

**Textural and Physical Properties of Fat-Free
Turkey-Beef Frankfurters: Effects of Non-Meat
Ingredients and End-Point Temperature**

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Thesis submitted to the Faculty of
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Food Science and Technology

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December 4, 1998

Blacksburg, Virginia

Key Words: fat-free frankfurter, salt, milk protein, added water, end point temperature

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ABSTRACT

The effects of NaCl (1 and 2%), added-water (AW; 30 and 40%), milk protein hydrolysate (MPH; 1, 2 and 3%), and end-point cooking temperature (EPT; 71.1 and 76.7 °C) were examined. Regardless of the formulation, all turkey-beef frankfurters contained less than 0.4% fat. As levels of NaCl in the formula increased, the frankfurters had lower ($P < 0.05$) penetration values (total energy and peak force) but higher shear stress and shear strain. In addition, higher salt levels resulted in lower cooking loss, moisture content, protein content, and darker frankfurters. Increasing AW level reduced ($P < 0.05$) penetration values (total energy and peak force), shear stress, shear modulus, and hardness but increased cohesiveness. Higher levels of AW not only resulted in higher ($P < 0.05$) moisture content but also resulted in higher cooking loss and purge loss. Higher AW products were lighter ($P < 0.05$) in color and less red. Increasing the amount of MPH increased ($P < 0.05$) shear stress and shear modulus but lowered shear strain. Higher MPH reduced cooking loss and produced ($P < 0.05$) darker, more yellow, and less red frankfurters. Higher EPT increased ($P < 0.05$) cooking loss, shear stress, and shear modulus but decreased penetration values (total energy and peak force), shear strain, and cohesiveness. Higher EPT produced lighter ($P < 0.05$) colored frankfurters. There were some two and three-way independent variable interactions ($P < 0.05$) for shear stress, shear strain, and cohesiveness. Of the four independent variables evaluated, AW and EPT most influenced textural properties. By using various combinations of these four independent variables, meat processors would have the ability to improve the quality characteristics of fat-free frankfurters.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude and respect to my advisor Dr. James R. Claus for his ideas, patience, and advice throughout my Master's program. I am thankful for his willingness to take the time to make suggestions and help me achieve my goals. His support, guidance, and encouragement were most appreciated.

Thanks are also expressed to the members of my committee, Dr. Paul P. Graham and Dr. Joseph E. Marcy. I would like to thank all of the graduate students and technicians that assisted in this research. In particular, I am grateful to Dr. Hengjian Wang for his assistance on the statistical analysis and laboratory techniques and Mrs. Harriet Williams for her help in contacting the turkey companies in order to obtain the samples.

Many thanks go to my close friends who helped on several days of manufacturing in the lab from dusk till dawn. Finally, I would especially like to thank my parents for their love, financial support, and encouragement that they have given me throughout my academic career.

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Chapter 1

INTRODUCTION

Currently, consumers are not only interested in quality products which taste good and are convenient but also in the nutrition, safety and wholesomeness of the foods they consume. Thus, diet and health advice serve as a driving force to redirect the types of food considered to be most beneficial in terms of improved health and quality of life for Americans. The amount of fat and cholesterol in the food, especially from meat products has become the major health conscious consumer's topic (Ghazi, 1991). The growth and development of low/no-fat processed meat products are strongly linked to consumer demands for healthier foods. Concern over fat and sodium in the diet has caused meat processors to assess the effects of fat and salt reduction in sausage products (Matulis et al., 1994).

Commercial products can vary from 21 to 26% fat. Frankfurters have been prepared with the fat content varying from 23 % to 10 % by replacing fat with water (Mittal and Barbut, 1994). These products offer the greatest opportunity for fat reduction by reformulation with fat substitutes. However, flavor intensity, juiciness, and tenderness of meat products were directly related to the fat content. Consequently, the reduction of fat decreased the overall acceptability of meat products (Mittal and Barbut, 1994). Upon development of products to meet the consumer expectations, many functional ingredients and fat replacements have been studied. Fat replacements should contribute a minimum of calories to a product and should not be detrimental to its sensory qualities.

Low-fat processed meat products are defined as 3 grams of fat per Recommended Amount Customarily Consumed (RACC) and less than 0.5% fat in no-fat products (Miles, 1996). For products with a 55 gram RACC such as frankfurters, the maximum fat content is 5.45% in low-fat and 0.9% fat in no-fat frankfurters (Miles, 1996). The physico-chemical and textural attributes of various low fat ground and emulsified products have been studied. Reduced fat meat products may have less desirable flavor and texture attributes than the traditional products. Attempts, with some success, have been made to retain sensory and textural attributes through fat reduction by selecting leaner meats and by replacing fat with water (Claus, et al., 1989), monosaturated oil

(Marquez et al., 1989; Park et al., 1990), carbohydrate-based fat substitutes (Berry and Wergin, 1990), protein-based fat substitutes (Reitmeier and Prusa, 1991).

Water added to replace fat prevented undesirable textural changes associated with low-fat products. According to USDA (1988) guidelines, water may replace fat in the formulation on an equal weight basis. The “40-PERCENT” RULE (USDA, 1988), which permits addition of any combination of fat (not to exceed 30%) and water equal to 40%, has been used to formulate the low fat products. Claus et al. (1989, 1990) studied the effects of substituting added water for fat on textural and sensory properties of bologna. Cooking and purge losses increased as fat content was decreased and added water content was increased. Low fat, high-added water bologna was generally less firm, more cohesive, juicier, and darker than a 30% fat-10% added water control, if the protein content was similar (Claus et al., 1989).

Sodium chloride is a principle ingredient in producing processed meat due to its flavor, preservative, and protein extractability. Comminution of meat in the presence of sufficient salt induces a partial extraction of the myofibrillar protein components (Acton et al., 1983). Reduced salt content decreases protein extraction and water binding in addition to changing palatability attributes such as saltiness, flavor intensity, and juiciness (Schut, 1975). Some water binding properties that may be lessened by salt reduction may be partially compensated by adding other non-meat ingredients such as milk protein and starch. The combination of starches and/or proteins appear to provide a useful means of replacing a notable portion of fat in meat products (Keeton, 1992).

Milk proteins act as emulsifiers and water/fat binders in the comminuted meat products (Mortensen, 1986). The effect of different milk proteins on the quality of comminuted meat products has been investigated (Baardseth et al., 1992). Milk proteins have been widely used for their positive water binding properties in uncooked meat batters. Ellekjaer et al. (1996) reported that sausages (20% fat) with 1.5% milk protein had minimum cooking loss but were not similar in sensory quality to the control (20% fat, no added milk protein).

Few studies have systematically identified the most appropriate combinations of starch, non-meat protein, and salt for producing fat-free or no-fat processed meats. Such studies are important because the behavior of an ingredient may be influenced not only

by varying concentrations of other ingredients or additives, but also by the medium in which it functions (fat, water and protein level, and ionic strength).

Storing the batter for a longer time may offer a possible alternative for improving water binding and protein-protein interaction in the no-fat sausage production because of increase in protein extraction, solubilization, and protein-protein interaction. Claus et al. (1990) found that massaging ground meat batter resulted in a slight increase in hardness and moisture retention. However, extended mixing had minimal effects on yield, purge, and texture (Sylvia, 1994).

Most investigations on comminuted sausage demonstrated that thermal processing played a critical role in quality and texture. Siripurapu et al. (1987) found that during the cooking step, coagulation of myofibrillar proteins occurred on heating at 30 to 40°C (coagulation was complete at 55°C). By the time meat temperature reached 60°C, the majority of the sarcoplasmic and myofibrillar proteins were denatured. The denaturation was accompanied by decreased water holding capacity and increased rigidity (Siripurapu et al., 1987). Matulis et al. (1994) reported that when increasing end-point cooking temperature, Instron hardness, shear force, sensory hardness increased while water holding capacity and juiciness scores decreased with increasing end-point cooking temperature. However, an end-point temperature effect on no-fat frankfurters has not been reported.

Because of the need to meet the consumer acceptability and expectations of no-fat turkey-beef frankfurters, the objectives of this study were to determine the effects of non-meat ingredients such as added water (USDA AW: 30, 40%), sodium chloride (1, 2%), milk protein hydrolysate (1, 2, and 3%), and cooking end point temperature (71.1 and 76.7°C) on the texture and physical properties in of these products.

Chapter 2

LITERATURE REVIEW

2.1 Low/no-fat meat products

2.1.1 Meat Consumption trends

According to the standards established by the National Heart, Lung and Blood Institute, about half of Americans have a cholesterol problem (Crawford, 1991) and the number one cause of death among adults in the USA is coronary heart disease (CHD). Diet and health advice serve as a driving force to redirect the types of foods considered to be the most beneficial in the terms of improved health and quality of life. Consumers now have established some consumption trends towards selection of lean cuts of red meat, use of low-fat cooking methods, removal of visible fat, and increased purchase of fish or skinless poultry (Keeton, 1994). Many consumers are advised to trim down the fat level in their favorite foods and appropriately eat healthier foods that are introduced into the market. From 1970 to 1991, total beef consumption declined 19.9% but consumption of hamburger or ground beef increased by 23.2% from 10 to 13 kg per capita (Keeton, 1994). Regular raw ground beef normally contains 26.6 g fat per 100 g edible portion (USDA, 1985). However, Savell et al. (1991) reported that on the average ground beef at the retail level had a fat content of 20%. Because of the excess fat content in ground beef, opportunities exist to significantly reduce fat consumption by reformation or substitution of the fat in the meat products (Keeton, 1994).

2.1.2 Definition of low/no fat meat products

Miles (1996) reported that low-fat meat product is defined as 3 grams of fat per Recommended Amount Customarily Consumed (RACC) or serving size. However, low-fat products can have a slightly different fat content depending on product category and RACC. RACC normally varies according to product category (Miles, 1996). For instance, the RACC for a frankfurter is 55 grams, and therefore the maximum fat content for a low-fat frankfurter is 5.45% fat. The RACC for breakfast strips is 18 grams, but because of the low serving size (30 grams or less), USDA requires 3 grams of fat or less

per 50 grams. Thus, the maximum fat content of a low-fat breakfast strip is 6%. Raw cuts of meat have a comparatively large RACC of 114 grams so the low-fat raw cuts of meat must have no more than 2.63% fat. Thus, the RACC is a critical parameter in determining a no-fat claim (Miles, 1996). The fat grams per RACC and serving size of no-fat meat product must be 0.5 grams or less. For a product with 55 grams RACC like frankfurters, the actual percentage of fat content can be as high as 0.9% fat. But the same fat percentage on the turkey breast with a RACC of 114 grams would not support a fat-free claim (Miles, 1996). In addition, lean product is defined as less than 10 grams of total fat, 4 grams saturated fat, and 95 mg cholesterol per reference amount or per 100 grams. According to the USDA (1995), processors that reduced fat in cooked and fermented sausages, fresh pork sausage and ground beef products, can still label them by their traditional names (in combination with reduced-fat qualifiers and if certain restrictions are followed) and use the terms defined in the regulations such as “Lean”, “Reduced-fat”, and “Low-fat” (Keeton, 1996). Moreover, the modification from the standardized or traditional sausages must be explained on the ingredient statement with an asterisk (Keeton, 1996).

2.1.3 The low/no-fat product-challenges

There are multiple challenges in formulating low/no-fat sausages. Most research efforts have focused on improving the textural characteristics. Replacing fat using a variety of ingredients such as starches, carrageenan, milk proteins and gelatin have demonstrated some degree (Keeton, 1996). Some low and no-fat sausage products are classified as modified food products if they contain ingredients that would be precluded or restricted in the traditional products. To qualify for a modified food product, the precluded or restricted ingredient must be used to replace fat and must be GRAS (Miles, 1996). Miles (1996) found that flavor balance was a problem with low/no-fat versions of traditional cooked sausages such as smoked sausage, frankfurters and bologna since the aromatic herbs and spices tend to taste artificially stronger in the absence of fat. In addition to addressing flavor, texture, and appearance challenges, the formulation must also address shelf life challenges. Low/no-fat processed meat essentially replaced fat

with non-meat ingredients and water. The additional water would lower the salt concentration and may reduce the shelf life.

2.1.4 Development of low/no-fat sausages and frankfurters

Giese (1992) reported that two recent amendments to the standards of identity for frankfurters and other similar cooked sausages have produced and will continue to produce major changes in how these products are formulated (USDA, 1988; 1991). The first ruling was designed to make the regulations less restrictive against the development of the low-fat processed meat products. According to the USDA (1988), the proposal provides for a maximum fat plus added water combination of 40% in the manufacture of these products while not exceeding the maximum fat content of 30% in the finished product. Under the older cooked sausage regulations, the fat content of frankfurters was 29-30% and added water content 9-10%. These products are now being formulated with about 18-22% fat and 16-19% added water (Murray, 1989). One of the consequences of the ruling is that water-binding properties have become more important than fat-binding properties. The second ruling concerns the labeling of binders in frankfurters and other similar products. Basically, the ruling deletes requirements for the prominent disclosure of binders on the product label. However, usage levels for these products are still in effect and the binders must still be listed by order of predominance in the ingredient statement (Giese, 1992).

Giese (1992) reported that the level of binders permitted in traditional sausage products is individually or collectively up to 3.5% of cereal, starch, vegetable flour, soy protein concentrate, non-fat dry milk, and calcium reduced non-fat dry milk in the finished sausage products. Isolated soy protein and caseinate are restricted to 2%. Traditional sausages containing more than 3.5% of the various binders or more than 2% of isolated soy protein or caseinate are required to be labeled as imitation (Giese, 1992).

Fat reduction in further processed meat products can be achieved by using leaner cuts of meat or by substituting water and other ingredients for fat (Claus et al., 1990). Typical nutritional content of bologna report fat values per 100 g that range from a low of 15 g for turkey to a high of 28.4 g for beef while the typical low-fat, added water bologna contains 10% fat and 30% added water (Giese, 1992). The most difficult problems encountered in formulating low-fat bologna as compared to the full-fat product are the

changes in textural characteristics and the increase in purge accumulation during storage (Claus et al., 1990).

Claus et al. (1989) characterized the sensory and textural properties of bologna formulated with different combinations of fat and added water totaling 40%. Results indicated that the substitution of added water for fat could effectively produce acceptable low-fat bologna. However, low-fat products with the maximum added water were softer and juicier than high-fat bologna. Unfortunately, purge accumulation in packages of high added water products was a significant problem.

The addition of binders such as dietary fiber, macromolecular hydrocolloids, and starches were evaluated for their ability to increase water binding properties (Claus and Hunt, 1991). Results indicated that oat fiber, pea fiber, modified food starch, and isolated soy protein could beneficially improve texture and reduce purge in low-fat bologna. Another approach to producing a low-fat frankfurter was to replace the fat with a water-gum suspension. Foegeding and Ramsey (1986) evaluated the addition of various gums, carrageenan mixtures, and methylcellulose on sensory and textural properties of low-fat frankfurters. The most advantageous formulations contained iota- and kappa-carrageenan mixtures (Giese, 1992). However, all the low-fat treatments were deemed similar and comparable to a full-fat control during sensory testing. A kappa-iota carrageenan blend can be used to produce a low-fat meat link which provides a 50% reduction over the typical 30% fat frankfurter (FMC, 1988). However, the suggested formulation does not conform to the 40% fat and added water ruling (Giese, 1992). Sofos and Allen (1977) found that high levels of hydrated textured soy protein (45%) could reduce the stability of emulsions when the formulations were low in fat. Product softness caused by increased levels of soy incorporation was improved by lowering the fat and increasing the soy levels. However, when fat levels were very low (10%) product softness was decreased. To counter this effect, some of the beef was replaced with lower-binding pork. The use of soy proteins can be an advantage when producing low-fat, high-protein sausages. A recommended formulation to produce an acceptable wiener-type product contained 45-50% lean meat, 15-20% fat, 5% hydrated soy protein isolate, and 25-30% hydrated textured soy protein.

In a study of the effects of preblending and reduction of fat and salt, Hand et al. (1987) found that preblending did not affect the textural properties of the low-fat frankfurters. However, products containing 1.5% salt had softer texture when compared to products with 2.0% or 2.5% salt. Claus et al. (1990) indicated that massaging of low-fat formulations tended to increase shear values measured against preblended or non-preblended low-fat bologna. High added water products produced by massaging had less purge during storage than low-fat treatments that were not massaged. However, none of the combinations of low-fat processing systems were able to produce bologna with sufficient water-binding capacity necessary to provide an acceptable product in terms of cook and drip loss. In addition, the bologna had a soft texture.

Frankfurters are meat emulsions formed from a coarse dispersion of water, fat, and protein. Heating the emulsion transforms the highly viscous dispersion into a protein gel filled with fat particles. Some problems associated with producing a low-fat frankfurter are loss of flavor and increase in toughness. Binding the added water is difficult with reduced levels of fat, and color also may be changed significantly (Geise, 1992).

In an attempt to increase health benefits, low-fat frankfurters formulated with increased ratios of monounsaturated to saturated fats have been explored (Giese, 1992). St. John et al. (1986) increased the monounsaturated to saturated lipid ratio and reduced fat by 25% in frankfurters to produce a reduced fat product with some health benefits. The evaluations showed that a frankfurter with less total and saturated fat could be produced that was similar to full-fat controls.

Park et al. (1989) reported that frankfurters which were formulated with omega-3 polyunsaturated fish oils and monounsaturated fatty acids (high-oleic acid sunflower oil) to replace of animal fats did not affect emulsion stability in low-fat frankfurters. However, the 5% fish oil products had very low sensory scores due to an undesirable fish flavor. The authors also found that the reduction in total fat caused texture problems such as increased firmness and decreased juiciness (Park et al., 1989).

