Ingredients and Processing Factors that Control Muscle Protein Functionality

Retaining water-binding, fat-binding, and gelation abilities of myofibrillar proteins is essential for achieving the desired textural properties of meat products

R.C. Whiting

□ FUNCTIONALITY OF PROTEINS refers to their ability to give the desired properties, whether defined in terms of biochemical interactions, analytical methods, or sensory characteristics. This article will focus on protein's role in meat product texture and the steps a processor can use to achieve the optimum functionality necessary for his particular product. Accepted practices as well as recent research will be discussed.

Functional Properties

Muscle proteins can be viewed as participating in three classes of interactions: protein-water, protein-lipid, and protein-protein (Acton and Dick, 1984). These basic interactions are characterized by the basic functional properties of water binding, fat binding, and gelation. They are measured by a variety of tests-e.g., water-holding capacity, extract release volume, fat binding, emulsifying capacity, and shear force. They are, in turn, described by industry terms, such as drip, yield, fat caps, and bite. None of these industry terms represent simple or independent properties. Increased protein-protein interactions in a frankfurter, for example, may improve firmness and simultaneously smokehouse yield and fat binding.

Different functional properties are important to different meat products. Bone-in hams and corned beef retain the muscular structure, and water binding is of primary importance. Increased water binding is usually desirable, but not in a dry-cured ham or fermented-dried sausage. Poultry rolls and restructured products require adhesion of meat chunks as well as water binding. Liver sausages require water and fat binding and a spreadable texture, whereas the proteins in frankfurters must bind water and fat and form a firm, elastic gel. Meat proteins are usually gelled by heat; however, in sausages, such as salami, the proteins are gelled by the combination of salt, lactic acid, and dehydration.

Processing Steps

The general sequence of processing steps to make meat products is: choosing and handling the lean meats and fatty tissues, grinding, adding spices, cutting, salting, curing (nitrite, nitrate, and/or ascorbate), fermenting, drying, smoking, cooking, shaping, and packaging. Individual steps are selected and controlled by the processor to create each meat product.

Excellent descriptions of the proteins' functionality at the molecular level were published by Acton et al. (1983), Ziegler and Acton (1984), Acton and Dick (1984), Jones (1984), and Regenstein (1984). Myosin (actomyosin in the postrigor state) is the muscle protein responsible for most of the textural properties of meat products. Myosin exists in a highly ordered and aggregated state in vivo. An ionic strength of about 0.6 is necessary to swell, hydrate, extract, and solubilize myosin or actomyosin. When binding meat pieces together, tumbling and massaging effectively accelerate this process, especially if under vacuum.

For frankfurters, chopping destroys cellular structure; the actomyosin is probably best characterized as a sol. Sarcoplasmic proteins are in solution, and connective tissue proteins are in suspension. Adipose tissue is then added and chopped until fat particles less than 200 μ are suspended in the water-protein matrix. Even though myosin/actomyosin can emulsify oil in model systems, the term "meat emulsion" is being replaced by "meat batter" to indicate the more complex nature of the system and to shift emphasis to the gelation and heat-setting behavior of the meat proteins. SEM micrographs show protein encapsulating the fat droplets and forming the surrounding matrix (Jones and Mandigo, 1982). The protein layer surrounding the fat must be strong enough to retain the fat yet flexible enough to withstand fat liquification and expansion during cooking.

Cooking causes protein unfolding and formation of an ordered, three-dimensional network stabilized by hydrophobic and hydrogen bonding. This formation of network has been hypothesized to involve first the aggregation of the globular head regions of myosin at 30–50°C followed by formation of a cross-linked gel by the tail section at temperatures above 50°C (Acton and Dick, 1984). To form a successful frankfurter, the processor must control a sensitive balance of protein interactions. Too little myosin extraction or protein-protein interaction results in excessive exudation and a mushy texture, but too much interaction can result in protein aggregation and batter failure. This batter and gel must contain the fat and water and retain the elastic texture through several cycles of solid-liquid fat transitions during smokehouse cooking, storage, freezing, and recooking in the home.

