are potential ingredients to modify the texture of sausage (Lantto and others 2006). However, because high amounts of dietary fibers increase the hardness of cooked sausage, their application level should be kept to low levels, for example, <2%.

### REFERENCES