An interesting consumer study discussed consumer acceptability of fat-reduced meat products. The study compared consumer acceptance of low-fat (12%) and fat (20%) smoked sausages. Of the 347 consumers, 189 preferred the 20% fat sausages, 146

preferred the 12% sausages, and 12 did not expressed a preference. When the consumers were informed of the fat content of the sausages, a substantial proportion changed their preference with a trend for preference of the 12% fat product. Many consumers changed their preference even when misinformed about the fat content of the sausages. The study concluded that consumer acceptance is based more on perceived rather than on real product differences (Solheim, 1990).

2.2 Methods of reducing fat

Recent commitments by processed meat manufacturers to the development of low/no-fat products for retail has led to the need to trim external and intermuscular fat, study genetic and dietary modifications, and evaluate numerous fat substitutes and fat replacement (Keeton, 1994). Although some understanding of the use of fat replacements has been gained, much remains to be learned about the interaction of substitutes with the classical sausage ingredients, processing procedures, storage conditions, and final product preparation (Keeton, 1994).

2.2.1 Trimming external and intermuscular fat

Savell et al. (1991) reported that the supermarket retailers had trimmed all external fat from 42% of the beef retail cuts as a result of consumer demand. In addition, they found that overall subcutaneous fat thickness for steaks and roasts from the chuck, rib, loin, and round was only 0.32 cm and that ground beef was leaner. When these data were compared with the 1986 USDA Handbook 8-13, beef steaks and roasts had 27.4% less fat and ground beef contained 10.2% less fat (Keeton, 1994).

2.2.2 Genetic and dietary modification

Compositional variation has been documented among and within breeds of livestock due to genetic selection for specific traits (CAST, 1991). In addition, physiological and chronological ages at slaughter, level of nutrition and management systems were contributing factors that determined the composition of carcass cuts and trimmings. Modifications of ruminant diets with forage and grain could cause large differences in the fat content of edible tissues and slight alternation of the fatty acid

profile (CAST, 1991; Keeton, 1994). Inclusion of different types of fat in monogastric (pork, poultry, and turkey) diets could dramatically alter carcass composition and affect processing characteristics (CAST, 1991).

2.2.3 Functional ingredients

Functional ingredients used in the formulation of low-fat and low-salt processed meats may classify into different groups including: thickeners, binders, fillers, fat replacers/substitutes and fat extenders (McAuley and Mawson, 1994). Thickeners are added to bind or hold water in processed meats (McAuley and Mawson, 1994). Starches are often used for this purpose, and begin to absorb water at 65-75°C when meat proteins gel (Anonymous, 1993). Binders have both cohesive and water-binding properties and are often able to emulsify fats (McAuley and Mawson, 1994). They include protein based ingredients such as wheat gluten, soy protein and caseinate products (Anonymous, 1993). Fillers, such as maltodextrins of bran, provide bulk to give emulsion stability, enhanced flavors, greater cooking yields, improved slicing characteristics and reduced formulation costs (Anonymous, 1993). Fat replacers aim to have the same viscosity, lubricity, absorption and other qualities as fat (Glicksman, 1991). Fat substitution is also best achieved by using combinations of ingredients (Glicksman, 1991). No single fat substitute can be used to replace the fat in all processed meat products, since there is a wide variety of functional and palatability attributes to imitate (Yackel and Cox, 1992). In fat replacement systems, the majority of fat is replaced by water. Water replacement alone makes products too soft and may result in excess water loss during cooking (Yackel and Cox, 1992). If too much lean meat is substituted for fat in a product, a tougher, drier, more costly food results (Yackel and Cox, 1992). Fat extenders are used for partial fat replacement, creating the impression that foods contain more fat than they actually do (Pszczola, 1992). These fat extension ingredients are often similar to those used for fat replacement. When reformulating foods using fat substitutes, several points need to be considered: cohesiveness, firmness, dryness, juiciness, flavor, texture, appearance, cost, availability, ease of use, labeling, food safety, water activity, and shelf stability (Yackel and Cox, 1992). High water levels in product formulations can reduce shelf stability by raising the product water activity and thus increasing microbial spoilage. Certain

texturising agents can be used to improve the eating texture of fat reduced processed meats without necessarily mimicking the texture of fat. Trout et al. (1992) found that the use of texturising agents was feasible in improving palatability of 5% and 10% fat ground beef patties, especially with regards to firmness, dryness and cohesiveness. The texturising agents tested were polydextrose, sugar beet fiber, potato starch, oat fiber and pea fiber.

2.3 Effect of ingredients on low/no-fat meat products

2.3.1 Lean raw material and recovered tissues

Very lean, relatively expensive, raw materials are required as the primary formulation base to produce low/no-fat products. These can include such items as bull meat, cow meat, picnic pork cushions, trimmed ham muscles, skinless turkey thighs, turkey drum meat, poultry lean, finely textured lean, recovered lean tissue, and trimmings from deboned vertebral material (Keeton, 1996).

2.3.2 Added water

Typically, water is the principal component in fresh meat and in processed meat products, and has an important influence on the product characteristics. The amount of water present has an important role in meat emulsion stability. Added water is required in all low-/no-fat formulations as a partial replacement for fat and for adequate protein hydration to activate their functional, fat-like properties. Prior to 1988, the United States Department of Agriculture (USDA) restricted cooked sausages to a maximum of 10% added water ($AW = \% \text{ moisture} - 4 \times \% \text{ protein}$), but currently the amount of added water is controlled by the “40 percent rule” that was described as the substitution of added water (AW) for fat (equal or less than 30% up to a combined (water plus fat) total of 40% (USDA, 1988). However, maximizing retention of added water and/or the water indigenous to muscle tissue allows for its interaction with other ingredients and contributes to the juiciness, texture and other sensory properties that are essential for acceptable and economically competitive low/no-fat meat products. Studies utilizing the higher limit have shown that some undesirable effects associated with fat reduction by additional formulation water (Claus et al., 1989; Park et al., 1990).

Claus et al. (1989) studied the effects of substituting added water (AW) for fat on textural and sensory properties of bologna formulated with different combination of fat and AW (ranging from 30% fat-10% AW to 5% fat-35% AW) following the 40% rule. In general, substituting AW for fat was effective in preventing undesirable sensory changes associated with low-fat products. Increasing AW in the formulation resulted in lower Instron fracturability, hardness, and shear values and higher cooking and purge losses (Claus et al., 1989; Rust and Olson, 1988). Low-fat bologna was darker, softer but juicier than higher fat products. In addition, sensory springiness, firmness, and cohesiveness increased with higher protein content (Claus et al., 1989). The low-fat, high added water processed meats can be more benefit in texture by incorporation with non-meat ingredients such as dietary fiber, macromolecule hydrocolloids and starches utilized to improve water binding capacity in low-fat products (Claus and Hunt, 1991). Ahmed et al. (1990) studied the effects of various levels of added water on low-fat fresh pork sausage processed and found that cooking losses, color and textural characteristics of low-fat sausages were similar to control sausages.

2.3.3 Fat replacements

Fat substitutes are ingredients which have basically the same physical (and in some cases, chemical) properties of fat or lipids. Fat replacements are ingredients that mimic some aspects of physical attributes of fat. However, fat substitutes and replacements ideally are ingredients which contribute a minimum of calories to formulated meats and do not dramatically alter flavor, juiciness, mouthfeel, viscosity or other organoleptic and processing properties (Keeton, 1991). The primary goals for utilizing fat substitutes and replacements in the process include (1) reducing total fat, calories from fat; (2) meeting consumer expectation for healthier foods; (3) retaining product palatability such as flavor, texture, and mouthfeel; (4) stabilizing meat product moisture and appearance; (5) providing low-fat products at or near the cost of traditional meat items and (6) optimizing ingredients which mimic the functional and sensory properties of tissue lipids (fat). Several articles had summarized the types, characteristics, properties and potential problems of fat substitutes and replacements appropriate in meat products (Claus, 1991; Dikeman, 1987; Giese, 1992; Huffman et al.,

1991; Keeton, 1991, 1994; McAuley and Mawson, 1994; Pearson et al., 1987; and Shand and Schmidt, 1990). Most substitutes were used for partial replacement of the fat and could be categorized as: (1) leaner raw meat materials and recovered tissues (reduced fat beef, partially chopped beef/pork, mechanically separated or deboned meat such as beef, pork, poultry, and turkey); (2) added water; (3) protein-based substitutes (blood plasma, eggs protein, milk caseinates, non-fat dry milk, oat bran, soy proteins, whey protein, vital wheat gluten, surimi, wheat proteins, and whey proteins); (4) carbohydrate-based substitutes (fiber, cellulose, starches, maltodextrins, dextrins, hydrocolloids or gums); (5) synthetic compounds (Polydextrose, Olestra or sucrose polyester) (Keeton, 1994).

A recent survey of fat-free frankfurter products available at retail identified the following non-meat ingredients as fat replacements: Modified potato starch, soy protein concentrates, potato starch, modified food starch, sodium caseinate and gelatin (Murphy, 1995). Supplemental ingredients included: Alkaline sodium phosphates, hydrolyzed beef, sodium lactate, hydrolyzed milk protein and autolyzed yeast. Whole-muscle, brine-pumped items such as gams, poultry/turkey rolls and similar items often contain soy protein isolate, starch and carrageenan to control moisture, retain desirable textural characteristics and reduce the fat content (Keeton, 1996).

Protein-Based Replacements: Plant-Derived

Plant protein sources include soybeans, wheat, corn, peas, cottonseed and oats (Keeton, 1996). Proteins used as fat replacements in meat products offer essential functional characteristics, such as increased emulsification capacity, product stabilization, increased viscosity, firmer texture and greater water-holding capacity (Rakosky, 1988). In addition, proteins can contribute to the nutritional amino acid profile and in some cases, increasing product economy (Giese, 1994).

Soy proteins are produced in the form of flours, grits, concentrates and isolates and texturized forms of these products (Giese, 1994). Soy flour or grits are the least refined (40% to 54% protein) form of soy proteins and are produced by grinding and screening soybean flakes, either before or after the oil is removed. Defatted flours (52% to 54% protein) are prepared by grinding defatted flakes through a No. 100 U.S. Standard screen size. Moist heat treatment is used to produce products with a Nitrogen Solubility Index of high (85-90), medium (20-60) or low (<20) grades. Defatted grits are the same

as flour except that they are passed through a No. 10 and 80 screen size. This product has application in ground meat systems and bakery products (Keeton, 1996).

Soy protein concentrates (>70% protein) are prepared from defatted soybean flakes by acid leaching (~ pH 4.5) and extraction with aqueous alcohol (60 to 70%). Soy protein isolate (>90% protein), on the other hand, is extracted from the same starting material, defatted soybean flakes, by removing most of the non-protein components with a water or mild alkali wash at pH 8 to 9, followed by centrifugation to remove insoluble fibrous residue. The pH of the extract is adjusted to pH 4.5 to precipitate the protein curd. Soluble oligosaccharides are separated from the curd by centrifugation. The curd is then neutralized with sodium or potassium salts to make the protein more soluble and functional, followed by multiple washings and spray drying. Approximately one-third of the starting material is recovered as an isolate. Soy protein isolates and neutralized soy protein concentrates are often incorporated into finely ground meats such as bologna and frankfurters to retain moisture, bind fat and stabilize the emulsion (Keeton, 1996).

Textured soy products (flours, concentrates and isolates) can be extruded to give texture and shape. Isolates may be extruded into an acid-salt bath that coagulates the protein into fibers that are combined with binders to form fiber bundles, but these textured isolates must be frozen to prevent spoilage. Textured soy proteins (flours and concentrates) are most often used in coarse chopped or ground meats such as pizza toppings, taco meats, meat balls, meat patties and Salisbury steaks to give structure, reduce cooking loss and extend freshness (Keeton, 1996).

Wheat proteins are predominantly storage proteins found in wheat kernels that consist primarily of gluten. Gluten is separated from the wheat flour by a water wash to remove starch and other soluble components, leaving the insoluble gluten. Vital wheat gluten retains its viscoelastic properties and is used in many bakery goods and breakfast foods. It is suited for meat and fish products heated above 185°F because of the protein's ability to retain elasticity under high heat conditions (Keeton, 1996).

Corn protein isolate is processed by a cold-filtration process (Keeton, 1996) to yield a cream-colored product containing 92% to 98% protein. Currently, it is being used to bind water and fat in ice cream, as a gel or whipping agent in toppings, or to increase viscosity in frozen aerated desserts (Keeton, 1996).

Pea protein flours and isolates are both available commercially, but the isolate (83% protein) is more functional in terms of its ability to bind water, emulsify fat and contribute foaming and gelling characteristics (Keeton, 1996). The isolate has been used mostly to formulate frozen non-dairy desserts and to replace albumen in sponge cakes (Giese, 1994).

Protein-Base Replacements: Animal-Derived

The major commercially derived animal proteins are obtained from a variety of sources including animal skins, eggs, milk and fish. Milk protein are derived from whole milk (87.5% water, 4.5% lactose, 3.5% fat, 1.0% ash and 3.5% protein) with the most primary product being non-fat dry milk (NFDM). NFDM is produced from pasteurized skim milk that is concentrated and spray-dried, resulting in a cream-colored powder. NFDM contains lactose, milk proteins and minerals in the same relative proportions as fresh milk. Examples of additional milk-derived proteins for use in low/no-fat meat products are caseinates, dried whey, whey protein concentrate, and whey protein isolate (Keeton, 1996).

Milk contains two principal protein components, casein and whey proteins. Casein is extracted from milk through either isoelectric or enzymatic (lactic acid fermentation) precipitation. The caseinates are derived from lactic or acid (enzymatically produced) casein by rinsing, treating with various alkaline salts, heating and spray-drying. They are most often used in processed meats as fat emulsifiers and to improve moistness and smoothness (Giese, 1994). In emulsified meat products, caseinates compete with myofibrillar proteins and are preferentially absorbed onto fat globules over the meat proteins to stabilize the emulsion and reduce water loss during heating (Keeton, 1996).

The effect of different milk proteins on the quality of comminuted meat products has been investigated (Baardseth et al., 1992). Milk protein is widely used to improve water binding in uncooked batters. Ellekjaer et al. (1996) reported that sausages (20% fat) with 1.5% milk protein had minimum cooking loss and were not similar in sensory quality to the control (20% fat, no added milk protein). Skim milk powder (35% protein) has good water binding effects, but lactose may cause discoloration of meat products because of the Millard reaction with proteins (Mortensen, 1986). Whey protein acts as

binder and extender and gels when heated (Mittal and Usborne, 1985a). Caseinate is completely soluble in water and is an ideal emulsifier with a strong effect on fat/water or air/water interfaces. It emulsifies free fat and forms stable emulsions (Van den Hoven, 1987) because of the high proline and low sulfuric amino acids content. Caseinate will have a random coil structure with a low percent helix. As a consequence, caseinate will show no heat gelation and will make batter high viscosity. Also, caseinate has a high electrical charge and several very hydrophobic groups. The high charge makes caseinate soluble in water (Van den Hoven, 1987).

Whey is the by-product of cheese and casein manufactures and can be processed into a variety of protein forms, including concentrates and isolates. Lactalbumin (85% to 90% protein) is a special type of whey protein concentrate (WPC) that has been heat denatured (90°C) which in turn causes the whey proteins to self-aggregate and precipitate, making this protein less soluble than whey proteins (Huffman, 1996). Whey protein concentrates are spray-dried white powders that serve as a good source of essential amino acids especially leucine, isoleucine and valine. The undenatured proteins are soluble below 70°C and with a pH above 3 to 5 with isoelectric points in the 4.5 to 5.3 range (Keeton, 1996). Added sugar improves heat stability. When heated, WPCs increase in viscosity (slightly) and water-holding capacity due to a partial unfolding the exposure of more hydrophilic groups for water retention. Whey proteins have both hydrophilic and hydrophobic regions and act as fat emulsifiers. When heated to approximately 65°C, gelation begins which yields smooth, strong, elastic gels similar to egg white. In aqueous solutions, gelation begins at approximately 7% protein concentration, but in food systems, gelation may occur at 0.5 to 3.0% protein (Keeton, 1996). This gelation is particularly important in meat and seafood products to stabilize the food matrix. Additionally, the adhesion properties of whey proteins increase batter retention to meat and fish products and can also serve to bind meat pieces to each other. Commercially, whey protein concentrates are used to prevent or minimize shrinkage during cooking, act as emulsifiers and/or retain juiciness. Product applications for WPCs include ham item, frankfurters and luncheon meats (Keeton, 1996).

Gelatin is a widely used ingredient in meat products and it is produced by partial hydrolysis of collagen (chief component of skins, hides and white connective tissues of

animals). Two types of gelatin are produced, Type A and Type B. Type A is produced by acid processing of collagenous raw material and has an isoelectric point between pH 7 and 9. Type B collagen is alkaline (lime) processed and has an isoelectric point between pH 4.8 and 5.2. Gelatin is used in a variety of meat products, dairy products and confectionery for its ability to stabilize water, but its largest use is in making gelatin desserts (Keeton, 1996).

Egg proteins are derived from the whole egg, yolk or whites. These products are valued for their foaming, binding and thickening ability, emulsifying power and ability to tenderize and retain moisture, but they are not widely used in meat products (Keeton, 1996). Carballo et al. (1995) reported that egg white caused variation in the texture of sausages and found that hardness and chewiness of sausages increase with higher egg white level, while springiness and cohesiveness were not affected.