Having provided a general description of the process, this article will specifically discuss such steps as selection of meat ingredients, formulation, comminution, stuffing, and smoking and cooking.

● **Selection of Meat Ingredients.** Probably all skeletal muscle can be made into processed meat products. Currently, in the United States, poultry products are strongly challenging those made from beef and pork. Many workers are exploring the uses of minced fish and surimi (Lanier, 1985; Babbitt, 1986; Regenstein, 1986). The literature describes products made from mutton (Bartholomew and Osuala, 1986),

Author is Research Food Technologist, Eastern Regional Research Center, Agricultural Research Service, United States Department of Agriculture, 600 E. Mermaid Lane, Philadelphia, PA 19118

buffalo and goat (Kondaiah et al., 1985), water buffalo and sheep (Turgut, 1984), rabbit (Whiting and Jenkins, 1981a; Jolley et al., 1983) and reindeer (Roos and Paakkonen, 1986). Differences do exist between species just as differences exist between muscles within a carcass. Thermal transitions of fish proteins occur at lower temperatures than mammalian or avian proteins (Lanier, 1985). Fat and connective tissue contents must be considered; color depends on myoglobin content; and strong-flavored fats may need to be avoided.

Fresh meat with neither excessively low pH, including pale, soft, and exudative (PSE) pork from a rapid pH decline, nor excessive sarcomere contraction from cold shortening has good functionality. Water binding decreases with decreasing pH until the proteins' isoelectric point nears pH 5.2. Optimum gelation is at pH 5.5–6.0 (Acton et al., 1983; Whiting, 1984). Dark, firm, and dry (DFD) meat with a high pH and water-holding capacity may be advantageous in some products. Proper pre-slaughter handling of the animals and prerigor treatment of the meat are important to achieve the maximum amount of meat with a normal pH.

Frozen meat is not as good as fresh meat, but the former still has adequate functionality. This functionality is best preserved by using fast freezing rates, which increase juiciness and tenderness in ground beef patties because of smaller ice crystals, while slow freezing results in larger ice crystals and a tough and rubbery texture (Nusbaum et al., 1983). Constant storage temperatures (less than −20°C) slow growth of the ice crystals. However, even under optimal conditions, freezing is not a permanent preservation. Miller et al. (1980) showed significant declines in the functional quality during extended frozen storage (Fig. 1). It is frequently better to directly incorporate frozen meat into the product without thawing (Groninger et al., 1983).

Prerigor muscles have superior water-holding capacities and batter-forming abilities because their myosin is readily extractable at the higher pH values and adenosine triphosphate (ATP) concentrations (Marsh, 1981; Reagan, 1983). These properties are used in the pork sausage industry where the meat is immediately cut off the bones and processed into fresh sausages. Salt can be added to ground prerigor meat to temporarily preserve the high-functional qualities (Hamm, 1982; Park et al., 1987).

Mechanically separated or deboned meats are a major meat source in the poultry industry (Froning, 1981). In general, the processing properties of mechanically separated meats compare favorably to hand-boned meats (Field, 1981), although products containing too much mechanically separated meat have been described as having "less texture." The bone marrow content may improve processing properties by raising the pH and increasing the water-holding capacity, but higher iron, copper, and magnesium of bone marrow may reverse this gain. Expanded use of mechanically separated red meats is held back more by regulatory and acceptance problems than by technical ones.

Preblending refers to mixing salt into ground meat and then allowing time for protein extraction. When subsequently made into sausages or frankfurters, preblended meat has improved water- and fat-binding properties over meat that has just had salt added (Puolanne and Terrell, 1983a, b).

