Optimizing Utility of Low Water-Holding Capacity Meats

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INTRODUCTION

What is "meat" and how is low water-holding capacity (WHC) meat characterized? Meat is edible tissue derived from livestock which contains varying amounts of moisture, fat and protein. The protein component is subdivided into sarcoplasmic, myofibrillar and stromal proteins based on solubility in neutral salt solutions. Because of health concerns associated with fat consumption and since passage of the "40% rule" in the United States that allows any combination of fat and added water so that the total does not exceed 40% and fat does not exceed 30%, there is a greater variety of fat-reduced products available to consumers. Products manufactured with 20% to 30% added water reinforce the importance of optimizing protein-water interactions in the meat component of the formulation, although technology of nonmeat water-binding agents has been successfully developed. In fresh and further-processed muscle foods, retaining inherent and added water is an extremely important economic and palatability trait.

In low-WHC meats, either the salt-extractable myofibrillar component becomes more dilute due to an increase in connective tissue or there is reduced functionality associated with the protein source and anomalies of post-mortem metabolism (Saffle and Galbreath, 1964; Wiley et al., 1979; Townsend et al., 1980; Nuckles et al., 1990). Saffle and Galbreath (1964) quantified salt-soluble (3% NaCl) protein from various meats and demonstrated differences in the amount of salt-extractable protein and differences in the amount of oil that could be emulsified by extracted protein. Percent salt-extractable protein and volume of oil emulsified were considered to develop bind values that are used as restraints in least-cost analysis. In many further-processed meats, low water-binding raw materials are used. Therefore, when used, it is particularly challenging to manufacture high added-water frankfurters, bologna, or "similar cooked sausages" with these raw materials.

Of the three categories of muscle proteins, the myofibrillar component is recognized for its significant contribution to water- and fat-binding and thus texture development in further-processed meats. Therefore, maximizing the WHC of this component is a priority, not forgetting the contributions to WHC by other components, in particular, the stromal components. The primary focus of this summary is how we optimize protein-protein and protein-water interactions in processed meats where low-WHC meats are a part of the formulation. In optimizing utility of low-WHC meats, one has to consider that the product application is for the raw material. The constraints of a precooked restructured meat system are quite different from those for a comminuted meat system.

SALT AND PHOSPHATE

During formulation, NaCl concentration gradients exist in raw products prior to thermal processing, particularly when there is a large variation in particle size. In meat batters, where particle size is uniform, manipulation of the raw batter will result in little improvement in product yield; whereas in restructured meats, physical manipulation is used to facilitate surface extraction of protein because the thermal gelling of these proteins is important for texture development. Length of muscle protein's exposure to NaCl is important because as the salt equilibrates, a less than optimum ionic strength may occur at the surface of the muscle chunks. Booren (1982) showed that after 12 to 18 minutes of mixing, there was a reduction in the myofibrillar protein in muscle exudate for products formulated with 0.5% NaCl.

The solvent environment during formulation and thermal processing dictates myofibrillar and stromal protein behavior in processed systems. The pH and ionic strength of the aqueous phase of a meat system should be considered first (Whiting, 1988). Meat proteins are categorized as sarcoplasmic (0.1M KCl), myofibrillar (0.5M KCl), and stromal (insoluble) based on their solubilities in neutral salt solutions (Szent-Gyorgi, 1960). High ionic strength (>0.5 IS)

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soluble proteins are primarily responsible for the water and fat binding properties. However, protein-water interactions to the point of dissolution may not be a prerequisite for functionality, as demonstrated by Gaska and Regenstein (1982) in which an insoluble portion was shown to participate in fat emulsification. Trout and Schmidt (1984) have shown, in restructured systems where ionic strength is not high enough to elicit solubilization, adequate bind and cook yields can be achieved. A constraint for using optimal salt levels is that the level of NaCl used in meat systems is precluded by what consumers consider palatable. One way to address this challenge is through preblending, a process whereby the lean block of a sausage product is mixed with all of the salt. This mixture might be held for 8-24 h and subsequently blended to an acceptable salt level with the remaining raw material. The combination of high ionic strength and prolonged exposure time maximizes protein-water interactions and facilitates more efficient use of the myofibrillar component.