Fish protein concentrate is manufactured from deboned whole fish after fat and water extraction with a solvent such as isopropyl alcohol. The extracted material is then dried and serves as a binder (Keeton, 1996). Surimi, a minced water-washed fish protein concentrate that has been treated with cryoprotectants and frozen, and could be used in meats to increase the myofibrillar protein content, decrease fat and increase the gelling properties of lean meats (Lanier, 1994).

Carbohydrate-based replacements: starches

Starches are carbohydrate granules of glucose that usually contain amylose, a linear, straight chain α -1,4 glucopyranose polymer and amylopectin, a branched (tumble weed-like) α -1,4 glucopyranose polymer with branching components at 1,6 linkages (Shand and Schmidt, 1990). Granule size, shape and distribution and the amylose/amylopectin ratio of a starch vary with the plant source. The most common sources are corn, potato, wheat, tapioca and rice (Keeton, 1996). Starches are extracted by wet or dry milling, followed by enzymatic hydrolysis to make smaller molecular weight starch polymers in the range 5,000 to >1,000,000 daltons. The amylose component determines the gelling properties of a particular starch due to its ability to form hydrogen bonds with adjacent molecules to build a three-dimensional network. Gelatinization or granule swelling in the presence of water is critical for starch to emulate

fat, reduce moisture loss and improve freeze-thaw stability in low/no-fat meat products. Starches do not participate in the binding or emulsification process (Keeton, 1996).

Food starch can be modified by hydrolysis (HCl treatment in a slurry or dry state), oxidation with sodium hypochlorite, cross-linking between hydroxyl groups (phosphorous oxychloride and adipic acid) and substitution of hydroxyl groups with monofunctional groups (acetic anhydride or propylene oxide);(Luallen, 1985). Modifications can alter viscosity, hydration capacity, solubility and gelatinization and starch properties. Most starches that are used as fat replacements are pregelatinized or modified to enhance their hydration capacity between 125° and 150°F, since this heat processing range is insufficient to gelatinize untreated starch (Keeton, 1996).

Starch-based fat replacers have been used in a wide variety of low/no fat products. Alexander (1995) stated that starch was used because it formed a gel when heated that was necessary to obtain the texture and mouthfeel of the original fat containing products. Also, its molecular weight was similar to that of the fat being replaced. Replacing fat with carbohydrate-based products lowered calories. However, the effects of adding starch will vary depending on the source of the starch, type of modification, processing conditions, other added non-meat ingredients, and type of product (Colmenero, 1996). Several types of starch have been used in varying proportions (2% to 5%) to formulate reduced fat emulsions (Keeton, 1992). Modified starch such as Oatrim may be produced by enzymatic hydrolysis of oat starch while maltodextrins are manufactured by hydrolyzing potato or corn starch with acid or an enzyme. Maltodextrins have a dextrose equivalent (DE) of less than or equal to 20 and are characterized by a bland flavor and smooth mouthfeel (Keeton, 1996).

Resistant starches

Resistant starches are so named because they are resistant to digestive enzymes and act more like dietary fiber than starch (Kevin, 1995). These modified starch molecules are composed of retrograded amylose, known as RS3, that pass through the small intestine. They are partially fermented to produce short chain fatty acids (mostly butyric). There appears to be evidence that consuming resistant starch could provide a direct health benefit to the colon, since butyric acid has been shown to inhibit cancer cell growth. The raw starting material for the starch is a hybrid variety of high amylose corn

yielding a resistant starch with an effective total dietary fiber content of 30% and 2.8 Kcal/gm. The commercial product is a white crystalline powder with no odor or taste that could improve the processing and/or quality of fiber-fortified foods, overcoming flavor and textural problems associated with traditional fiber ingredients. These starches are biochemically modified corn starches that are GRAS and labeled as malodextrins. Two commercial products currently available are Novelose from National Starch and Chemical Company and CrystaLean from Opta Food Ingredients, Inc (Keeton, 1996).

Carrageenan

By definition, hydrocolloids are long-chain polymeric materials that thicken or gel in aqueous systems and include a broad classification of edible gums (Glicksman, 1991). Some of these ingredients have been applied to meat systems as fat substitutes because of their sensation of fattiness or oiliness that tends to mimic the mouthfeel of animal fat. Carrageenan has been the most utilized hydrocolloid for reducing the fat content of ground meats (McDonalds McLean Delux) as well as enhancing the texture of low-fat meat products such as deli-rolls, turkey breasts, turkey breakfast sausage, low-fat frankfurters, beef franks, poultry lunch meats and hams (Murphy, 1995).

Carrageenan is a high molecule weight polysaccharide extracted by a variety of methods from eucheuma, chondrus and gigartina seaweeds. The raw base material for carrageenan is harvested principally from coastal waters surrounding the Philippines, Indonesia, Ireland and parts of East Africa. Three types of refined carrageenan are derived from these raw materials including kappa, iota, and lambda carrageenans (Keeton, 1996).

Carrageenan is available in three forms containing refined, semi-refined or a blend of the two. Semi-refined is also known as Philippine Natural Grade (PNG) with some cellulose fibers remaining in the gel matrix of the carrageenan. Natural Grade carrageenans cost less and differ in functionality from the refined form (Keeton, 1996). Some suppliers have promoted the semi-refined as offering the following advantages in brined products: including (1) better brine absorption prior to cooking, (2) less sensitivity to temperature increases which cause premature swelling and clogging of injector needles and filler screens, (3) less syneresis in sliced product, possibly due to the cellulose fibers, (4) less rubbery texture than with refined carrageenan (Keeton, 1996).

Neither refined nor Natural Grade carrageenans improve the functionality of meat proteins, but serve to form a separate hydrocolloid network which congeals and binds water in conjunction with the myofibrillar proteins in meat and poultry products (Keeton, 1996). In addition, carrageenan maintains a higher pH in the products which enhances the water-holding capacity of myofibrillar proteins. Carrageenan is somewhat like fat in that it forms a thermally reversible gel that is stable at room temperature, melts upon cooking and recongels with minimal loss of gel strength when cooled. For the products such as low-fat bologna, this improves texture, firmness and sliceability. Carrageenan can be added directly to meat block in a blender prior to tumbling; alternatively, some processors premix carrageenan with the dry ingredients prior to tumbling. In chilled brines, carrageenan should be dispersed after the addition of alkaline phosphate and salt. Salt inhibits hydrocolloid swelling and prevents plugging of the injector needles (Keeton, 1996).

Konjac

Konjac is a polysaccharide powder classified as a glucomannan hydrocolloid that is composed of β -1,4-linked mannose and glucose units at a molecular ratio of approximately 3:2 respectively. The molecular weight is greater than 300,000 Daltons (Tye, 1991). Acetyl groups are scattered randomly along the essentially linear molecule with an occurrence of approximately 1 per 19 glucose/mannose units. The acetyl groups impart water solubility in an otherwise amylose-like molecule. Traditionally, konjac solutions are cooked with mild alkaline to produce thermal stable gels. Mild alkaline cleaves acetyl groups reduced water solubility, allowing a three dimensional hydrogen bonded network to form. This gel network has remarkable stability in hot and cold acid and alkali systems (Tye, 1991). Deacetylation of konjac with alkaline and/or heat causes formation of a thermally irreversible gel while thermally reversible gels may be made by treatment of konjac with 1% KCl + 0.2% CaCl₂, mechanical agitation and heat (80° to 85°C) (Keeton, 1996). When konjac flour is mixed with water, the small sacs absorb moisture and begin to swell. As the sacs swell, the viscosity of the dispersion increases until the sacs burst releasing the glucomannan. The rate of hydration of konjac flour depends on temperature and time (Tye, 1991). Konjac powder normally hydrates rapidly and binds a volume of water 80 to 100 times its weight (Keeton, 1996).

In the presence of mild alkali such as potassium carbonate, konjac sols form tough gels which retain their shape even in boiling water. Gels made with konjac flour actually increase their strength when heated and are stable to repeated thermal cycling. It is theorized that acetyl groups of konjac flour prevent the molecules from coming together to form a gel network. Hence, konjac flour dispersed and heated in water will not gel. However, mild alkali cleaves the acetyl groups enabling the molecules to interact and form a gel (Tye, 1991).

Combination of carrageenan, xanthan gum or locust bean gum are synergistic with konjac and produce gels varying in strength and elasticity. Konjac and konjac blends may be successfully incorporated into coarse ground pork sausage and emulsified low/no-fat meats in pregelled forms to serve as a fat replacer and water binder (Osburn and Keeton, 1994). USDA-FSIS approval for konjac use in meat products was obtained in July 1996 with the same formula limitations as starch (a maximum of 3.5%). Konjac flour used with starch systems functionally interacts with most starches to give a considerable increase in viscosity which is maintained during cooking and cooling (Keeton, 1996).

Cellulose

Cellulose is a carbohydrate polymer of glucose units having β -1,4 linkages. Cellulose is not digested by humans and thus does not contribute to the caloric value of food when used as an ingredient (Keeton, 1996). Cellulose derivatives such as microcrystalline cellulose and carboxy methyl cellulose, methyl cellulose and hydroxypropyl cellulose are used as food stabilizers, thickeners and texture modifiers. When dispersed in water, cellulose derivatives produce a gel network that stabilizes foams and emulsions and increases viscosity and dietary fiber content (Keeton, 1996). Carboxy methyl cellulose (CMC), a synthetic water-soluble gum is primarily used as a stabilizing, thickening agent in many kinds of food. Different CMCs had been studied in reduced-fat frankfurters and have been shown to soften the texture of the frankfurters (Lin et al., 1988) which may be a positive attribute for this category of products. Microcrystalline cellulose and cellulose gel is partially depolymerized cellulose and its used as an anticaking agent, binding agent and a dispersing agent (Keeton, 1996). As a fat replacer, it is used in combination with other hydrocolloids. Todd et al. (1990)

reported that microcrystalline cellulose at 3.5% and 7% in ground pork produced a grainy texture. Methyl cellulose and hydroxymethyl cellulose can form viscous, colloidal suspensions and serve as bulking agents, stabilizers and food binders (Keeton, 1996). Hill and Prusa (1988) found that these ingredients increased patty gumminess, decreased Instron compression scores and decreased meat flavor when used at 0.5% or 1% in lean beef (5.4% fat).

2.3.4 Sodium chloride

In response to the concern about the sodium level in the western diet, recommendations to reduce dietary sodium have been made. Excessive intake of sodium is a concern as it is related to an increased incidence of hypertension (Dahl, 1972). The recommendations are an attempt to decrease the incidence of hypertension and the subsequent occurrence of cardiovascular disease in individuals susceptible to those conditions (Dahl, 1972). Consequently, the meat industry is searching for ways to reduce the salt content of some of the processed meat products and develop the low-fat and/or low salt products to meet customer expectations. However, salt and fat reduction is not as simple as just removing the fat or lowering the salt level because reducing salt in processed meats may be detrimental to emulsion stability, cook yield, flavor and juiciness (McAuley and Mawson, 1994).

The salt concentration affects flavor of processed meat products because it not only imparts a salty flavor but enhances other flavor characteristics (Mickelsen, 1982). Other benefits of using salt as an ingredient are to limit microbial deterioration, prolong shelf life, and improve textural characteristics of processed meat products. The approaches of salt reduction in meat products generally involved reducing the addition of NaCl, substituting other chloride salts for NaCl, adding other ingredients, and/or altering processing techniques (Barbut and Mittal, 1990; Whiting, 1984).

Comminution of meat in the presence of sufficient salt induces a partial extraction and solubilization of the myofibrillar proteins which were denatured on the surface of the fat particles during comminution (Acton et al., 1983). Salt-soluble proteins form a stable emulsion (Acton et al., 1983; Wirth, 1987) and produce low-fat products that have firmer texture and increased shelf life (Terrell and Brown, 1981). At NaCl concentrations

widely used in the meat industry, myofibrils quickly swells to about twice their original volume (Offer and Trinick, 1983; Wirth, 1987). The precise degree of swelling of the protein network depends on the concentration of ions absorbed. While not necessary for extraction, salt enhances the tendency of water soluble proteins to stabilize fat emulsions, though this contribution is minimal (Swift et al., 1961).

Salt primarily affects the ionic strength of meat proteins since actomyosin probably absorbs both anions and cations from neutral salt solutions (Seigel and Schmidt, 1979). Thus, the internal forces of attraction between oppositely charged groups within the protein molecules tend to decrease (Alexander and Johnson, 1950). Hamm (1960) and Schut (1975) reported that the effect is primarily due to chloride ions being bound to the protein much more strongly than the sodium ions. When the pH is above the isoelectric point (pI), chloride ion binding breaks the salt bridges and results in an increased negative charge and greater water holding capacity. Hamm (1960) reported that salt produced an apparent shift in the pI of the protein. Aside from increased protein extraction, salt enhances the dissociation of actomyosin to actin and myosin in the presence of ATP (Hamm, 1975; Wirth, 1987). Changes in the structure and charge of the salt soluble proteins have a destabilizing effect on these proteins evidenced by lowering of denaturation temperatures (Quinn et al., 1980). Higher levels of salt increase the extractability of proteins in meat (Gillett et al., 1977).

Water binding capacity and cooking yields are higher with increasing salt levels (Hamm, 1975; Aberle et al., 1980; Puolanne and Terrell, 1983; Hand et al., 1987; Trout and Schmidt, 1986; Barbut, 1988; Girard et al., 1990). The optimum salt concentration generally varies from 2 to 3%. The replacement of NaCl in processed meat is limited. Trout and Schmidt (1986) reported that a decrease in salt content of an emulsified product resulted in decrease temperature to which the products could be heated before water binding ability was affected. Whiting (1984) reported that raw emulsions made with reduced salt levels (below 2%) had a sharp increase in water released by the batter. Gel strength gradually decreased with salt reductions from 3.5% to 1.0%. In addition, salt reduction resulted in lower hardness, peak force, gumminess scores, and increased elasticity.

Effects of reducing salt from 2.5% to 1.5% and salt preblending prior to processing resulted in minimal physical and chemical changes. But the products tasted less “salty” (Puolanne and Terrell, 1983). Salt reduction to 1.0% resulted in decreased water binding capacity despite preblending treatments (Puolanne and Terrell, 1983). Similar results were obtained for fat holding ability (Swift and Sulzbacher, 1963).

Salt is considered a prooxidant and contributes to the acceleration of rancidity in meat products (Sylvia et al., 1994). Rancidity increases with higher salt levels as evidenced by higher thiobarbituric acid (TBA) or peroxide value (Ellis et al., 1968; Waldman et al., 1974; Judge and Aberle, 1980; Drerup et al., 1981). Waldman et al. (1974) stated that no significant increase in the TBA values were observed in salt level above 1.5%. The physiological state of the meat to which salt is added has been reported to affect TBA values. Susceptibility to autoxidation was reduced in prerigor ground and salted sausages due to higher pH compared to the control which was salted post-rigor (Judge and Aberle, 1980; Drerup et al., 1981).

2.3.5 Phosphates

Inorganic phosphates are known to enhance water holding capacity of cured meat products (Schmidt, 1987). Phosphates also are known to affect the color (Marriott et al., 1983), flavor (Molins, 1991), tenderness (Marriott et al., 1983), oxidative changes (Watts 1954; Choi et al., 1987b), and microbiological characteristics (Choi et al., 1987b) of processed meats. Among the phosphates commonly used in the meat product industry, sodium tripolyphosphate (STP) is the most popular phosphate added to processed meats, poultry, and seafood (Fennema, 1985). However, pyrophosphates are more effective at increasing the cooked yield (Knipe et al., 1990). Sodium or potassium phosphates are used in the U.S. at levels up to 0.5% of the final product weight for reducing moisture losses during cooking (USDA, 1985).

There are three classes of phosphates including neutral, acidic, and basic (Sylvia, 1994). Schmidt (1987) reported that only the alkaline phosphates are effective in improving water binding because acid phosphates may lower the pH and cause greater shrinkage. In contrast, Barbut (1988) reported that all classes offer at least some benefit.

Sodium acid pyrophosphate (SAPP) was the most effective phosphate for improving the firmness and springiness of frankfurters (Hargett et al., 1980).

The mechanism by which phosphates and polyphosphates enhance meat hydration is not clearly understood despite extensive studies (Fennema et al., 1985). The possible modes of action of phosphate could be: (1) buffering (raising) the pH, (2) increasing the anionic electrolytes, (3) sequestering cations, (4) raising the ionic strength, and (5) dissociating actomyosin (Ellinger, 1972; Knipe, 1983; Seigel and Schmidt, 1979; Trout and Schmidt, 1983). Phosphates may also crosslink proteins or block reactive sites. Phosphate may absorb onto proteins or react with charged groups in polypeptides to form complexes, thereby exerting direct effects on the protein characteristics such as hydration, swelling, gelation, thermal denaturation, and protein-protein interactions (Molins, 1991). Bendall (1954) reported that phosphate actions had been claimed due to a nonspecific effect reflecting the increase in ionic strength of the aqueous phase of the muscle. Alkaline phosphate addition resulted in an increase in pH (Bendall, 1954; Choi et al., 1987a). If this increase in the pH is away from the isoelectric point of the myofibrillar proteins, protein solubility is enhanced owing to an increase in the electrostatic repulsion between protein molecules. This results from an increased net negative charge associated with higher pH (Molins, 1991).