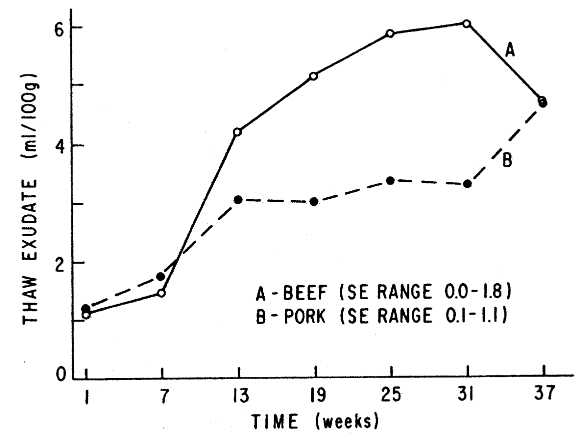

Figure 1—**Thaw Exudation** *from frozen meat*

High pressure (150 atmospheres)-treated meats show improved protein solubilization, water-holding capacity, and pattie-binding strength when subsequently incorporated into a product (Macfarlane and McKenzie, 1976; Kennick and Elgasim, 1981; Macfarlane et al., 1984). High pressure is most effective on prerigor meats. Berry et al. (1986) described the making of restructured beef steak from prerigor pressure-treated meat without use of salt or any other binding agent.

Low-frequency ultrasound (15 kHz) was found by Vimini et al. (1983) to increase fiber disruption and separation. Restructured beef rolls made from treated meat had improved cook yields and breaking strengths compared to unsonicated meat.

Electrical stimulation immediately post-mortem is widely used to increase slaughter-plant efficiencies and improve the quality of steaks (Pearson and Dutson, 1985). The process has little effect on the processing properties of the remaining portions of the carcass (Whiting et al., 1981; Terrell et al., 1981, 1982a,b; Swasdee et al., 1983).

Nonspecific proteases, such as papain, ficin, and bromelin, are used to tenderize steaks (Fogle et al., 1982). However, the objectives of recent protease research has been to specifically degrade connective tissues. Antemortem papain injection into chicken legs successfully degrades extracellular collagen (Brooks et al., 1985), but addition of microbial collagenases from sources such as clostridia has failed thus far to improve texture of beef steaks (Foegeding and Larick, 1986; Cronlund and Woychik, 1987).

Marinades with 1.5% acetic or lactic acids tenderize spent fowl drumsticks (Kijowski and Mast, 1986). Alkaline marinating with bicarbonate causes swelling and loss of adhesion between muscle fibers (Skurray et al., 1986). Acidified meat at pH 4.1–4.6 is described as being highly swollen and having increased water-holding capacity and tenderness (Gault, 1985).

• **Formulation.** Batter stability requires a minimum amount of added water (ca. 10%) for myosin extraction (Morrison et al., 1971; Whiting, 1984). An increasing concentration of meat proteins increases firmness, but too much increases rubberiness and dryness. Harder (more saturated) fats tend to increase the firmness of the frankfurter (Lee and Abdollahi, 1981; Whiting, 1987a). However, St. John et al. (1986) described good quality frankfurters manufactured with polyunsaturated vegetable oil and reduced amounts of animal fat. Collagen shrinks and becomes granular at 60°C during smokehouse cooking and, if the meat contains excessive amounts, causes poor yields and texture. At 80°C collagen gelatinizes and forms undesirable pockets of a heat-reversible gel (Wu et al., 1985).

Salt (NaCl) is essential for the creation of meat products (Sofos, 1986). Maximum water-holding capacity is with 0.8-1.0 M NaCl (4.6 to 5.8% salt) (Offer and Trinick, 1983), but 0.4-0.6 M is generally sufficient for good functionality (Trout and Schmidt, 1983). Frankfurters typically contain 2.5% salt (4.5% brine). Although quantities are frequently expressed in simple percentages, the percent brine expresses the salt concentration in the aqueous phase and more accurately reflects the proteins' behavior. Sofos (1983a, b) and Whiting (1984) show that reducing sodium chloride levels below 2.0% (3.5% brine) result in increased water losses and a softer and eventually mealy texture (Fig. 2). Only 0.5% to 0.75% salt is needed in fresh sausages and restructured products, but the salt is initially present in the thin extracted layer that binds the pieces together and, therefore, is at a much higher percent brine (Coon et al., 1983).