Kenney and Hunt (1990) investigated the effect of water and salt content on protein solubility and water retention in meat preblends. They found that an aqueous phase concentration of 5.8 M caused the largest protein dissolution and water retention. Additionally, as a larger portion of the water was preblended with the meat and salt, more water was retained following centrifugation. Although the *M. semimembranosus* used is not considered low-WHC meat, it demonstrated that preblending a high connective tissue (CT) meat may enhance its water-binding abilities if some residual myofibrillar component is present. This would be the case for shank CT that had been removed with a mechanical disinewer. Ranganayaki et al. (1982) monitored the hydration of native and freeze-dried bovine hide collagen. Six percent NaCl increased hydration in the pH range 6-8, but at pH values lower than 5 and greater than 8, NaCl reduced hydration. They also found that polyphosphate salts depressed hydration of freeze-dried collagen from pH 6 to pH 8.

Phosphates enhance functionality of the myofibrillar component in processed meats (Trout, 1983). These ingredients have elicited their effects by increasing pH and, to a lesser extent, ionic strength. One of the proposed mechanisms whereby phosphate elicits greater protein-water interactions in muscle is through chelation of metals. However, Inklaar (1967) reported that phosphates do not complex with calcium bound to meat proteins. Their results indicate that approximately 60% of the calcium and 20% of the magnesium are firmly bound and are not available for reaction with phosphates.

HIGH COLLAGEN MEATS

Whiting (1989) indicated that modest amounts of collagen improve the firmness and elasticity of comminuted meats; however, too much can cause batter instability, resulting in moisture and fat losses during processing. Raw materials used in processed meats contain varying amounts of collagen. Wiley et al. (1979) evaluated the connective profiles of 21 sausage raw materials. They reported a significant negative correlation between the amount of soluble collagen and the water and fat-binding properties of the raw material. Total collagen was 9.7 and 25.3 mg/g for pork heart and beef cheek meat, respectively. These ingredients were examples of low- and high-collagen raw materials evaluated.

Because meat contains varying amounts of the three protein categories, it is important to consider how each group responds to temperature, pH and ionic strength. Further-processed meats are cooked to 68° to 72°C. They typically would have a pH 6.2-6.4 and an aqueous phase NaCl concentration of 3.3-4.2. Stromal proteins, primarily collagen, and myofibrillar proteins, primarily myosin, actin and actomyosin, respond differently to temperature, pH and ionic strength. Collagen is insoluble in neutral salt solutions; however, solubility increases as a function of heating. Myofibrillar proteins gel as a result of thermal denaturation and thus become insoluble. In high connective-tissue meats, moist heat cookery is recommended to take advantage of the tenderization that occurs as a result of hydrolysis of collagen.

In recent work (Kenney et al., 1992a; Eilert et al., 1993; and Letelier et al., 1995), the product application, the particle size of the connective tissue material, and pretreatment with heat are important considerations when using high-collagen raw material in processed meats. The serving temperature of the product would dictate the ultimate utility of the raw material. Gelatin resulting from collagen hydrolysis would bind considerable water and form a cold-set gel that remelts at approximately 50° to 55°C. The processor could take advantage of this functionality in comminuted products that are served chilled such as bologna; however, it may not work as well in products that are reheated prior to serving, such as frankfurters and some restructured roast beef items.

Kenney at el. (1992a) demonstrated that various collagen products (commercial gelatin, raw and preheated epimysium) would enhance the textural integrity of precooked, restructured beef (5% fat, 0.2% NaCl). In an earlier study, Kenney et al. (1986) reported that 0.4% sodium tripolyphosphate (STPP) reduced the solubility of native wet-hide collagen when thermal hydrolysis was used to increase solubility. Gelatin, produced as a result of thermal hydrolysis, would have an isoelectric point near 9.0; therefore, the increased pH associated with phosphate may explain why phosphate depressed gelatin solubility for a 100% native-wet-hide-collagen system. The pH of this system was 8.38. Ladwig et al., (1989) investigated the effects of collagen and 0.4% STPP on chopping time, emulsion stability and protein solubility of fine-cut meat systems. Adding collagen to meat emulsions resulted in shorter total chopping time, and decreased emulsion stability. When phosphate was used, the high collagen/phosphate treatment has less fat, gel-liquid, solid and total cookout compared to the phosphate or low-collagen/phosphate treatments. Unfortunately, in this study there was no treatment to account for STPP's effect on the myofibrillar component. It appears that the increased functionality of the high collagen/phosphate treatment was associated with STPP's effect on the myofibrillar component and not the stromal component, specifically collagen.