There may be an ionic strength threshold as pyrophosphate had a positive effect on both cooked yield and tensile strength at ionic strength above 0.25 M, but a negative effect at lesser ionic strengths (Trout and Schmidt, 1987). These scientists stated that this was possibly due to changes in electrostatic interactions produced by pyrophosphate at the low ionic strength which destabilized the protein structure making the proteins more heat labile. In contrast, pyrophosphate affected hydrophobic interactions at high ionic strength such that these interactions stabilized the protein structure increasing the thermal stability of the protein. At intermediate ionic strengths the detrimental electrostatic effects of pyrophosphate are counteracted by positive hydrophobic effects (Trout and Schmidt, 1987). But other studies indicated that was not the case (Seman et al., 1980; Knipe et al., 1990). The addition of 0.3% sodium pyrophosphate or tripolyphosphate increased cooking yields of the low salt (0.75%) comminuted meat emulsions although ionic strength remained relatively constant at 0.12M (Knipe et al., 1990). Another

important function of phosphates in comminuted products is their ability to dissociate actomyosin to actin and myosin which is at least partially independent of the pH altering effects (Hamm, 1975; Seigel and Schmidt, 1979). However, phosphates can not exert this effect on salted prerigor tissue as actin and myosin will not be associated.

Salt and phosphate have a synergistic effect for altering meat properties. Therefore, the sodium content in processed meats reduced by lowering NaCl levels in the presence of sodium phosphates, since NaCl contains about 40% sodium and most sodium phosphates contain about 30% sodium. The addition of phosphates substantially reduces the sodium chloride concentration required for maximum swelling of myofibrils (Bendall, 1954; Offer and Trinick, 1983; Trout and Schmidt, 1983; Molins, 1991) and water binding (Seman et al., 1980; Trout and Schmidt, 1983; Girard et al., 1990). Seman et al. (1980) reported that lowering the ionic strength of bologna from 0.42 to 0.21 resulted in less stable emulsions with lower hardness values.

Various phosphates have antimicrobial potential. Nelson et al. (1983) reported that pyrophosphate combined with potassium sorbate in reduced nitrite chicken frankfurters had greater inhibition on botulinal toxin production than inhibition provided by either STP or sodium hexametaphosphate (HMP). Barbut et al. (1986) showed the effect of reduced salt (2.0% and 1.5% NaCl) and 0.4% sodium acid pyrophosphate in turkey frankfurters could inhibit *C. botulinum* toxin formation better than a similar addition of STP.

2.4 Effect of processing on low/no-fat meat products

The variation of fat and protein content in the preparation of no-fat and low-fat emulsions influence the sensory characteristics and texture of products. A variety of technological procedures such as massaging, pre-blending, and cooking conditions are also important factors that can offset the effect of fat reduction and help obtain acceptable no-fat and low-fat meat products. Indeed, processing conditions are greatly responsible for many aspects of the final quality in the meat products.

2.4.1 Effects of preblending

Preblending is the grinding and mixing of raw material several hours before batter production (Judge et al., 1989) with the different ingredients. All preblends include salt and most include phosphate and/or some water and nitrite (Acton and Saffle, 1969; Hand et al., 1987; Judge et al., 1989). Preblending may offer a possible alternative by allowing additional time for protein solubilization and swelling to take place as well as time for sampling and analysis of protein, moisture and fat content of raw materials (Judge et al., 1989). Acton and Saffle (1969) reported that preblending is of particular value in postrigor meats but was not beneficial for its functional value in ground prerigor meat.

Preblending has been reported to enhance binding ability, color, and water and fat holding capacity (Acton and Saffle, 1969) but not to affect the texture of frankfurters (Hand et al., 1987). Hand et al. (1987) found that preblending had an equalizing effect on perceived saltiness between low and high fat frankfurters with the same salt content. Another important result of preblending was the reduction in the total bacterial counts, most probably due to the adverse effects of added salt on the bacteria (Acton and Saffle, 1969).

2.4.2 Effect of massaging

Mixing develops uniform distribution of fat and lean particles and dispersion of various components in a mixture. Several studies have been performed using extended mixing time or “massaging” (Sylvia, 1994). In addition, extended mixing can reduce the visibility of particles (Gregg et al., 1992). Massaging may help improve water binding in low-fat, high added water products by increasing protein-protein and protein-water interactions. Massaging reduces processing time, increases uniformity in color, texture and fat distribution. It also improves binding in sectioned and formed meat products (Seigel and Schmidt, 1979). In addition, the extended mixing time increased the concentration of protein extracted from ground meat slurries with the highest rate being observed during the first two minutes followed by only slight increases during the subsequent 30 minutes (Gillett et al., 1977). With prerigor beef, extracted crude myosin appeared to level off after 1.5 hours of mixing (Solomon and Schmidt, 1980).

Claus et al. (1990) investigated the effect of massaging on a batter-type product and concluded that the benefits of massaging low-fat, high added water bologna formulations were not as apparent as the known benefits in manufacturing sectioned and formed cured pork. It was theorized that mincing after massaging may have disrupted the bonds formed during massaging and lessened the advantages of massaging. Gregg et al. (1993) reported that massaging did not affect pH or cook/chill losses but increased batter viscosity. Massaging in low-fat products generally increased purge accumulation, regardless of degree of vacuumization and also resulted in less cohesiveness, softer, and juicier products than high-fat bologna. Sylvia et al. (1994) reported that extended mixing of postminced batter (2°C) resulted in higher hardness values in cooked frankfurters. Other research indicated negative effects of extended mixing time. In a ground beef model system, increased mixing times (30 to 150 minutes) caused a linear decrease in binding ability of a crude myosin extract and increased the amount of protein required to form a gel (Solomon and Schmidt, 1980). They proposed that myosin aggregates, which decreased the water binding ability of the protein, may have been formed with prolonged mixing. Webb et al. (1975) believed that a greater degree of protein denaturation would occur with prolonged or excessive mechanical agitation and thereby reduce the emulsification of fats.

2.4.3 Effect of grinding, mincing, chopping

Water-binding capacity is the critical issue in the low-fat meat production (Rust and Olson, 1988). Therefore, methods to achieve maximum protein-water binding that have been studied include: prolonged chopping, mincing, and temperature of chopping compared to the binding ability in traditional processes. The aim of grinding, chopping and mincing is to reduce the particle size for the extraction of the myofibrillar proteins needed for water and fat holding, as well as gelation (Wirth, 1987). Grinding or mincing cuts the fibrils and destroys the sarcolemma, releasing the myofibrils and myofilaments into the batter system (Hamm, 1975; Schut, 1975). Water binding is reportedly better when the water is added after grinding. Otherwise the meat fibers are dispersed in the water and are not ground thoroughly (Hamm, 1960). For prerigor muscle, grinding

accelerated the rate of pH decline, though it appeared to limit the extent of its decline as compared to postrigor muscle pH (Judge and Aberle, 1980).

Water added during comminution is initially in the free or bulk phase and the objective is to have enough salt-activated myofibrillar protein to bind both the muscle tissue bulk water and the added process water (Acton et al., 1983). Fat, which is comparatively soft, is broken up early in the comminution process but the globule size is reduced as chopping continues (Hansen, 1960). If the moisture content is increased during chopping, increased fat particle size will result due to decreased batter viscosity offering less restriction to fat mobility (Lee, 1985). The optimum endpoint chopping temperature ranges from 15 to 23°C for batters containing 30% fat and added water levels <10% (Brown and Toledo, 1975).

Hensley and Hand (1995) studied chopping temperatures in the range 9 to 15°C and found that low-fat, high moisture frankfurters chopped at 12°C tended to have the highest firmness. Sutton et al. (1995) found that as end point chopping temperature increased, batter stability and shear force decreased. In addition, the initial temperature did not affect textural properties or batter stability. End point chopping temperature of $\leq 15^\circ\text{C}$ resulted in most stable batters and chopping $>15^\circ\text{C}$ lowered Kramer energy to shear (Sutton et al., 1995).

Prolonged chopping resulted in changes in fat and water binding (Brown and Toledo, 1975). Hansen (1960) reported that chopping time must be sufficient to form a protein matrix enclosing the dispersed fat, and myosin and actomyosin appeared to supply these stabilizing membranes around the fat globules. However, excessive chopping time can also cause emulsion instability. According to Wilson (1960), myosin is salt extracted from the meat during chopping to form an interface between solubilized protein and fat phases of an emulsion. With continued chopping, semisolid fat is cut into increasingly smaller fat globules, creating a larger total fat surface for the protein to cover. If insufficient myosin is available, fat globules not fully surrounded will coalesce, causing emulsion breakdown. Both underchopping (Lee et al., 1987) and overchopping (Brown and Toledo, 1975) resulted in increased fat and moisture losses, but overchopping resulted in the higher loss (Payne and Rizvi, 1988). Lee et al. (1987) stated

that underchopping the batter resulted in poorer protein extraction and lower firmness, chewiness, and elasticity scores.

As comminution time increases, meat emulsion temperature will increase and the frictional heat will cause fat phase transition in which the solid fat becomes a liquid (Acton et al., 1983). Emulsification temperature also has a profound effect on product characteristics such as water and fat holding as well as texture. Fat emulsification usually has an optimum temperature in the range 15° to 21°C and exceeding these temperatures results in unstable emulsions (Hansen, 1960; Swift et al., 1961; Helmer and Saffle, 1963; Brown and Toledo, 1975; Webb et al., 1975). Hansen (1960) attributed this phenomenon to excessive temperatures during chopping which denatured or broke the protein matrix. Increase in comminution temperatures have also been associated with decreases in frankfurter skin strength (Townsend et al., 1971) and larger fat globule size (Helmer and Saffle, 1963). However, Ackerman et al. (1971) reported that the numbers of lipid particles of 5 microns or less in diameter increased as comminution was continued to higher temperatures.

Recent studies have indicated a complex effect that not only includes final chopping temperature, but also materials present during various stages of particle size reduction, individual component temperature, and chopping speed. Batter composition affected the final temperature with increased fat and/or decreased moisture resulted in higher temperatures after mincing (Claus et al., 1989). There was a direct relationship between temperature and protein-protein interaction of actomyosin (Deng et al., 1976), however any protein-protein interaction and molecular aggregation that occurred was reversible between 4 and 30°C (Deng et al., 1981). Chopping at low temperatures, where actomyosin protein-protein interactions are at a minimum, allowed prolonged chopping without losses in fat and water binding abilities (Deng et al., 1981). A final chopping temperature of 7°C resulted in firmer texture, lower percentage of free water (press method) and moisture loss (Cook method) in emulsion-type pork sausage than either 12.8 or 18.3°C, although the 12.8°C treatment had the highest cook yield (Okerman and Wu, 1990). Barbut (1990) reported that chopping all ingredients together to the desired temperature resulted in a higher cooking loss even it chopped to the similar to the optimum temperature for protein extraction of 7.2°C reported by Gillett et al. (1977).

Webb et al. (1975) indicated that adding cold fat to the chopper did not yield the highest stability. Instead, adding the fat at high temperature (76.7°C) produced higher cook stability than fat added at 1.7 or 20°C. Faster rates of molten fat addition have been shown to lead to higher emulsification possibly due to reduced damage to protective membranes with decreased mixing (Swift et al., 1961).

2.4.4 Effect of heat processing

Textural characteristics are closely associated with a heating regime used in thermal processing due to the effect on gelation as demonstrated in gels made from individual salt-soluble proteins or in complex muscle frankfurters (Saliba et al., 1987; Camou et al., 1989; Barbut and Mittal, 1990). To enhance the sensory characteristics of no-fat and low-fat meat products, many researchers have studied the effects of heat processing.

2.4.4.1 Thermal properties and mass transfer

The thermal properties of a meat product establish the distribution of heat within a meat sample (Dikerson and Read, 1968). These thermal properties include heat transfer properties such as thermal conductivity and specific heat as well as physical properties such as product density and geometry. During heating, the thermal properties of the products were altered due to fat melting, protein denaturation and water evaporation, making accurate measurements of these properties difficult (Holtz et al., 1984).

The thermal conductivity of a food is a measure of the rate of heat flow through a product. The thermal conductivity of a meat batter increased with increasing temperatures and moisture (Agrawal, 1976; Mittal and Blaisdell, 1984). Thermal conductivity was more highly correlated with water content than with temperature. Perez and Calvelo (1984) concluded that the thermal conductivity of a product solely depended on its water content. Heldman (1975) summarized the effects of the various thermophysical properties on the cooking times of the meat products. Cooking times would increase with an increase in product size, density and /or specific heat.

During cooking, mass transfer occurs as moisture diffuses from the product's interior to the surface, and as moisture evaporates from the product surface to the air

(Bengtsson et al., 1976). The moisture evaporation rate from the product surface to the air was controlled by the moisture concentration differences between the surface and the air (Skjoldebrand, 1980; Toledo, 1980). Moisture migration within the product's interior is dependent on the product's temperature, composition, moisture concentration, and water-holding capacity (Agrawal, 1976; Skjoldebrand and Hallstrom, 1980; Mittal and Blaisdell, 1984; Mittal and Usborne, 1985b). Moisture diffusivity was found to increase with increased temperatures and moisture concentrations. Mittal and Blaisdell (1984) reported that the moisture diffusivity increased with a decrease in the fat/protein ratio. Only free water was involved in moisture transfer, and therefore moisture migration was dependent on the water-holding capacity of the product (Skjoldebrand, 1980).

2.4.4.2 Smokehouse process

There are several operations accompanied with the smoking and cooking of the meat emulsion. The sequential and systematic organization of these operations is known as the thermal schedule. The following is a brief review of the various stages of meat emulsion thermal processing: (1) Drying. Drying is closely related to skin formation which affects shrinkage and influences surface conditions of the products which affect smoke deposition and color development; (2) Smoking. The primary purposes of smoking meat are the development of flavor and color, protection from oxidation and preservation; (3) Resting. Resting period allows smoke penetration into product and settlement of the mist; (4) Cooking. Cooking improves food safety and increases storage life, coagulates the meat proteins, improves peelability of the final products, stabilizes red color in cured meat and modifies the product texture; and (5) Chilling. The purpose of spray chilling is to rapidly remove the heat below 4°C and optimize shelf life (Mittal et al., 1987).

2.4.4.3 Thermal processing

The computer controlled smokehouse systems offer potential for the optimization of thermal processing schedule. High temperature and high humidity were reported to have an adverse effect on emulsion stability, texture and color development (Saffle et al., 1967; Monagle et al., 1974). Simon et al. (1965) reported that high relative humidity

during emulsion cooking reduced the firmness of the final product. Various investigators (Monagle et al., 1974; Townsend et al., 1971; Saffle et al., 1967) suggested that a steady rate of increase in the smokehouse temperature resulted in a more acceptable product. Monagle et al. (1974) started the cooking cycle at 55°C and increased the temperature by 5 to 6°C every 10 min to 83°C. With this cycle, better scores were obtained for both product color and texture acceptability, but resulted in greater shrinkage.

Most investigations of comminuted sausages have stressed the evaluation of the direct heat stability of raw prepared mixes without much attention being given to changes within the systems from the end of comminution (18°C) to the final product temperature about 66 to 71°C (Acton et al., 1983). Following formation of the fat dispersion within the protein sol matrix, and the application of thermal energy during heat processing, protein-protein aggregation occurs (Acton et al., 1983). The aggregated filamentous network is suitably structured to entrap both water and fat.

2.4.4.4 Effect of temperature on meat proteins

Thermal gelation of myofibrillar protein is largely responsible for the textural properties of processed meat products (Asghar et al., 1985). Cheng and Parrish (1979) reported that myofibrillar proteins of bovine longissimus muscle denatured as follows: alpha-actinin is insoluble at 50°C, myosin heavy and light chains by 55°C, actin between 70 to 80°C, and troponin and tropomyosin above 80°C. Further studies on the myosin molecule where the differential shear modulus was plotted against temperature revealed two transition temperatures for myosin at 43 and 55°C (Ishioroshi et al., 1979). Park (1991) found that myofibrils from beef or pork formed gels with greater hardness than commercial fish surimi above 55°C. As concentration of myofibrillar proteins in the gel increased, gel hardness increased regardless of cooking temperature or species (Park, 1991). Asghar et al. (1985) reported that myosin or actomyosin largely determined the quality and strength of binding in sausages. Heating to temperatures of less than 35°C resulted in only minor increases in shear modulus (Ishioroshi et al., 1979) and modest increase in shear modulus when heating from 45 to 50°C (Seigel and Schmidt, 1979). Further temperature increase above 50°C resulted in maximum textural strength and

binding ability (Ishioroshi et al., 1979; Siegel and Schmidt, 1979; Foegeding et al., 1986; Barbut and Mittal, 1990).

Water binding ability of cooked meat products was at its maximum at low temperature and progressively decreased as the cooking temperature increased above approximately 55°C, though increasing the level of salt (0.72 to 2.52%) raised the minimum temperature for significant water loss (Trout and Schmidt, 1986). Cooking water loss may result from shrinkage or aggregation and coalescence of filament lattice (Offer and Trinick, 1983; Hermansson, 1985). A chemical basis for this was explained by Hamm and Deatherage (1960) who demonstrated that heating at temperatures of 40 to 50°C and 55 to 80°C decreased the number of acidic groups. At neutral pH, the muscle proteins carry a net negative charge. This negative charge is responsible for repulsive forces between protein molecules which prevent them from interacting. This charge may be reduced by lowering the pH or increasing the salt concentration. Thus, electrostatic repulsion between protein molecules is reduced and proteins can interact. At low pH, muscle proteins are soluble because the proteins have a net positive charge, leading to a loosening of protein structure and consequently increased WHC. The decrease in the number of carboxyl groups explained why the pI shifted to higher values at higher cooking temperature. Basic groups appeared to be unaffected during heating. Awonorin and Rotimi (1992) found that weight loss, compressive and penetration stresses increased as the end point temperature of meat products increased.