Other salts have been used in meat systems to reduce the sodium content (Seman et al., 1980; Terrell et al., 1981). Textural properties are generally good with monovalent cations, but they are destroyed by transition elements, probably because of excessive protein aggregation (Whiting, 1987b). These batters were mushy and mealy rather than elastic. Calcium and magnesium salts have been inconsistent in their actions in meats (Seman et al., 1980; Hand et al., 1982; Weinberg et al., 1984; Whiting, 1987b). Various anions and cations affected the water-binding potential, extractable moisture, and texture panel binding scores of minced fish loaves, but not in ways readily rationalized (Regenstein, 1984; Weinberg et al., 1984). The influence of various salts showed that protein functionality is dependent on the balance of interactions between protein, salt, and water. The specific functional properties needed in a particular product must be considered and tested for rather than relying on generalized recommendations.

KCl is the primary NaCl substitute used by the food industry and in general is functionally equivalent to NaCl in meat products at equal ionic strength. It has been substituted for NaCl in dry cured hams (Keeton, 1984), tumbled ham (Frye et al., 1986) restructured beef (Miller et al., 1986), bologna (Seman et al., 1980), and frankfurters (Whiting and Jenkins, 1981b; Hand et al., 1982). Many researchers have used 50% substitution of NaCl by KCl, but care must be taken that the bitterness of potassium does not become objectionable.

Phosphates are widely used to improve or retain protein functionality. The most common forms for use in meat products are sodium acid pyrophosphate (SAPP), tetra sodium pyrophosphate (TSPP), and sodium tripolyphosphate (STPP). The first reduces the pH of the meat product, and the latter two increase

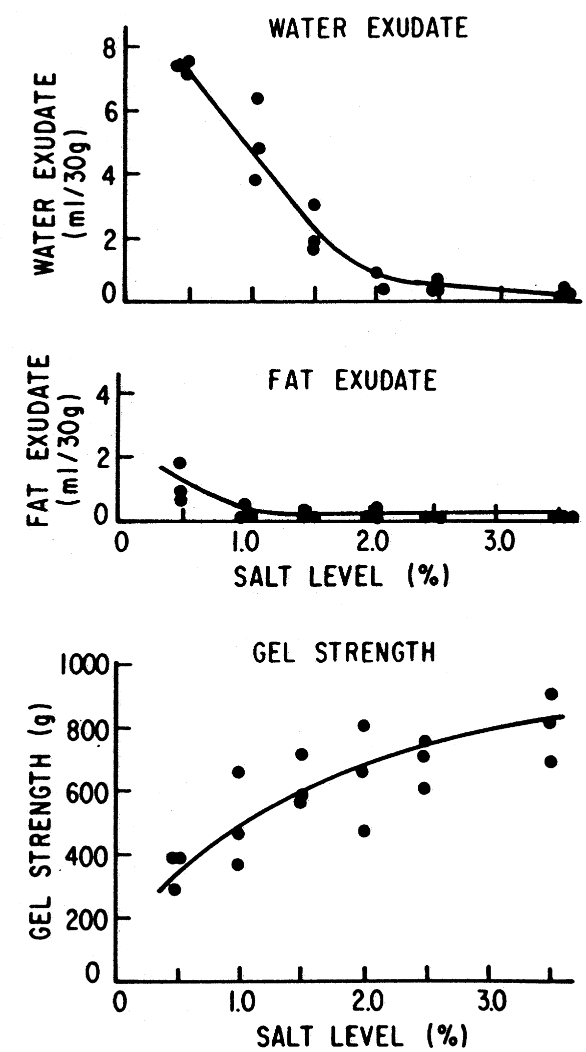

Figure 2—**Water Exudate, Fat Exudate, and Gel Strength** *of batters made with varying salt levels*

the pH about 0.2 units, which is frequently beneficial. TSPP is not readily water soluble and is more difficult to use in brines. Current regulations allow a total addition of 0.5%, but more than approximately 0.4% can give a metallic, astringent flavor. Potassium salts are also permitted.

Possible mechanisms for phosphates' effects include higher pH and ionic strength, interaction with specific proteins including dissociation of actomyosin by pyrophosphate, and chelation of cations. Trout and Schmidt (1983, 1986b) demonstrate that pH and ionic strength are most important; some synergism between the two mechanisms may exist—a pH of 6.0 and a total ionic strength of 0.6 is needed for satisfactory binding in a restructured product.