When high-collagen raw material is used in processed meats, particle size affects functionality. Kenney et al. (1992a) obtained epimyseal connective tissue, froze the raw material, subsequently sawed the frozen raw material into 2-3 cm cubes, and pulverized the material using liquid nitrogen. When mixed with muscle chunks for restructuring, the raw material appeared as "hair-like" fibers. These products were cooked to 64.4°C, and 5% to 10% raw connective tissue was not detrimental to product textural traits. Preheating epimyseal connective tissue to 60°C was detrimental to appearance without an improvement in bind. Any myofibrillar or sarcoplasmic protein associated with the CT would have been denatured to some extent, not to mention that this temperature was not high enough to cause any collagen gelatinization. Adding 10% raw CT increased cook yields, suggesting that added connective assisted in the water-binding properties of the product. Eilert et al. (1993) used connective tissue obtained from hindshanks in meat batters. These researchers processed this connective tissue by grinding it through a double-plate grinder at -2° to -4°C and subsequently flaking it with an Urschel comitrol (1.5 mm). This ground and flaked material was stored (-32°C) until used. They observed, in agreement with Kenney et al. (1992a), that increasing levels of modified connective tissue reduced thermal processing losses without reduced batter stability. Letelier et al. (1995) similarly obtained CT from a commercial desin-ewing operation. The sinew in this work was not preground prior to flaking and these investigators evaluated two particle sizes in a cooked salami as opposed to a batter-type product for Eilert et al. (1993). Letelier et al. (1995) observed that yields decreased as flaked sinew increased; however, these treatments did have less purge. The latter observation may have been a function of either less water in the product or the ability of thermally-hydrolyzed collagen to bind water.

Defects such as poor peelability, gel pocket formation and wrinkling have been associated with using too much of these high-collagen ingredients. Jones (1984) indicated that when tripe was used, at levels up to 40% of the formulation, in bologna (30% fat) that smokehouse yields were reduced and the product became more "brittle." This study in combination with Eilert et al. (1993) suggests that the product fat and water levels may be important considerations when using high-CT raw materials in processed meats. Eilert et al. (1993) showed that as the fat level increased, modified connective tissue increased batter stability. The difference in utility of either tripe or physically-modified connective tissue appears to have been associated with the physical form of addition.

Other industry co-products that would have reduced water-holding capacity are partially-defatted pork fatty tissue and partially-defatted beef fatty tissue. For these products, raw materials, prior to low-temperature rendering, must have at least 12% visible lean. The finished material, following low-temperature rendering, contains 70% moisture, 20% protein and 10% fat. Although Breedlove and Brown (1991) reported that a parallel separator is used to remove connective tissue form the raw material, considerable collagen would remain, given its role in the connective tissue framework of adipose tissue. The temperature of fat-reduced beef would not exceed 42° to 49°C during the rendering process; thus minimal thermal denaturation would have occurred in the connective tissue component of this material. As with other CT materials, particle size would be an important consideration for optimizing utility of the raw material.

ORGAN MEATS

Another source of low-WHC meats are organ meats from the beef, pork and lamb packing industry. When Saffle and Galbreath (1964) quantified the protein soluble in 3% NaCl of various types of meats, beef and pork hearts had high solubility, second only to pork cheek meat. Although connective tissue was not high, relatively speaking, heart meat had lower bind values. Nuckles et al. (1990) investigated meat by-product protein composition and functional properties. They performed low ionic strength (0.05M sodium phosphate buffer, pH 7.4) and high ionic strength (0.6M NaCl, 0.05M sodium phosphate buffer, pH 7.4) extractions with the remaining residue designated as insoluble. Additionally, total collagen was determined. The reheat yield of the cooked batter (30% fat, 56% moisture and 2% NaCl) was positively correlated with the amount of the high ionic strength fraction and the percentage of myosin and actin in this fraction. Cook yields were 91.2% and 93.7% while reheat yields were 69.8% and 82.6% for pork lung and beef hearts, respectively. The pork lung had the highest collagen when expressed as a percent of the total protein. In optimizing the utility of these low water-holding capacity meats, this study again points to the significance of the proportion of collagen in the raw materials. Those raw materials with the lowest reheat yield had the lowest actin:myosin ratio as well as less myosin than either beef heart or mechanically-deboned chicken. In these products, heating to 72°C was sufficient to hydrolyze or partially hydrolyze collagen to gelatin, which in turn could serve as a cold-set binder. However, when reheated (95°C, 10 min.), the gelatin gel would readily melt and be lost during the process, contributing to the decreased reheat yield.