2.4.4.5 Effect of the heating rate

Selecting an appropriate heating rate for cooking a meat product is important in determining the final product quality and its production cost because heating rate affects the type of protein-protein interactions that occurred during cooking (Barbut and Mittal, 1990). Normally, the use of slow heating rate in cooking meat products resulted in greater gel strength of salt soluble proteins and higher modulus of rigidity (G), hardness, gumminess, and chewiness values because the slow heating rate may allow more complete and stronger protein-protein interactions, resulting in more ordered formation, more uniform and stronger 3-dimensional gel structure of the protein molecules (Hermansson, 1978; Foegeding et al., 1986; Camou et al., 1989). However, the adverse

effect were higher fluid losses during cooking (Camou et al., 1989). Also, increasing the heating rate resulted in an increase of protein in the liquid exuded after compression (Camou et al., 1989). A more ordered denaturation leading to gelation, rather than aggregation, resulted in a higher degree of elasticity and finer gel network (Hermansson, 1978). However, the heating rate did not have any significant effect on the total water loss from the gel (Camou et al., 1989). Unlike Camou's study, under smokehouse conditions, faster rates of heating decreased moisture losses (Lee et al., 1987; Mittal et al., 1987; Barbut and Mittal, 1990).

2.4.3.6 Effect of relative humidity

Relative humidity (RH) is defined as the ratio of amount of moisture in the air compared to the maximum amount that can be contained at a specific temperature (Saffle et al., 1967). The use of low relative humidity during cooking resulted in better texture, color improvement but greater shrinkage (Saffle et al., 1967). Higher RH during cooking may limit moisture losses (Monagle et al., 1974; Mittal et al., 1987), and may decrease the cooking time due to higher energy level in the air (Saffle et al., 1967). Higher fat emulsion stability values occurred with higher rates (1.1 to 3.9% per min) of RH increases (Mittal et al., 1987). Awonorin and Rotimi (1992) found that the internal temperature of samples increased rapidly using higher levels of humidity in the smokehouse because heat transfer during thermal processing was enhanced by both high heat transfer coefficient of the condensing stream, and the temperature difference between the product surface and its center, thus, processing time was shorter. The surface temperature is a function of wet bulb temperature in the smokehouse. The use of high humidity resulted in increasing the sample weight about 3 to 9% in the initial stages of processing but decreasing both the compressive and penetration stresses.

2.5 REFERENCES

- Aberle, E.D., Drerup, D.L., and Judge, M.D. 1980. Inhibition of lipid oxidation and enhanced acceptability of prerigor ground and salted pork. Proc. 26th Meeting European Meat Res. Workers. Abstract.
- Ackerman, S.A., Swift, C.E., Carroll, R.L., and Townsend, W.E. 1971. Effects of type of fat and of rates and temperatures of comminution on dispersion of lipids in frankfurters. *J. Food Sci.* 36: 266-269.
- Acton, J.C. and Saffle, R.L. 1969. Preblended and prerigor meat in sausage emulsions. *Food Technol.* 23: 93-97.
- Acton, J.C., Ziegler, G.R., and Burge, D.L., Jr. 1983. Functionality of muscle constituents in the processing of comminuted meat products. *CRC Critical Reviews in Food Science and Nutrition* pp.99-121.
- Agrawal, Y.C. 1976. Modeling and experimental analysis of moisture and heat transport in meat emulsion products during smokehouse thermal processing. Ph.D. Thesis. The Ohio State University.
- Ahmed, P.O., Miller, M.F., Lyon, C.E., Vaughters, H.M., and Reagan, J.O. 1990. Physical and sensory characteristics of low-fat fresh pork sausage processed with various levels of added water. *J. Food Sci.* 55: 625-628.
- Alexander, A.E. and Johnson, P. 1950. *Colloid Science. 2nd ed.* Clarendon Press, Oxford. In Sherman, P. 1962. The water-binding capacity of fresh pork. *Food Technol.* 16(4): 91.
- Alexander, R.J. 1995. Fat replacers based on starch. *Cereal Foods World* 40: 366-368.
- Anonymous. 1993. Functional ingredient for processed meat products. *Food Technol. NZ.* 28: 26-29.
- Asghar, A., Samejima, K., and Yasui, T. 1985. Functionality of muscle protein in gelation mechanisms of structured meat products. *CRC Crit. Rev. Food Sci.Nutr.* 22: 27-106.
- Awonorin, S.O. and Rotimi, D.K. 1992. Influence of end point temperature, humidity and cold storage on mechanical and sensory properties of smoked chicken sausage. *J. Food Service Studies* 7: 43-53.
- Baardseth, P., Naes, T., Mielnik, J., Skrede, G., Holland, S., and Eide, O. 1992. Dairy ingredients affects on sausage sensory properties studied by principal component analysis. *J. Food Sci.* 57: 822-828.

- Barbut, S. 1988. Microstructure of reduced salt meat batters as affected by polyphosphates and chopping time. *J. Food Sci.* 53: 1300-1304.
- Barbut, S. 1990. Effects of three chopping methods on bologna characteristics. *Can. Inst. Of Food Sci. Technol. J.* 23: 149-153.
- Barbut, S. and Mittal, G.S. 1990. Effect of heating rate on meat batter stability, texture and gelation. *J. Food Sci.* 55:334-337.
- Barbut, S., Tanaka, N., Cassens, R.G., and Maurer, A.J. 1986. Effects of sodium chloride reduction and polyphosphate addition on *Clostridium botulinum* toxin production in turkey frankfurters. *J. Food Sci.* 51: 1136.
- Bendall, J.R. 1954. The swelling effect of polyphosphates on lean meat. *J. Sci. Food Agri.* 5: 465-468.
- Bengtsson, N.E., Jakobsson, B., and Dagerskog, M. 1976. Cooking of beef by oven roasting: A study of heat and mass transfer. *J. Food Sci.* 41: 1047-1053.
- Berry, B.W. and Wergin, W.P. 1990. Effects of fat levels, starch gel usage and freezing rate on various properties of ground beef patties. *J. Anim. Sci.* 68: 204.
- Brown, D.D. and Toledo, R.T. 1975. Relationship between chopping temperatures and fat and water binding in comminuted meat batters. *J. Food Sci.* 40: 1061-1064.
- Camou, J.P., Sebranek, J.G., and Olson, D.G. 1989. Effect of heating rate and protein concentration on gel strength and water loss of muscle protein gels. *J. Food Sci.* 54: 850-854.
- Carballo, J., Barreto, G., and Colmenero, F.J. 1995. Starch and egg white influence on properties of bologna sausage as related to fat content. *J. Food Sci.* 60: 673-677.
- CAST. 1991. In *Foods, Fats and Health*. Council for Agricultural Science and Technology, Task Force Report No 118, Chapter 6.
- Cheng, C. and Parrish, F.C., Jr. 1979. Heat-induced changes in myofibrillar proteins of bovine longissimus muscle. *J. Food Sci.* 44: 22-24.
- Choi, Y.I., Kastner, C.L., and Kropf, D.H. 1987a. Effects of hot boning and various levels of salt and phosphate on protein solubility, functionality, and storage characteristics of preblended pork used in frankfurters. *J. Food Prot.* 50: 1025-1036.
- Choi, Y.I., Kastner, C.L., and Kropf, D.H. 1987b. Effects of hot boning and various levels of salt and phosphate on microbial, TBA, and pH values of preblended pork during cooling storage. *J. Food. Prot.* 50: 1037-1043.

- Claus, J.R. 1991. Fat reduction in comminuted meat systems. *Proceedings of the Recip. Meat Conf.* June 9-12. Manhattan, Kansas. American Meat Sci. Assoc. 44: 93-99.
- Claus, J.R. and Hunt, M.C. 1991. Low-fat, high added water bologna formulated with texture-modified ingredients. *J. Food Sci.* 56: 643-647, 652.
- Claus, J.R., Hunt, M.C., and Kastner, C.L. 1989. Effects of substituting added water for fat on textural, sensory, and processing characteristics of bologna. *J. Muscle Foods* 1:1-21.
- Claus, J.R., Hunt, M.C., Kastner, C.L., and Kropf, D.H. 1990. Low-fat, high added water bologna: Effects of massaging, preblending, and time of addition of water and fat on physical and sensory characteristics. *J. Food Sci.* 55: 338-341, 345.
- Colmenero, F.J. 1996. Technologies for developing low-fat meat products. *Trends Food Sci. Technol.* 7:41.
- Crawford, D. 1991. Meat and poultry see the "lite". *Prepared foods new products annual* 1991. p. 116.
- Dahl, L.K. 1972. Salt and hypertension. *Am. J. Clin. Nut.* 25: 231.
- Deng, J.C., Toledo, R.T., and Lillard, D.A. 1976. Effect of temperature and pH on protein-protein interaction in actomyosin solutions. *J. Food Sci.* 41: 273-277.
- Deng, J.C., Toledo, R.T., and Lillard, D.A. 1981. Protein-protein interaction and fat and water binding in comminuted fresh products. *J. Food Sci.* 46: 1117-1121.
- Dikeman, M.E. 1987. Fat reduction in animals and the effects on palatability and consumer acceptance of meat products. *Proceedings of the Recip. Meat Conf.* June 28-July 1. St. Paul, Minnesota. American Meat Sci. Assoc. 40: 93-103.
- Dikerson, R.W. and Read, R.B. 1968. Calculation and measurement of heat transfer in foods. *Food Technol.* 22: 1533-1548.
- Drerup, D.L., Judge, M.D., and Aberle, E.D. 1981. Sensory properties and lipid oxidation in prerigor processed fresh pork sausage. *J. Food Sci.* 46:1659-1661.
- Ellekjaer, M.R., Naes, T., and Baardseth, P. 1996. Milk proteins affect yield and sensory quality of cooked sausages. *J. Food Sci.* 61: 660-666.
- Ellinger, R.H. 1972. Phosphates in food processing. In *Handbook of Food Additives*. 2nd ed., (Ed) T.E. Furia. CRC Press, Cleaveland, OH.

- Ellis, R., Currie, G.T., Thronton, F.E., Bollinger, N.C., and Gaddis, A.M. 1968. Carbonyls in oxidizing fat. II. The effect of the pro-oxidant activity of sodium chloride on pork tissue. *J. Food Sci.* 33: 555-561.
- Fennema, O.R. 1985. *Food Chemistry*. Marcel Dekker, Inc. New York, N.Y.
- FMC. 1988. Low-fat meat-links (non-standard frankfurters). Bull., No. B-60. FMC corp., Philadelphia, Pa.
- Foegeding, E.A., Allen, C.E., and Dayton, W.R. 1986. Effect of heating rate on thermally formed myosin, fibrinogen and albumin gels. *J. Food Sci.* 51: 104-108.
- Foegeding, E.A. and Ramsey, S.R. 1986. Effects of gums on low-fat meat batters. *J. Food Sci.* 51: 33-36, 46.
- Ghazi, H.T. 1991. Functional ingredient blend produces low-fat meat products to meet consumer expectations. *Food Technol.* 45: 70-74.
- Giese, J. 1992. Developing low-fat meat products. *Food Technol.* 46: 100-108.
- Giese, J. 1994. Proteins as ingredients: types, functions, applications. *Food Technol.* 48: 50-60.
- Gillett, T.A., Meiburg, D.E., Brown, C.L., and Simon, S. 1977. Parameters affecting meat protein extraction and interpretation of model system data for meat emulsion formation. *J. Food Sci.* 42: 1606-1610.
- Girard, J.P., Culioli, J., Maillard, T., Denoyer, C., and Touraille, C. 1990. Influence of technological parameters on the structure of the batter and the texture of frankfurter type sausages. *Meat Sci.* 27: 13-28.
- Glicksman, M. 1991. Hydrocolloids and the search for the "oily grail". *Food Technol.* 45: 94-103.
- Gregg, L.L., Claus, J.R., Hackney, C.R., and Marriott, N.G. 1993. Low-fat, high added water bologna from massaged, minced batter. *J. Food Sci.* 58: 259-264.
- Hamm, R. 1960. Biochemistry of meat hydration. *Adv. Food Research* 10: 355-463.
- Hamm, R. 1975. On the rheology of minced meat. *J. Texture Studies* 6: 281-296.
- Hamm, R. and Deatherage, F.E. 1960. Changes in hydration, solubility and charges of muscle proteins during heating of meat. *Food Res.* 25: 587.

- Hand, L.W., Hollingsworth, C.A., Calkins, C.R., and Mandigo, R.W. 1987. Effects of preblending, reduced fat and salt levels on frankfurter characteristics. *J. Food Sci.* 52: 1149-1151.
- Hansen, L.J. 1960. Emulsion formation in finely comminuted sausage. *Food Technol.* 14: 565-572.
- Hargett, S.M., Blumer, T.N., Hamann, D.D., Keeton, J.T., and Monroe, R.J. 1980. Effect of sodium acid pyrophosphate on sensory, chemical, and physical properties of frankfurters. *J. Food Sci.* 45: 905-911.
- Heldman, D.R. 1975. Heat transfer in meat. *Proceedings of the Recip. Meat Conf.* National Live Stock and Meat Broad, Chicago. *American Meat Sci. Assoc.* 28: 314-325.
- Helmer, R.L. and Saffle, R.L. 1963. Effect of chopping temperature on the stability of sausage emulsions. *Food Tech.* 17(6): 115-119.
- Hensley, J.L. and Hand, L.W. 1995. Formulation and chopping temperature effects on beef frankfurters. *J. Food Sci.* 60: 55-57, 67.
- Hermansson, A.M. 1978. Physico-chemical aspects of soy proteins structure formation. *J. Texture Studies* 9: 33-58.
- Hermansson, A.M. 1985. Water- and fat-holding. Ch. 6. In *Functional Properties of Food Macromolecules*, J.R. Mitchell and D.A. Ledward (Ed.), p.273. Elsevier Science Publishing Co., Inc., New York, N.Y.
- Hill, S.E. and Prusa, K.J. 1988. Physical and sensory properties of lean ground beef patties containing methylcellulose and hydroxypropylmethyl cellulose. *J. Food Qual.* 11: 331.
- Holtz, E., Skjoldebrand, C., Bogнар, D.A., and Pickarski, J. 1984. Modeling the baking process of meat products using convection ovens. In "Thermal Processing and Quality of Foods". Elsevier Science Publishing Co., Inc., New York, N.Y. pp. 329-338.
- Huffman, D.L., Egbert, W.R., Chen, C., and Dylewski, D.P. 1991. Technology for low-fat ground beef. *Proceedings of the Recip. Meat Conf.* June 9-12. Manhattan, Kansas. *American Meat Sci. Assoc.* 44: 73-77.
- Huffman, L.M. 1996. Processing whey protein for use as a food ingredient. *Food Technol.* 50: 49-52.
- Ishioroshi, M., Samejima, K., and Yasui, T. 1979. Heat-induced gelation of myosin: factors of pH and salt concentration. *J. Food Sci.* 44: 1280-1285.

- Judge, M.D. and Aberle, E.D. 1980. Effect of preigor processing on the oxidative rancidity of ground light and dark porcine muscles. *J. Food Sci.* 45: 1736-1739.
- Judge, M.D., Aberle, E.D., Forrest, J., Hedrick, H., and Merkel, R. 1989. *Principal of Meat science, 2nd ed.* Kendall/hunt Publishing Co. Dubuque, Iowa.
- Keeton, J.T. 1991. Fat substitutes and fat modification in processing. *Proceedings of the Recip. Meat Conf.* June 9-12. Manhattan, Kansas. American Meat Sci. Assoc. 44: 79-91.
- Keeton, J.T. 1992. Low-fat meat products-Technological problems with processing. *Proceedings of International Congress of Meat Science and Technology.* Clermont-Ferrand France. 38(1): 175-182.
- Keeton, J.T. 1994. Low-fat meat products-Technological problems with processing. *Meat Science* 36: 261-276.
- Keeton, J.T. 1996. Non-meat ingredients for low-/no-fat processed meats. *Proceedings of the Recip. Meat Conf.* June 9-12. Provo, Utah. American Meat Sci. Assoc. 49: 23-31.
- Kevin, K. 1995. "Starch de resistance." *Food Processing* 56(1): 65-67.
- Knipe, C.L., Rust, R.E., and Olson, D.G. 1990. Some physical parameters involved in the addition of inorganic phosphates to reduce-sodium meat emulsions. *J. Food Sci.* 55: 23-29.
- Knipe, T.C. 1983. Effects of inorganic polyphosphates on reduced sodium and conventional meat emulsion characteristic. Ph.D. thesis, Iowa State Univ., Ames, Ia.
- Lanier, T.C. 1994. Functional food protein ingredients from fish. In "Sea food proteins." Ed. Sikorski, Z.E., Pan, B.S., and Shahidi, F. pp. 127-159. Chapman and Hall, New York, NY.
- Lee, C.M. 1985. Microstructure of meat emulsions in relation to fat stabilization. *Food Microstructure* 4: 63-72.
- Lee, C.M., Whiting, R.C., Jenkins, R.K. 1987. Texture and sensory evaluations of frankfurters made with different formulations and processes. *J. Food Sci.* 52: 896-900.
- Lin, K.C., Keeton, J.T., Gilchrist, C.L., and Cross, H.L. 1988. Compositions of carboxymethyl cellulose with differing molecule features in low-fat frankfurters. *J. Food. Sci.* 53: 1592-1595.