There is extensive literature on phosphates' effects in meat products. They increase juiciness, water holding, yield, binding, batter stability, and texture score. Recent examples of phosphates' uses in meat products include: chicken patties (Young et al., 1987), roasts (Smith et al., 1984), pork sausage (Matlock et al., 1984), mechanically deboned catfish (Burgin et al., 1985), restructured beef (Trout and Schmidt, 1984; Lamkey et al., 1986), and frankfurter batters (Madril and Sofos, 1985; Whiting, 1984). Sofos (1986) extensively reviews the use of phosphates in sodium-reduced meat products.

Binders are added to improve meat products, primarily by retaining water. Proteins, modified proteins, and carbohydrates can be chosen depending on the specific product and process. A sampling of recent literature demonstrating product improvement with protein includes soy in frankfurters (Terrell et al., 1979a), vital wheat glutin and egg white for binding meat pieces together (Siegel et al., 1979), plasma, egg albumin, soy and vital wheat glutin for binding (Terrell et al., 1982a), bone and plasma proteins in sausages (Caldironi and Ockerman, 1982), glutin, calcium-reduced skim milk and soy in frankfurters (Keeton et al., 1984), and mechanically separated beef, soy and vital wheat glutin in restructured steaks (Parks and Carpenter, 1987). Blood fractions have received attention because plasma proteins have excellent functional properties (Suter et al., 1976; Terrell et al., 1979b). The red blood cell portion is high in dietary iron but may accelerate oxidation and interfere with nitrite inhibition of *Clostridium botulinum*.

Protein modification includes acylation and hydrolysis. Acylation with acetic anhydride and succinic anhydride improves the poor emulsification properties of beef heart myosin (Eisele and Brekke, 1981). Protease-modified, mechanically deboned fowl restores the texture of salt-reduced frankfurters (Smith and Brekke, 1985). Soy protein hydrolysates lower the Aw and can replace salt in extending the shelf life of meat products (Vallejo-Cordoba et al., 1986). Watanabe et al. (1981) reports effective proteinaceous surfactants from gelatin by papain-catalyzed incorporation of leucine n-alkyl esters.

Carbohydrates used in meat products include sugars, glycerol, cereals, starch, and gums. Of particular interest is the use of calcium alginate for binding restructured meats (Means and Schmidt, 1986). This product remains cohesive at room temperature in contrast to salt/phosphate restructured products which must remain frozen until cooked. Iota carrageenan and carboxymethyl cellulose improve water-holding capacity and texture of frozen, minced cod (Ponte et al., 1985, 1986), and carrageenan is the most promising gum tested in low-salt frankfurters (Foegeding and Ramsey, 1986, 1987). Carbohydrates can potentially serve as cryoprotectants in meat products (Park et al., 1987). Surimi contains sugar and sorbitol for this purpose (Lee, 1986).

Food emulsifiers have not been successfully used in meat batters although Honikel (1982) reports that citric and lactic acid esters of mono- and diglycerides are effective. The HLB value (hydrophilic-lipophilic balance) of meat proteins is 14 (Eerd, 1971), but Tween 80, glycerides, and lecithin do not improve fat retention (Whiting, 1987a).

• **Comminution.** In the typical American frankfurter, no cellular structure and few intact myofibrils remain in the batter after chopping. Temperatures between 5–7°C are best for actomyosin extraction, and dry ice can be added to prolong the chopping time. Vacuum chopping improves stability (Tantikarnjathep et al., 1983) and avoids small air pockets that decrease textural strength (Mawson et al., 1983).