Nuckles and Smith (1991) evaluated skeletal muscle (*M. semimembranosus*) and beef lung, spleen and hearts in a model system batter. They reported a positive correlation of high ionic strength soluble protein and myosin with reheat yield and structural integrity of the product. Substitution of skeletal meat with spleen resulted in the most detrimental effects on model system traits. The apparent strain and stress at failure were lower for formulations containing spleen compared to lung. The formulation containing 44% heart, compared to the 100% skeletal muscle, had less of the high ionic strength fraction and more of the insoluble fractions. Nonetheless, the reheat yields and myosin concentration, as a percent of high ionic strength portion, were very similar. They suggested that the reason substitution of heart resulted in little reduction in batter strength compared to the control was because of the high myosin concentration in these formulations. Jordan (1994) investigated preblending treatments to improve the binding ability of heart meat. She demonstrated that preblending improves water-binding of heart meat as observed by higher cook yields. She also showed that, in 10% fat bologna, up to 45% cardiac muscle may be added without compromising the texture of the product when this raw material is preblended.

The surimi-washing process has been investigated as a potential means to alter raw material composition and thereby improve the functionalty of under-utilized co-products, particularly cardiac muscle. Kenney et al. (1992b) evaluated this process to improve the function of beef hearts as a binding adjunct in low-fat restructured beef. This material was compared to fish surimi, and a washed skeletal muscle counterpart. The binding adjunct was presalted (4% NaCl) and the muscle chunks were blended with tetrasodium phosphate (0.5%) and held for 12 h prior to formulation. Preblended binder (5%) and muscle chunks (95%) were subsequently combined. Muscle washing improved the utility of cardiac muscle. The authors suggested that this may have been associated with removal of certain less functional water-soluble proteins or alterations in the composition of mono- and divalent cations present in the binding adjunct.

OTHER FACTORS

Cations and water-holding capacity.

In situ, divalent cations, particularly Ca^{2+} and Mg^{2+}, are intimately involved in the interaction of muscle proteins. Hamm (1985) indicated that calcium binds to meat, decreasing myofibrillar swelling and thereby increasing extracellular space.

There are data which suggest that a portion of the myofibrillar component is insoluble. In exhaustively washed chicken breast muscle, Gaska and Regenstein (1982) found a portion of the myofibrillar component remains insoluble. Regenstein (1988) reported that there appears to be a portion of myosin and actomyosin that is insoluble, regardless of pH and IS of the aqueous phase. Nuckles and Smith (1991) reported that when heart meat was used to replace 44% of the skeletal meat, the insoluble protein fraction increased; however, as a percentage of the high ionic strength fraction, myosin remained relatively constant. Initially, one may surmise that an increase in the insoluble fraction was associated with increased connective tissue. This does not appear to be the case because Wiley et al. (1979) showed that, pork hearts contained 7.6 mg/g total collagen compared to 24.3 mg/g for pork blade meat and cheek trim. Thus poor bind values for beef and pork hearts may be associated with an increased insoluble myofibrillar fraction. Kenney et al. (1992b) suggested that improved functionality associated with washing cardiac muscle was associated with altering the amount of sodium, iron, magnesium and calcium. These cations were decreased by washing, except calcium, which increased 2-3 fold. In a later study, with mechanically-separated pork, Wimmer et al. (1993) observed an increase in calcium for washed MSP. They suggested that this was due to the ability of numerous membranes and proteins to bind calcium. Depending on how well the co-product and other skeletal muscle raw material sequester minerals and how much mineral is in the water, the uptake of minerals may be a significant variable to consider when evaluating procedures to improve the utility of low water-holding capacity meats.