- Luallen, T.E. 1985. Starch as a functional ingredient. *Food Technol.* 39: 59-63.
- Marquez, E.J., Ahmed, E.M., West, R.L., and Johnson, D.D. 1989. Emulsion stability and sensory quality of beef frankfurters produced at different fat or peanut oil levels. *J. Food Sci.* 55: 867-870, 873.
- Marriott, N.G., Graham, P.P., and Bovard, K.P., 1983. Comparison of restructured chops manufactured from prerigor and postrigor pork. *J. Food Prot.* 46: 589-591, 595.
- Matulis, R.J., McKeith, F.K., Brewer, M.S., and Bechtel, P.J. 1994. Characteristics of frankfurters with different cooking parameters. *J. Muscle Foods* 5: 431-448.
- McAuley, C. and Mawson, R. 1994. Low-fat and low-salt meat product ingredients. *Food Australia* 46: 283-285.
- Mickelsen, O. 1982. The nutritional importance of sodium. In *Sodium Intake-Dietary Concerns*, T.M. Freeman and O.W. Gregg (Ed.), p. 1. The American Association of Cereal Chemists. St. Paul, Minn.
- Miles, R.S. 1996. Developing and manufacturing low/no-fat products and processes. *Proceedings of the Recip. Meat Conf.* June 9-12. Provo, Utah. American Meat Sci. Assoc. 49: 17-20.
- Mittal G.S. and Barbut, S. 1994. Effects of fat reduction on frankfurters' physical and sensory characteristics. *Food Research International* 27: 425-431.
- Mittal, G.S. and Blaisdell, J.L. 1984. Heat and mass transfer properties of meat emulsion. *Lebensmittel-Wissenschaft-Technologie* 17(2): 94-98.
- Mittal, G.S. and Osborne, W.R. 1985a. Meat emulsion extenders. *Food Technol.* 39: 121-130.
- Mittal, G.S. and Osborne, W.R. 1985b. Moisture isotherms for uncooked meat emulsions of different composition. *J. Food Sci.* 50: 1576-1579.
- Mittal, G.S., Wang, C.Y., and Osborne, W.R. 1987. Smokehouse process conditions for meat emulsion cooking. *J. Food Sci.* 52: 1140-1146, 1154.
- Molins, R.A. 1991. *Phosphates in Food*. CRC Press, Inc. Boca Raton, Fl.
- Monagle, C.W., Wang, C.Y., and Saffle, R.L. 1974. Effect of smokehouse temperature, humidity and air velocity on rate of heating and quality of frankfurters. *J. Food Sci.* 39: 602-604.

- Mortensen, B.K. 1986. The use of milk powder in food products. *Proceedings of the Intern. Dairy Congress*. Sept 29-Oct3. Hague, Brussels. International Dairy Federation 22: 709.
- Murphy, D. 1995. "Free...at last." *Meat Marketing & Technology*. October. 1995. pp. 19-24.
- Murray, D.G. 1989. Formulating lower-fat and lower-salt processed meats. *Food Engineering* Sept.
- Nelson, K.A., Busta, B.F., Sofos, J.N., and Wagner, M.K. 1983. Effects of polyphosphates in combination with nitrite-sorbate or sorbate on *C. botulinum* growth and toxin production in chicken frankfurter emulsions. *J. Food Prot.*46: 846.
- Offer, G. and Trinick, J. 1983. On the mechanism of water holding in meat: the swelling and shrinking of myofibrils. *Meat Sci.* 8: 245-281.
- Okerman, H.W. and Wu, Y.C. 1990. Hot boning, tumbling, salt and chopping temperature effects on cooking yield and acceptability of emulsion-type pork sausage. *J. Food Sci.* 55: 1255-1257.
- Osburn, W.N. and Keeton, J.T. 1994. Konjac flour gel as a fat substitute in low fat prerigor fresh pork sausage. *J. Food Sci.* 58: 484-589.
- Park, J., Rhee, K.S., Keeton, J.T., and Rhee, K.C. 1989. Properties of low-fat frankfurters containing monosaturated and Omega-3 polyunsaturated oils. *J. Food Sci.* 54: 500-504.
- Park, J., Rhee, K.S., and Ziprin, Y.A. 1990. Low-fat frankfurters with elevated levels of water and oleic acid. *J. Food Sci.* 55: 871-872, 874.
- Park, S.C. 1991. A surimi-like material made from beef and pork and a novel protease in bovine and porcine skeletal muscle. Ph.D. thesis, Univ. of Illinois at Urbana-Champaign.
- Payne, N.N. and Rizvi, S.S.H. 1988. Rheological behavior of comminuted meat batters. *J. Food Sci.* 55: 70-73,87.
- Pearson, A.M., Asghar, A., Gray, J.I., and Booren, A.M. 1987. Impact of fat reduction on palatability and consumer acceptance of processed meat. *Proceedings of the Recip. Meat Conf.* June 28-July 1. St. Paul, Minnesota. American Meat Sci. Assoc. 40: 105-114.
- Perez, M.G.R. and Calvelo, A. 1984. Modeling the thermal conductivity of cooked meat. *J. Food Sci.* 49: 152-156.

- Pszczola, D.E. 1992. Functional ingredients enhance value of low-fat foods and microwaved foods. *Food Technol.* 46: 116-117.
- Puolanne, E.J. and Terrell, R.N. 1983. Effects of salt levels in prerigor blends and cooked sausages on water binding, released fat and pH. *J. Food Sci.* 48: 1022-1024.
- Quinn, J.R., Raymond, D.P., and Harwalkar, V.R. 1980. Differential scanning calorimetry of meta proteins as affected by processing treatment. *J. Food Sci.* 45: 1146-1152, 1160.
- Rakosky, J. 1988. Protein additives in foodservice applications. AVI, Van Nostrand Reinhold, New York, N.Y.
- Reitmeier, C.A. and Prusa, K.J. 1991. Composition, cooking loss, color and compression of ground pork with dry- and wet- milled corn germ meals. *J. Food Sci.* 56: 216-219.
- Rust, R. and Olson, D. 1988. Making good "lite" sausage. *Meat & Poultry* 34: 10.
- Saffle, R.L., Carpenter, J.A., and Zirkle, S.B. 1967. Rapid method to determine stability of sausage emulsion and effect of processing temperature and humidities. *Food Technol.* 21: 784-788.
- Saliba, D.A., Foegeding, E.A. and Hamann, D.D. 1987. Structural failure and nondestructive rheological analyses of frankfurter batters: effect of heating rates and sugars. *J. Texture Studies* 18: 241-259.
- Savell, J.W., Harris, J.J., Cross, H.R., Hale, D.S., and Beasley, L. 1991. National beef market basket survey. *J. Anim. Sci.* 69: 2883-2903.
- Schmidt, G.R. 1987. Functional behavior of meat components in processing. Ch. 11. In *The Science of Meat and Meat products*, 3rd ed., J.F. Price and B.S. Schweigert (Ed.), p.413. Food and Nutrition Press, Inc., Westport, Conn.
- Schut, J. 1975. Meat Emulsions. Ch 8. In *Food Emulsions*, S. Friberg (Ed.), p. 385. Marcel Dekker, Inc., New York, NY.
- Seigel, D.G. and Schmidt, G.R. 1979. Ionic, pH and temperature effects on the binding ability of myosin. *J. Food Sci.* 44: 1686-1869.
- Seman, D.L., Olson, D.G., and Mandigo, R.W. 1980. Effect of reduction and partial replacement of sodium on bologna characteristics and acceptability. *J. Food Sci.* 45: 1116-1121.

- Shand, P.J. and Schmidt, G.R. 1990. New technology for low-fat meat products. *Proceedings of the Recip. Meat Conf.* June 10-13. Mississippi State, Mississippi, American Meat Sci. Assoc. 43: 37-46.
- Simon, S., Field, J.C., Kramlich, W.E., and Tauber, F.W. 1965. Factors affecting frankfurter texture and method of measurement. *Food Technol.* 19(3): 410-413.
- Siripurapu, S.C.B., Mittal, G.S., and Blaisdell, J.L. 1987. Texture and viscoelastic characteristics of meat emulsion products during cooking. *Lebensmittel-Wissenschaft-Technologie* 20: 68-73.
- Skjoldebrand, C. 1980. Convection oven flying: Heat and mass transfer between air and product. *J. Food Sci.* 45: 1354-1362.
- Skjoldebrand, C. and Hallstrom, B. 1980. Convection oven flying: Heat and mass transport in the product. *J. Food Sci.* 45: 1347-1353.
- Sofos, J.N. and Allen, C.E. 1977. Effects of lean meat source and levels of fat and soy protein on the properties of wiener-type products. *J. Food Sci.* 42: 875-878.
- Solheim, R. 1990. Will customers accept sausages with a reduced fat content? *Inform MAT* 3: 22-27.
- Solomon, L.W. and Schmidt, G.R. 1980. Effect of vacuum and mixing time on the extractability and functionality of pre-and post-rigor beef. *J. Food Sci.* 45: 283-287.
- St. John, L.C., Buryck, M.J., Keeton, J.T., Leu, R., and Smith, S.B. 1986. Sensory and physical attributes of frankfurters with reduced fat and elevated monosaturated fat. *J. Food. Sci.* 51: 1144-1146.
- Sutton, D.S., Hand, L.W., and Newkirk, K.A. 1995. Reduced fat, high moisture beef frankfurters as affected by chopping temperature. *J. Food Sci.* 60: 580-582, 586.
- Swift, C.E., Lockett, C., and Fryar, A.J. 1961. Comminuted meat emulsions-the capacity of meats for emulsifying fat. *Food Technol.* 15 : 468-473.
- Swift, C.E. and Sulzbacher, W.L. 1963. Comminuted meat emulsions: factors affect meat protein as emulsion stabilizers. *Food Technol.* 17(2): 106-108.
- Sylvia, S.F., Claus J.R., Marriott, N.G., and Eigel, W.N. 1994. Low-fat, high moisture frankfurters: Effects of temperature and water during extended mixing. *J. Food Sci.* 59: 937-940, 945.
- Terrell, R.N., Brown, J.A. 1981. Salt, water, and oilseed proteins affect brine content of sausages. *J. Food Prot.* 44: 43-46.

- Todd, S.L., Cunningham, F.E., Schwenke, J.R., and Goetsch, S.J. 1990. Sensory analysis of fiber formulated ground pork patties. *J. Sensory Stud.* 5: 145-157.
- Toledo, R.T. 1980. *Fundamentals of Food Process Engineering*. AVI Publishing Company, Westport, CT.
- Townsend, W.E., Ackerman, S.A., Witnauer, L.P., Plam, W.E., and Swift, C.E. 1971. Effects of types and levels of fat and rates and temperatures of comminution on the processing and characteristics of frankfurters. *J. Food Sci.* 36: 261-265.
- Trout, E.S., Hunt, M.C., Johnson, D.E., Claus, J.R., Kastner, C.L., and Kropf, D.H. 1992. Characteristics of low-fat ground beef containing texture-modifying ingredients. *J. Food Sci.* 57: 19-24.
- Trout, G.R. and Schmidt, G.R. 1983. Utilization of phosphates in meat products. *Proceedings of the Recip. Meat Conf.* June 12-15. Fargo, North Dakota. American Meat Sci. Assoc. 36: 24-27.
- Trout, G.R. and Schmidt, G.R. 1986. Water binding ability of meat products: effect of fat level, effective salt concentration and cooking temperature. *J. Food Sci.* 51: 1061-1062.
- Tye, R.J. 1991. Konjac flour: properties and applications. *Food Technol.* 45: 82-92.
- USDA. 1982. Meat and poultry products. Phosphates and sodium hydroxide. Fed. Reg. 47: 10779-10783.
- USDA. 1985. Code of Federal Regulation, Title 9, Ch III:381.147.
- USDA. 1988. Standard for frankfurter and similar cooked sausages. Federal Register. 53(50): 8425-8428.
- USDA. 1991. Labeling of frankfurters and similar products containing binders and extender. Fed. Reg. 56: 41445-41448.
- USDA. 1995. Policy Memo 121B and 123. United States Department of Agriculture-Food Safety and Inspection Service. January 20, 1995.
- Van den Hoven, M. 1987. Functionality of dairy ingredients in meat products. *Food Technol.* 41: 72-73,76-77, 103.
- Waldman, R.C., Westerberg, D.O., and Simon, S. 1974. Influence of curing ingredients and storage time on the quality of preblended sausage meats and frankfurters. *J. Food Sci.* 39: 718-722.
- Watts, B.M. 1954. Oxidative rancidity and discoloration in meat. *Adv. Food Res.* 5: 1.

- Webb, N.B., Rao, V.N.M., howell, A.J., Barbour, B.C., and Monroe, R.J. 1975. Effect of lipid and chopping temperatures on sausage emulsion stability in a model system. *J. Food Sci.* 40: 1210-1231.
- Whiting, R.C. 1984. Stability and gel strength of frankfurter batters made with reduced NaCl. *J. Food Sci.* 49: 1350-1354, 1362.
- Wilson, G.D. 1960. Meat emulsions. In *The Science of Meat and Meat Products*. W.H. Freeman and Company, San Francisco, CA. pp. 351-352.
- Wirth, F. 1987. Frankfurter-type sausages water binding, fat binding, development of structure. *Fleischwirtsch. International*. 1: 24-31.
- Yackel, W.C., and Cox, C. 1992. Application of starch based-fat replacers. *Food Technol.* 46: 146-148.

Chapter 3

Textural and Physical Properties of Fat-Free Turkey-Beef Frankfurters: Effects of Non-Meat Ingredients and End Point Temperature

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ABSTRACT

The effects of NaCl (1 and 2%), added-water (AW; 30 and 40%), milk protein hydrolysate (MPH; 1, 2 and 3%), and end-point cooking temperature (EPT; 71.1 and 76.7 °C) were examined. Higher NaCl content resulted in lower ($P < 0.05$) cooking loss, darker frankfurters and lower penetration values (total energy and peak force) but higher shear stress and shear strain. Higher levels of AW resulted in higher ($P < 0.05$) cooking loss, purge loss, cohesiveness, and lighter and less red products but reduced ($P < 0.05$) penetration values, shear stress, shear modulus and hardness. Increasing the amount of MPH decreased ($P < 0.05$) cooking loss and shear strain and produced darker, more yellow, and less red frankfurters but increased ($P < 0.05$) shear stress, and shear modulus. Higher EPT produced ($P < 0.05$) lighter frankfurters and increased cooking loss, shear stress and shear modulus, but decreased penetration values, shear strain and cohesiveness. Changes in the texture of fat-free turkey frankfurters can be achieved by altering in the amount of salt, AW, MPH, and EPT level.

Key Words: fat-free frankfurter, salt, milk protein, added water, end point temperature

INTRODUCTION

Low-fat processed meat products are defined as these contain 3 grams of fat per Recommended Amount Customarily Consumed (RACC). “No-fat” products contain less than 0.5% fat (Miles, 1996). For a product with a 55-gram RACC such as frankfurters, the maximum fat content is 5.45% in low-fat and 0.9% in no-fat frankfurters (Miles, 1996). Reduced fat meat products may have less desirable flavor and textural attributes than traditional products. Attempts, with some success, have been made to retain sensory and textural attributes through fat reduction by replacing fat with water (Claus et al.,

1989, 1990), carbohydrate-based fat substitutes (Keeton, 1992), and protein-based fat substitutes (Reitmeier and Prusa, 1991).

NaCl is a principle ingredient in processed meat due to its flavor, enhancing and preservative properties and its effects on protein functionality. Comminution of meat in the presence of sufficient salt induces a partial extraction of the myofibrillar proteins (Acton et al., 1983). Reduced salt content decreases protein extraction and water binding in addition to changing palatability attributes such as saltiness, flavor intensity, and juiciness (Schut, 1975). The lessened binding properties may be partially compensated by adding other non-meat ingredients such as milk protein and starch (Ellekjaer et al., 1996; Keeton, 1992).

Water added to replace fat has been shown to prevent undesirable textural changes associated with low-fat products. The “40-PERCENT” RULE (USDA, 1988) that permits the addition of any combination of fat and added water (AW) up to a total of 40%, with a fat limitation of 30% has been used to formulate a variety of low-fat products. Claus et al. (1989, 1990) found that low-fat, high AW bologna was generally less firm, more cohesive, juicier, and darker than a 30% fat-10% added water control, if the protein content was similar.

Milk proteins act as emulsifiers and water/fat binders in comminuted meat products (Mortensen, 1986). Milk protein has been widely used to increase water holding capacity of the batter and improve yield of sausage (Girard et al., 1990). Ellekjaer et al. (1996) reported that sausages (20% fat) with 1.5% milk protein had minimum cooking loss and were most similar in sensory characteristics when compared to the control formulated with 20% fat and no added milk protein.

Thermal processing has a critical role in product quality and texture. Siripurapu et al. (1987) reported that coagulation of myofibrillar proteins occurred on heating at 30 to 40°C (coagulation was complete at 55°C). By the time the meat temperature reached 60°C, the majority of the sarcoplasmic and myofibrillar proteins were denatured. Meat protein denaturation is accompanied by decreased water holding capacity and increased rigidity (Siripurapu et al., 1987). Matulis et al. (1994) reported that an increase in end point temperature resulted in increased hardness and shear force whereas water holding capacity and juiciness scores decreased. However, very limited information has been

published on the effect of end point temperature in fat-free frankfurters. The objectives of this study were to determine the effects of added water (USDA AW; 30%, 40%), sodium chloride (1, 2%), milk protein hydrolysate (1, 2, 3%) and cooking end point temperature (71.1, 76.7°C) on the textural and physical properties of fat-free turkey-beef frankfurters.