The completion of the comminution depends on temperature rather than time, although excessive chopping can destabilize the batter. Pork fat is chopped to 15.5°C; exceeding this temperature risks catastrophic failure. Poultry frankfurters are chopped to 11°C to 12°C and all-beef franks to 18°C. The more saturated beef lipids are harder and have higher melting points. A batter chopped above these temperatures can be recooled and regain part of its functionality (Deng et al., 1981). Significant correlation coefficients exist between the functional properties of water and fat binding and gel strength and the percentage of saturated, monounsaturated, and polysaturated lipids in blends of various lipids in lard (Lee and Abdollahi, 1981; Whiting, 1987a). Further research is needed regarding the protein-lipid interactions during batter formation (Jones, 1984). As an example, the momentary temperature of the batter at the knife edge is probably considerably higher than the recorded bulk temperatures and would locally liquify the fat.

Pre-emulsifying the fat with other proteins before incorporating it into the batter can assist the meat proteins in a low-salt or otherwise marginal batter in binding the fat. Schmidt et al. (1983) preblended pork fat for a canned luncheon meat batter with soy protein concentrate, and Lin and Zayas (1987a,b) used corn germ protein to pre-emulsify lard.

• **Stuffing.** Good batters can be pumped from emulsifier to stuffer without causing their failure. However, they should be promptly moved only short distances through a large pipe with no turbulence. Stuffing under vacuum produces a more dense product with better binding and texture than nonvacuum stuffing.

• **Smoking and Cooking.** The irreversible gelation of the myosin begins at 55°C and peaks at 80°C (Siegel and Schmidt, 1979). Water binding decreases as the cooking temperature increases from 60°C to 80°C (Puolanne and Kukkonen, 1983). Weight loss during thermal processing is proportional to the product temperature and to the protein-fat ratio (Mittal and Blaisdell, 1983). Low-salt batters, assuming no replacement, have increased water losses (Trout and Schmidt, 1986a).

The initial low-temperature portion of the cooking cycle dries the surface and applies the smoke. Both natural wood smoke and liquid smoke contain organic acids that assist in forming the skin. The relative humidity is increased with the temperature to prevent excessive moisture loss. Too rapid a temperature rise results in a weak gel with some fat separation onto the surface and small fat pockets where the frankfurters touch the support rods (Rust, 1976). Rapid contraction of the proteins with expanding and liquifying fat leads to rupture of the protein barrier surrounding the fat droplets.

Fermented and Dried Sausages

Ground meat is salted, fermented to lower the pH, and dried in the production of these products. Relatively little research has been done on their texture (Palumbo et al., 1976). The pH is reduced to less than

5.2 at a relatively slow rate in the products' final casing. Generally a microbial fermentation using a starter culture takes 1–3 days at 21–35°C. Glucono-delta-lactone has been used also as an acidulant to lower the pH (Jedlicka, 1984). Drying removes 10–45% of the initial weight over a period of a week to 3–4 months. Conditions of 45–55°C and 70% relative humidity are optimum. Too slow a drying rate may result in a moldy surface with spoilage in the center. Too rapid a rate creates a hard, dry surface that impedes further drying.

Trends and Research Needs

Myosin gelation is the principal factor for forming the textural properties of meat products. Considerable information on myosin interactions has been developed, but further understanding of the biophysical interactions is needed to control the manufacturing of existing meat products and to develop new products.

Meat processors have addressed the issue of making products with less sodium; however, current products still contain relatively high amounts. Fat reduction is currently the primary issue for fresh meat, and trimming fat off steaks and chops appears to be improving the consumer's image of red meats. Meat products are very vulnerable on this issue, although some products such as ham and turkey rolls have only 5% and 10% fat, respectively. There have been calls for mandatory nutritional labelling and a 40% fat plus added water standard for frankfurters. Reducing fat will probably require binding more water by proteins or complex carbohydrates while retaining good yield and texture.

Leading the marketplace are foods with high sensory appeal and convenience, and meat products are well suited to these demands. Nontraditional species, mixed species, nonmeat ingredients, and new kinds of meat products and packaging will be coupled with individual serving sizes and microwavability. Precooked products are already appearing in the supermarkets. Perhaps a glimpse into the future will see products made by continuous restructuring of mechanically deboned chicken by high temperature short time extrusion-cooking (Megard et al., 1985) and the freeze texturing of alkali extracted, acid precipitated, mechanically-separated chicken meat (Lawrence et al., 1986) or shrimp protein (Yang, 1987).

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