The effect of various cations is associated with muscle type (Xiong and Brekke, 1991; Xiong, 1994; Nayak and Kenney, 1995). Xiong and Brekke (1991) demonstrated very different responses to $CaCl_2$ and $MgCl_2$ (100 mM) for myofibrils from chicken breast and thigh muscle. They found that these salts were generally detrimental to breast myofibril gel strength and water-holding capacity; however, both divalent salts enhance leg muscle myofibril gelation and water-binding properties. Nayak and Kenney (1995) reported that myosin solubility of turkey breast and thigh muscle responds differently to $CaCl_2$, $MgCl_2$, and $ZnCl_2$ (4-7 mM) as a function of NaCl concentration (0.13-0.85 M). Zinc chloride inhibited myosin solubility at 2 and 4% NaCl. Magnesium chloride elicited the greatest increase in actin and myosin solubility for thigh muscle at a high ionic strength (1.1). Breast muscle myosin was not affected by $CaCl_2$ or $MgCl_2$; whereas; breast actin was increased by 88% and 36% for $CaCl_2$ and $MgCl_2$, respectively. Young and Lyon (1986) evaluated effects of 4 mM $CaCl_2$ on water retention properties of chicken breast in the presence of 0.2 M NaCl and 8.2 mM STPP. Calcium chloride increased WHC and protein solubility associated with extraction of ground breast meat by STPP and a combination of STPP and NaCl. Young et al. (1991) evaluated effects of 0.2 M $CaCl_2$, 0.2 M $MnCl_2$, 0.2 M $MgCl_2$ or 0.6 M NaCl on the water-binding properties of chicken breast fillets. Moisture absorption and cooking losses were greater for prerigor fillets treated with divalent cations than for those treated with sodium ions. Regenstein and Stamm (1979) reported that WHC of trout muscle was not affected by calcium or magnesium ions. These ions depressed the increase in water-holding capacity associated with sodium pyrophosphate in lobster muscle. With the exception of reports by Xiong and Brekke (1991), much of the data that exists with regard to the role of divalent cations in the water-binding properties of meat is for relatively high concentrations. Millimolar levels of specific cations can enhance protein-water interactions; however, more research is needed in this area as it relates to the water-binding properties of low-WHC meats.

Pale, Soft and Exudate (PSE) muscle

An additional factor, characteristic of the skeletal meat raw materials, that can affect muscle food protein-water interactions is rigor state and thus pH. Anomalies of postmortem metabolism can either reduce (PSE) or enhance (dark, firm and dry; DFD) a muscle's ability to interact with water due to rate and degree of pH decline. PSE muscle is usually associated with a metabolic anomaly in pork as opposed to beef or lamb, and the muscle is characterized as pale and soft with a watery appearance. It is characterized as muscle that undergoes rapid glycolysis in the early post-mortem period while carcass temperature is high. This combination of lactic acid build-up and high temperature causes protein denaturation that is detrimental to protein-water interactions in this muscle.

As a raw material, PSE muscle is associated with reduced processing yields. Fermented sausages with PSE pork, normal pork and a 50/50 combination of each type were manufactured by Townsend et al. (1980). Water-holding capacity, water activity, and shear force were lowest for products manufactured with PSE pork. They reported that the PSE product was grainy, crumbly and lacked cohesion or bind, resulting in poor consistency and slicing qualities. The authors neither preblended nor indicated if they used phosphate; however, in the poor-binding PSE products, the use of phosphate and/or preblending may optimize the extractability of muscle proteins in these products. Perhaps these formulation changes would have brought the textural traits up to those for the "normal" treatment. Although the higher moisture diffusion rate may be advantageous for the production of dry sausages, unacceptable texture development precludes this processing trait advantage.

SUMMARY

Several variables alter utility of low-WHC meats, most notably temperature, pH, ionic strength and composition, and physical manipulation. The magnitude and nature of their effect is a function of the type and source of the raw material, specifically the level of myofibrillar and stromal proteins. Proteins of organ meats, such as liver and spleen, will have gelling characteristics dissimilar to myofibrillar and stromal protein. The myofibrillar component is most significant because of the amount present and its superior functional traits.

Because of trends to replace fat with water in processed meats, one has to consider the thresholds within the system relative for protein type and concentration where maximum protein-water interactions can be achieved that result in acceptable product yields and textures. This information would facilitate more efficient use of low-WHC meats as raw materials and warrants additional research.

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