MATERIALS AND METHODS

Preparation of meat tissues

Fresh lean turkey breast (approximately 1% fat) was obtained from different turkey plants in Virginia and refrigerated at 4°C for 1 day before further step. Fresh lean beef (approximately 3% fat) was obtained from a Virginia meat packing plant. The beef muscle used in this research was inside cow rounds (semimembranosus). The fresh beef was trimmed of subcutaneous and intermuscular fat and then frozen the same day purchased. The frozen beef was thawed by placing in a cooler for 1 day before grinding. Both the turkey breast and beef were separately ground twice (6.4-mm plate, model 4532 grinder, Hobart Manufacturing Co., Troy, OH) and then stored at 2 to 3°C before further processing. The lean turkey breast and lean beef were analyzed for moisture, protein, and fat (Foss-let Rapid Fat Analyzer, A/S N Foss Electric, Denmark) in triplicate (AOAC, 1995).

Formulation of Frankfurter Batters

All treatments were formulated using the Least Cost Formulator (version 2.19, Least Cost Formulations Ltd., Inc., Virginia Beach, VA). Each batch, approximately 7 kg (Table 1), utilized the raw material proximate analyses results, a projected cook loss of 7%, and finished product specification of: 0.5% fat, 30% or 40% USDA AW, 1 or 2% sodium chloride (NaCl), 1.1% dextrose (A.C. Legg Packing Co., Inc., Birmingham, AL), 2% corn syrup solid (A.C. Legg Packing Co., Inc., Birmingham, AL), 4% modified waxy maize starch (Thermax, National Starch Co., Bridgewater, NJ), 0.5% sodium tripolyphosphate (meat weight basis), 1, 2 or 3% milk protein hydrolysate (A.C. Legg Packing Co., Inc., Birmingham, AL), 1.13% seasoning mix (blend code 125, A.C. Legg Packing Co., Inc., Birmingham, AL), and 0.10-0.13% cure mix (6.25% sodium nitrite; meat weight basis; A.C. Legg Packing Co., Inc., Birmingham, AL).

Product Manufacture

All treatments in each replication were randomized by the order of mixing and chopping. The lean turkey and lean beef were mixed together (model A-200, Hobart Bowl Mixer, Hobart Manufacturing Co., Troy, OH) at 2 to 3 °C with sodium chloride, cure mix, sodium tripolyphosphate (STP), corn syrup solid, dextrose, seasoning and then gradually adding half of ice water for 2 min. The mix was placed in a cutter (model 4294, Stephan vertical-cutter/mixer, Stephan Machinery Corp., Columbus, OH), immediately chopped and minced for 3 min at the high speed, as well as processed under vacuum (approximately 21 mm Hg). The remaining ice water, modified waxy maize starch and milk protein hydrolysate were added into the batter and chopped for 1 min under vacuum. The batters from each treatment were divided into 2 equal amounts for cooking at the different end point temperatures (71.1 and 76.6 °C). The batters were vacuum packaged (model X180, Koch Supplies, Inc., Kansas City, MO) in Nylon / PE vacuum pouches (product code 014611, 3 mil Std. Barrier, Koch Supplies Inc., Kansas City, MO) and then stored at approximately 4.4 °C until all other treatment had been completed. Batters were randomized for order of stuffing. The frankfurters were formed by stuffing into 32-mm fibrous casings (code 27464, E-Z peel Nojax casings, C 32x70 clear, Viskase Co., Chicago, IL) with a piston stuffer (model E251, Fatos, Koch Supplies, Inc., Kansas City, MO) and then tied into 20-cm links. All frankfurters were weighed and allow temperature-equilibrate (approximate 7°C) for 15 min prior to being placed in the smokehouse. After being hung on a smokehouse truck, the stuffed products were heat-processed in the smokehouse (model TR-2, Vortron Inc., Beloit, WI). Before cooking the frankfurters, six frankfurters from each cooking treatment (3 frankfurters with 30% AW and 3 frankfurters with 40% AW) were randomly selected in the smokehouse by location and used to determine the cooking end point temperature. The end point temperature was measured with thermocouples (part number TG-T-30, Omega Engineering, Inc., Stamford, CT) attached to an electronic temperature recorder (model 5100, ECD data logger, Omega Engineering, Inc., Stamford, CT). For exact placement of the thermocouple wires in the center of the frankfurters, two plastic plugs that were manufactured out of polyethylene rods (product code 055735, Lowes, Blacksburg, VA) were fit into opposite ends of a sausage link (Fig. 1). These plugs were 30 mm in

diameter and 30 mm long. A 1.5 mm hole was drilled through the center of each plug. One plastic plug was inserted into end of casing and then thermocouple wire tied to a string (Moniflex monofilament line; 11.4 kg test) was inserted through the hole and extended about 7 cm into the frankfurters. The end of casing was tied and then stuffed with batter. The second plug was threaded with the string and then inserted into the casing. The batter was packed tight and the open end of the casing was tied. The link was suspended from a smokehouse rack. The stuffed products were heat-processed to internal end point temperature (71.1°C and 76.6°C) in the smokehouse using the following cycle; step 1: 51.7°C dry bulb temperature, 10 min; step 2: 57.2°C dry bulb temperature, 38 %RH, 15 min; step 3: 65.6°C dry bulb temperature, 55 %RH, 15 min; step 4: 76.7 °C dry bulb temperature, 65 %RH, 15 min; step 5: steam cook, 100 %RH until reaching the target EPT and then cold showered 10 min. Products were placed in a cooler (2-4°C).

Finished product analyses

Cooked-chilled loss

Cooked-chilled loss was determined as the difference in weight between the uncooked products and the cooked products (about 15 continuous linked frankfurters) after chilling (4.4°C) for 2 hr divided by the weight of the uncooked frankfurters and multiplied by 100. The weight of casing was accounted for in calculating cooking loss. The cooked-chilled loss was performed in triplicate and then the average values from each treatment were recorded.

Chemical analysis

Moisture, fat, and protein determinations (AOAC, 1995) were performed in triplicate within 48 hr after cooking. Three frankfurters from each treatment were randomly selected to determine moisture, fat and protein content. The average values of moisture, fat and protein content from sample frankfurters were calculated.

Purge determination

The casing was removed from the frankfurters. Three frankfurters from each treatment were randomly selected, weighed and then placed into Nylon / PE vacuum pouches (product code 014611, 3 mil Std. Barrier, Koch Supplies Inc., Kansas City, MO) and vacuum packaged (model X180, Koch Supplies Inc., Kansas City, MO). Vacuum

packaged products were stored for 30 days in the dark at 4.4°C. Upon removal, the frankfurters were removed from the packages, patted dry with paper towels, and weighed. Percentage purge was calculated as the weight loss of the frankfurters divided by the prepackaged weight of the frankfurters and multiplied by 100.

Color analysis

Two frankfurters from each treatment were randomly selected to determine color. Instrument color evaluation was performed 2 days after production using a Minolta Chromameter (model CR-200, Minolta Camera Co., Ltd., Osaka, Japan) calibrated to a white plate (CIE L* = 97.91, a* = -0.68, b* = +2.45, part # 2093326). CIE L* a* b* values were obtained from six repeated readings from the inner surface of longitudinally split frankfurters (approximate 7°C).

Puncture/skin test

Two frankfurter samples from each treatment were used to determine penetration force by a puncture test at three randomly selected longitudinal locations. A 3.2-mm diameter cylindrical steel punch rod was mounted into the drill chuck of an Instron Universal Testing Instrument (model 1011, Instron, Corp., Canton, MA). A crosshead speed of 100 mm/min was used. After touching the surface of the longitudinal frankfurters, the cylindrical rod traveled 10 mm into the sample to measure total energy to puncture (kg x mm) and peak force (kg).

Torsion test

Torsion analysis was used to determine failure properties of the frankfurters. Rheological properties of shear stress and shear strain were determined using a torsion gelometer (Gel Consultants Inc., Raleigh, NC). Two frankfurters (approximate 7°C) from each treatment were sampled and cut into 6 samples (25 mm long, 3/frank). The samples were glued (alpha cyanoacrylate ester) to notched styrene disposable disks and ground to form a dumbbell shaped with a sample diameter of 1.0 cm using a specimen shaping machine (Gel Consultants Inc., Raleigh, NC). The samples were equilibrated to room temperature and then twisted using the gelometer to measure shear stress (strength) and true shear strain (deformability) at sample failure. Shear modulus at failure (G), a measurement of gel rigidity, was calculated as true shear stress divided by true shear

strain at sample failure. The average value of 6 repeated measures was calculated and recorded.

Texture profile analysis

Textural characterization of the products was performed using an Instron Universal Testing Instrument (Model 1011, Instron, Corp., Canton, MA). All instrumental texture analyses were measured on chilled (approximate 7°C) samples (six cores, 3 cores / frank) that were randomly selected. Samples tested were 19-mm diameter, 19-mm high cylindrical cores. Frankfurters were cut to a length of 19 mm and then axially cored. The cores were prepared and stored in a 4°C cooler. For each treatment, six repeated measures were taken, and the average was recorded for each Instron trait. The Instron was programmed for a crosshead speed of 100 mm/min. A frankfurter core was axially compressed to 75% of its height in order to determine hardness (Bourne, 1978). A second core was compressed to 50% of its height for two cycles to determine cohesiveness. Cohesiveness was calculated as a unitless value defined as the ratio of the total energy of the second compression to the first multiplied by 100 (Claus et al., 1989).

Statistical analysis

Treatment data from dependent variables were analyzed using the General Linear Model (GLM) procedure (SAS Institute 1997, release 6.12) using a 2x2x3 factorial split-plot design. The whole plot was the 2 x 2 x 3 factorial design (the percentage of salt, USDA added water, and milk protein hydrolysate) and the split-plot was the end point temperature. If the model was found to contain significant differences ($P < 0.05$), mean values were separated using the Least Significant Difference procedure (SAS Institute 1997, release 6.12), based on mean square errors as the variance source.

RESULTS AND DISCUSSION

Cooking loss

Non-meat ingredients used in the formulation such as salt, added water, and milk protein hydrolysate and end point cooking temperature all affected the cooking yield of the finished products (Table 2). After heat processing, frankfurters lose some moisture

because of the denaturation of the protein structure and changes in protein-protein interactions. All fat-free frankfurters were formulated using a projected 7% cooking loss, which was based on cooking losses reported for low-fat, high added water processed meat products (Claus et al., 1989; Small et al., 1995). However, all fat-free turkey-beef frankfurter treatments resulted in less than 1.8% cooking loss which was less than that reported by Small et al. (1995) in low-fat, high moisture frankfurters (7.1%). This difference may be related to the fact that they did not use modified starch and milk protein hydrolysate (MPH) to facilitate water binding. Cooking losses greater than 6% for a frankfurter-type product would generally be considered high compared to those of bologna manufactured in the industry (Claus et al., 1989).

The cooking loss of frankfurters with 1.0% NaCl was 14.6% greater ($P < 0.05$) than the cooking loss of 2.0% NaCl products (Table 2). In batter systems, low salt content is known to yield a low ionic strength which increase the losses of water and fat during cooking (Trout and Schmidt, 1986). Reduction of added salt in frankfurter batters from 2.5% to 1.5% decreased water binding ability of frankfurters cooked at 70°C (Whiting, 1984). Fat release did not begin until the water loss had greatly increased and the gel strength had declined about 45% (Whiting, 1984). In addition, higher NaCl content and higher pH values were directly related to the higher cooking yield for frankfurters made with beef and pork blends (Sofos, 1983).

Cooking loss of the 40% added water (AW) frankfurters was 72.5% greater ($P < 0.05$) than 30% AW products (Table 2). Other authors reported that cooking loss of reduced fat bologna increased as added water increased and fat content decreased (Ahmed et al., 1990; Claus et al. 1989; 1990).

The cooking loss of frankfurters was decreased ($P < 0.05$) when milk protein hydrolysate (MPH) level in the formulation was increased (Table 2). Generally, water holding capacity was known to be improved by the addition of milk protein (Ellekjaer et al., 1996; Girard et al., 1990). Keeton et al. (1984) reported that adding 3.5% calcium reduced non-fat dry milk to frankfurter formulations containing 24% added water increased cooking yield. Dexter et al. (1993) found that milk protein was effective in decreasing cooking loss but the cooking loss tended to be higher when the test ingredient was added early in the chopping process. The authors stated that myofibrillar proteins

exhibited an increased water binding capacity when allowed to hydrate before the addition of test ingredients.

Increasing EPT level resulted in a higher ($P < 0.05$) cooking loss (Table 2). This was expected as Puolanne and Kukkonen (1983) reported that water binding decreased as core temperature rose within the range of 60-80°C and weight loss during thermal processing was found to be proportional to product temperature and/or protein/fat ratio (Mittal and Blaisdell, 1984). However, Carballo et al. (1996) reported that no differences in cooking loss of low-fat bologna-type sausages with respect to increased final internal product temperature. Our research may have differed from the previous studies because of the difference in product types (fat-free frankfurters and low-fat bologna) and heat processing. Bologna sausages were larger so there were greater temperature gradients in the interior than in frankfurter-type sausages.

Purge loss

AW level was the only independent variable that affected ($P < 0.05$) purge loss (Table 2). The purge loss of fat-free frankfurters at 30% AW was 17.1% less ($P < 0.05$) than at 40% AW (Table 2). The average purge loss for fat-free turkey-beef frankfurter treatments (3.11%) was less than that reported by Claus et al. (1990) in low-fat, high moisture bologna (5%). This difference may be related to the fact that they did not use modified starch and milk protein hydrolysate (MPH) to facilitate water binding. Bishop et al. (1993) reported that purge loss also increased as moisture content of reduced fat bologna increased. Claus et al. (1989) reported that purge loss was more highly correlated to USDA added water than percentage moisture or fat in reduced-fat bologna. In addition, they found that low-fat (5%), high added water (35%) bologna (beef and pork) had greater purge loss than a control formulated with 30% fat and 10% added water. Carballo et al. (1996) also reported that final cooking temperature did not affect purge loss of bologna sausages.

Chemical analysis of no-fat turkey-beef frankfurters

The overall means of the chemical analyses for the frankfurters were 78.5% moisture and 12.6% protein. All frankfurters in each independent variable contained less

than 0.4% fat (Table 2). The moisture and protein contents of frankfurters were lower ($P<0.05$) as salt level increased. However, fat content was not affected ($P>0.05$) by an increase in salt concentration. Higher added water in the formulation increased ($P<0.05$) moisture, and decreased the percentage of protein and fat.

As the level of milk protein hydrolysate (MPH) incorporation was increased, the moisture decreased and protein increased. Frankfurters containing 3% MPH had a slightly ($P<0.05$) higher fat content than either the 1% or 2% MPH treatments. Only the fat content was slightly ($P<0.05$) lower as EPT was increased.

Color analysis

Increasing amount of NaCl in the frankfurter formulation produced darker ($P<0.05$) products (lower CIE L^*) but did not affect CIE a^* and b^* (Table 2). Increasing AW levels produced ($P<0.05$) frankfurters that were lighter (higher CIE L^*) and less red (lower CIE a^*). AW levels did not affect yellowness (CIE b^*). The color of processed meat products can be influenced by fat content and added water (Claus et al., 1989; Ahmed et al., 1990), and by the amount of pigmentation, principally myoglobin. Since the most dominant color of cured meat products is red, a difference in CIE a^* value may be considered to have the greatest impact on product color (Bishop et al., 1993). Bologna-type products were darker (lower L^* values) and less yellowness (CIE b^* decreased) but redder (CIE a^* increased) as fat was reduced (Ahmed et al., 1990; Claus et al., 1989; Claus and Hunt, 1991). Only redness of meat products was affected by the change in intensity of pigmentation caused by variation of protein content. The lower protein content resulted in smaller a^* value because the reduction of protein content caused the dilution of myoglobin and consequently less red color (Carballo et al., 1995).

The interaction between NaCl and AW was found for CIE L^* value of frankfurters (Table 3). Frankfurters with 30% AW were not different in CIE L^* but frankfurters with 40% AW were darker ($P<0.05$) when the amount of NaCl was increased.

Frankfurters were darker, less red and more yellow ($P<0.05$) with higher MPH levels (Table 2). Ruby et al. (1994) found that adding whey protein in low-fat frankfurters tended to make the product more yellow in color. Rahardjo et al. (1994) also

reported that adding spray dried soymilk in the pork sausage patties increased yellowness (higher b^* value). Baardseth et al. (1992) reported that addition of milk protein affected all three color values.

EPT levels only affected CIE L^* and resulted in lighter ($P < 0.05$) products as EPT was increased. Hague et al. (1994) reported that the L^* values of ground beef patties increased (became lighter) whereas a^* and b^* values decreased (less red and less yellow, respectively) as EPT increased. A three-way interaction between NaCl, added water, and EPT for CIE a^* value was found (data not shown).

Puncture test

Skin formation and product firmness are important quality attributes of frankfurters. As the results of the total energy, puncture test yielded similar responses to the all independent variables only peak force data was discussed. Peak force of fat-free frankfurters with 1% NaCl was 7.7% greater ($P < 0.05$) than those with 2% NaCl (Table 4). The higher penetration force may have been related to greater protein skin formation as a result of the higher cooking loss associated with the lower NaCl level. Girard et al. (1990) found that the addition of increase quantities of NaCl from 0 to 2% decreased firmness by about 30% and increased the elasticity in the same proportion. The 30% AW treatments had 50% greater of peak force ($P < 0.05$) than the 40% AW treatments (Table 4). Claus et al. (1989) reported that peak force and break force of low-fat bologna, determined using Instron tensile measurements, tended to decrease as the percentage of AW increased. Bishop et al. (1993) also reported that the reduced-fat treatments with additional water were softer (lower total energy value) than the control.

No significant ($P > 0.05$) differences in peak force were found among the various MPH levels (Table 4). Milk protein has been found to be inferior to myosin for functionality in meat products as the salt soluble myofibrillar proteins provided ample water binding and gel strength (Whiting, 1984). However, in less optimal systems formulated with reduced salt, and high added water, beneficial effects may result from the addition of MPH and modified starch in the low-fat/ no-fat frankfurters.

When EPT levels were higher, total energy and peak force ($P < 0.05$) of fat-free frankfurters were decreased (Table 4). Total energy for the puncture test produced similar responses to all independent variables as the peak force test.

Torsion-gelometer test

Increasing NaCl levels resulted in greater ($P<0.05$) shear stress and shear strain (Fig. 2). However, no difference ($P>0.05$) between the means of shear modulus was found when increasing NaCl levels in the formulation of frankfurters (Table 4). Barbut and Mittal (1990) reported that meat batters with 2.5% NaCl resulted in higher G values (modulus of rigidity) than meat batters with 1.5% NaCl. The higher G value indicated the formation of firmer, more stable, and more elastic matrix structures. Whiting (1984) reported that the strength of protein gels increased with increasing salt levels over the entire 0.5-3.5% salt range tested.

Frankfurters with 30% AW had 41.4% greater ($P<0.05$) of shear stress than frankfurters with 40% AW (Fig. 2). AW level did not affect shear strain of the frankfurters. However, shear modulus of frankfurters was reduced ($P<0.05$) as AW was increased (Table 4). Claus et al. (1989) reported that within a given fat level, an increase in AW level in reduced fat bologna resulted in a decrease in shear force and the 20% fat/10% AW sausage had the largest total energy to shear. In addition, added water had a greater effect than either fat or protein on Instron shear (Claus et al., 1989). In comparison, Ahmed et al. (1990) found that shear values did not differ between 15% fat/13% AW and 25% fat/3% AW, nor between 25% fat/13% AW and 35% fat/3% AW in low-fat fresh pork sausage. The causes of the differences may have been related to the differences in type of products tested (coarse ground and finely comminuted), fat content, and heat processing regime. Nevertheless, the interaction of fat and added water on shear force was of particular interest in that it indicates the feasibility of replacing of fat with added water to modified product quality (Ahmed et al., 1990).

Higher MPH levels in the products increased ($P<0.05$) shear stress (Fig. 2) and shear modulus (Table 4). Shear strain for frankfurters containing 3% MPH was lowest ($P<0.05$). No difference was found in shear strain between frankfurters containing 1% and 2% MPH. The addition of milk proteins in low-fat/ no-fat frankfurters is useful because of their ability to form a gel and provide a structural matrix for holding water (Ellekjaer et al., 1996). Ruby et al. (1994) reported that low-fat frankfurters made with

whey protein and formulated to 15% and 5% fat at two hydration levels (water:whey protein; 1:1 and 0.5:1) resulted in no difference in the means of shear force.

As EPT levels were increased, shear stress (Fig. 2) and shear modulus (Table 4) increased ($P<0.05$, Table 3). Shear strain decreased ($P<0.05$) when EPT was increased (Table 3). However, Colmenero et al. (1995) reported that no difference in shear force was found in frankfurters cooked at different rates and end point temperatures. Awonorin and Rotimi (1992) reported that as EPT of smoked chicken sausages increased (from 70°C to 75°C), there was a toughening effect which caused partial drying due to increase weigh losses. Whiting (1984) reported that gel strength at 70°C was approximately twice that of sausage at 50°C with the same salt content. Other authors found that heating rate as well as EPT affected the textural properties (Barbut and Mittal, 1990; Camou et al., 1989; Saliba et al., 1987).

Interaction ($P<0.05$) between NaCl and AW levels was found in the shear properties (Table 3). Shear stress value for frankfurters with 40% AW increased ($P<0.05$) with higher NaCl concentration but were not different ($P>0.05$) in those with 30% AW (Fig. 2). As NaCl was increased, shear strain increased ($P<0.05$) in the 30% AW product and decreased ($P<0.05$) in the 40% AW product. An interaction ($P<0.05$) between NaCl and MPH levels was found in the shear properties (Table 5). Shear stress (Fig. 2) and shear modulus (Table 4) values for frankfurters with 1% and 2% MPH increased ($P<0.05$) with higher NaCl concentration but decreased in those with 3% MPH. As MPH was increased, shear strain decreased ($P<0.05$) in the 2% NaCl product but no difference ($P<0.05$) was found between 1% and 2% MPH in the 1% NaCl product. Independent variable interactions ($P<0.05$) were found between MPH and EPT (Table 5), AW and MPH (Table 6) and NaCl and EPT (Table 7). In addition, a four-way interaction between NaCl, AW, and MPH and EPT was found for shear stress, shear strain, and shear modulus (data not shown).

Texture profile analyses

Both NaCl and MPH concentrations did not affect ($P>0.05$) hardness and cohesiveness (Table 4). In contrast, Matulis et al. (1995) reported that frankfurter hardness decreased as salt concentration decreased because protein extraction and water

binding properties were reduced. Seman et al. (1980) also reported that salt reduction (from 2.5% to 1.25%) resulted in decreased hardness in bologna. The difference from our study may be caused by the addition of modified starch (4%) in batter emulsion. Modified starch incorporated with other non-meat ingredients such as MPH and NaCl, enhanced formation of firmer gels.

Fat-free frankfurters with 30% AW were firmer ($P<0.05$) but less cohesive ($P<0.05$) than those containing 40% AW. Gregg et al. (1993) found that an increase in AW level from 10% to 30%, resulted in bologna sausages that were less firm and more cohesiveness. Claus et al. (1990) found that controlling time of addition of water resulted in higher hardness values. Ahmed et al. (1990) studied the textural characteristics of pork sausages processed with varying AW levels and found that sausages with 3% AW resulted in higher hardness values than sausages with 13% AW.

EPT did not affect ($P>0.05$) hardness (Table 4). In contrast, Carballo et al. (1996) reported that hardness of meat emulsions was influenced by final internal temperature in high-/low-fat bologna type products. Myosin and actin, the two salt soluble proteins, were known to reach complete heat denaturation at 60°C in gel systems (Cheng and Parrish, 1979) therefore, even the lowest EPT used on our frankfurters may have been beyond the critical threshold associated with additional protein hardening (Ishioroshi et al., 1979). Starch is also known to increase firmness (Carballo et al., 1996). Also, starches normally gelatinized at 55-70°C. Therefore, gelatinization of the starch most likely was complete before the EPT of 71.1°C was reached.

Cohesiveness of fat-free frankfurters cooked at 71.1°C was greater ($P<0.05$) than frankfurters cooked at 76.7°C. However, other authors found that cohesiveness of bologna was not affected by end point cooking temperature (Carballo et al., 1996; Hunt et al., 1994). Interaction between NaCl and MPH for cohesiveness was determined (Table 5). Cohesiveness was not different between frankfurters containing either 1% and 2% NaCl formulated at 1% or 2% MPH. However, cohesiveness for frankfurters containing 3% MPH was lower ($P<0.05$) at 2% NaCl than those at 1% NaCl. Cohesiveness for frankfurters containing 1% NaCl was not affected by different MPH levels. However, frankfurters with 2% NaCl and 3% MPH were less cohesive ($P<0.05$) than those with 1% and 2% MPH at the same NaCl level. There was also an interaction between EPT and

AW for cohesiveness (Table 7). At 30% AW level, no differences ($P>0.05$) were found for cohesiveness values of fat-free frankfurters heat-processed at 71.1°C and 76.7°C but frankfurter with 40% AW tended to decrease cohesiveness as EPT levels were increased.

CONCLUSIONS

Regardless of the fact that all independent variables influenced the cooking loss, the means of all treatments were extremely low for high added water frankfurters. Purge loss was low for such high AW level; however further reductions would be beneficial. The addition of 4% starch in all of the treatments may have been the predominant controlling factor. Of the four independent variables evaluated, AW and EPT most influenced the textural properties. Increasing AW produced softer and more cohesive frankfurters whereas higher EPT had the opposite effect. Selected combinations of ingredients and/or processing factors may be more effective in altering the texture and processing characteristics of fat free turkey-beef frankfurters than single ingredient/processing variable alterations.

REFERENCES

- Acton, J.C., Ziegler, G.R., and Burge, D.L., Jr. 1983. Functionality of muscle constituents in the processing of comminuted meat products. *CRC Critical Reviews in Food Science and Nutrition*. pp. 99-121.
- Ahmed, P.O., Miller, M.F., Lyon, C.E., Vaughters, H.M., and Reagan, J.O. 1990. Physical and sensory characteristics of low-fat fresh pork sausage processed with various levels of added water. *J. Food Sci.* 55: 625-628.
- AOAC. 1995. *Official Method of Analysis of the Association of Official Analytical Chemists*. 16th ed. Association of Official Analytical Chemists, Inc. Washington, DC.
- Awonorin, S.O. and Rotimi, D.K. 1992. Influence of end point temperature, humidity and cold storage on mechanical and sensory properties of smoked chicken sausage. *J. Food Service Studies* 7: 43-53.

- Baardseth, P., Naes, T., Mielnik, J., Skrede, G., Holland, S., and Eide, O. 1992. Dairy ingredients affects on sausage sensory properties studied by principal component analysis. *J. Food Sci.* 57: 822-828.
- Barbut, S. and Mittal, G.S. 1990. Effect of heating rate on meat batter stability, texture and gelation. *J. Food Sci.* 55:334-337.
- Bishop, D.J., Olson, D.G., and Knipe, C.L. 1993. Pre-emulsified corn oil, pork fat, or added moisture affect quality of reduced fat bologna quality. *J. Food Sci.* 58: 484-487.
- Bourne, M.C. 1978. Texture profile analysis. *Food Technol.* 32: 62-65.
- Camou, J.P., Sebranek, J.G., and Olson, D.G. 1989. Effect of heating rate and protein concentration on gel strength and water loss of muscle protein gels. *J. Food Sci.* 54: 850-854.
- Carballo, J., Barreto, G., and Colmenero, F.J. 1995. Starch and egg white influence on properties of bologna sausage as related to fat content. *J. Food Sci.* 60: 673-677.
- Carballo, J., Ferandez, P., Barreto, G., Solas, M.T., and Colmenero, F.J. 1996. Characteristics of high- and low-fat bologna sausages as affected by final internal cooking temperature and chilling storage. *J. Sci. Food Agric.* 72: 40-48.
- Cheng, C. and Parrish, F.C., Jr. 1979. Heat-induced changes in myofibrillar proteins of bovine longissimus muscle. *J. Food Sci.* 44: 22-24.
- Claus, J.R. and Hunt, M.C. 1991. Low-fat, high added water bologna formulated with texture-modified ingredients. *J. Food Sci.* 56: 643-647, 652.
- Claus, J.R., Hunt, M.C., and Kastner, C.L. 1989. Effects of substituting added water for fat on textural, sensory, and processing characteristics of bologna. *J. Muscle Foods* 1:1-21.
- Claus, J.R., Hunt, M.C., Kastner, C.L., and Kropf, D.H. 1990. Low-fat, high added water bologna: Effects of massaging, preblending, and time of addition of water and fat on physical and sensory characteristics. *J. Food Sci.* 55: 338-341, 345.
- Colmenero, F.J., Barreto, G., Mota, N., and Carballo, J. 1995. Influence of protein and fat content and cooking temperature on texture and sensory evaluation of bologna sausage. *Lebensmittel-Wissenschaft-Technologie* 28: 481-487.
- Dexter, D.R., Sofos, J.N., and Schmidt, G.R. 1993. Quality characteristics of turkey bologna formulated with carrageenan, starch, milk and soy protein. *J. Muscle Foods* 4: 207-223.

- Ellekjaer, M.R., Naes, T., and Baardseth, P. 1996. Milk proteins affect yield and sensory quality of cooked sausages. *J. Food Sci.* 61: 660-666.
- Girard, J.P., Culioli, J., Maillard, T., Denoyer, C., and Touraille, C. 1990. Influence of technological parameters on the structure of the batter and the texture of frankfurter type sausages. *Meat Sci.* 27: 13-28.
- Gregg, L.L., Claus, J.R., Hackney, C.R., and Marriott, N.G. 1993. Low-fat, high added water bologna from massaged, minced batter. *J. Food Sci.* 58: 259-264.
- Hague, M.A., Warren, K.E., Hunt, M.C., Kropf, D.H., Kastner, C.L., Stroda, S.L., and Johuson, D.E. 1994. End point temperature, internal cooked color, and expressible juice color relationship ion ground beef patties. *J. Food Sci.* 59: 465-470.
- Hunt, M.C., Payne, A., and Seib, P.A. 1994. Properties of low-fat, high added water beef sausages containing phosphate starches. *Proceedings of the Recip. Meat Conf.* June 12-15. University Park, Pennsylvania. *American Meat Sci. Assoc.* 47: 18-20.
- Ishioroshi, M., Samejima, K., and Yasui, T. 1979. Heat-induced gelation of myosin: factors of pH and salt concentration. *J. Food Sci.* 44: 1280-1285.
- Keeton, J.T. 1992. Low-fat meat products-Technological problems with processing. *Proceedings of International Congress of Meat Science and Technology.* Clermont-Ferrand France. 38(1): 175-182.
- Keeton, J.T., Foegeding, E.A., and Patana-Anake, C. 1984. A comparison of non meat proteins, sodium tripolyphosphate and processing temperature effects on physical and sensory properties of frankfurters. *J. Food Sci.* 49: 1462-1465, 1474.
- Matulis, R.J., McKeith, F.K., Brewer, M.S., and Bechtel, P.J. 1994. Characteristics of frankfurters with different cooking parameters. *J. Muscle Foods* 5: 431-448.
- Matulis, R.J., McKeith, F.K., Sutherland, J.W., and Brewer, M.S. 1995. Sensory characteristics of frankfurters as affected by fat, salt and pH. *J. Food Sci.* 60: 42-47.
- Miles, R.S. 1996. Developing and manufacturing low/no-fat products and processes. *Proceedings of the Recip. Meat Conf.* June 9-12. Provo, Utah. *American Meat Sci. Assoc.* 49: 17-20.
- Mittal, G.S. and Blaisdell, J.L. 1984. Heat and mass transfer properties of meat emulsion. *Lebensmittel-Wissenschaft-Technologie* 17(2): 94-98.

- Mortensen, B.K. 1986. The use of milk powder in food products. *Proceedings of the Intern. Dairy Congress*. Sept 29-Oct3. Hague, Brussels. International Dairy Federation. 22: 709.
- Puolanne, E.J. and Kukkonen, E. 1983. Influence of core temperature at the end of cooking on the water binding capacity of the meat in Bruhwurst. *Fleischwirtsch.* 63: 1495-1496.
- Rahardjo, R., Wilson, L.A., and Sebranek, J.G. 1994. Spray dried soymilk used in reduced fat pork sausage patties. *J. Food Sci.* 59:1286-1290.
- Reitmeier, C.A. and Prusa, K.J. 1991. Composition, cooking loss, color and compression of ground pork with dry- and wet- milled corn germ meals. *J. Food Sci.* 56: 216-219.
- Ruby, B.F., Means, W.J., Riley, M.L., and Kalchayanand, N. 1994. Physical, chemical and sensory properties of low-fat frankfurters using whey protein as a fat substitute. *Proceedings of the Western Section*. American Society of Animal Science 45: 197-201.
- Saliba, D.A., Foegeding, E.A. and Hamann, D.D. 1987. Structural failure and nondestructive rheological analyses of frankfurter batters: effect of heating rates and sugars. *J. Texture Studies.* 18: 241-259.
- SAS Institute, 1997. SAS Institute Inc., Cary, N.C.
- Schut, J. 1975. Meat Emulsions. In *Advances in Food Research*. Academic Press, New York, N.Y.
- Seman, D.L., Olson, D.G., and Mandigo, R.W. 1980. Effect of reduction and partial replacement of sodium on bologna characteristics and acceptability. *J. Food Sci.* 45: 1116-1121.
- Siripurapu, S.C.B., Mittal, G.S., and Blaisdell, J.L. 1987. Texture and viscoelastic characteristics of meat emulsion products during cooking. *Lebensm-Wiss. U.-Technol.* 20: 68-73.
- Small, A.D., Claus, J.R., Wang, H., and Marriott, N.G. 1995. Particle size and mixing time effects on sensory and physical properties of low-fat, high moisture pork frankfurters. *J. Food Sci.* 60: 40-41, 54.
- Sofos, J.N. 1983. Effects of reduced salt (NaCl) levels on the stability of frankfurters. *J. Food Sci.* 48: 1684-1691.

Trout, G.R. and Schmidt, G.R. 1986. Water binding ability of meat products: effect of fat level, effective salt concentration and cooking temperature. *J. Food Sci.* 51: 1061-1062.

USDA. 1988. Standard for frankfurter and similar cooked sausages. *Federal Register*. 53: 8425-8428.

Whiting, R.C. 1984. Stability and gel strength of frankfurter batters made with reduced NaCl. *J. Food Sci.* 49: 1350-1354, 1362.

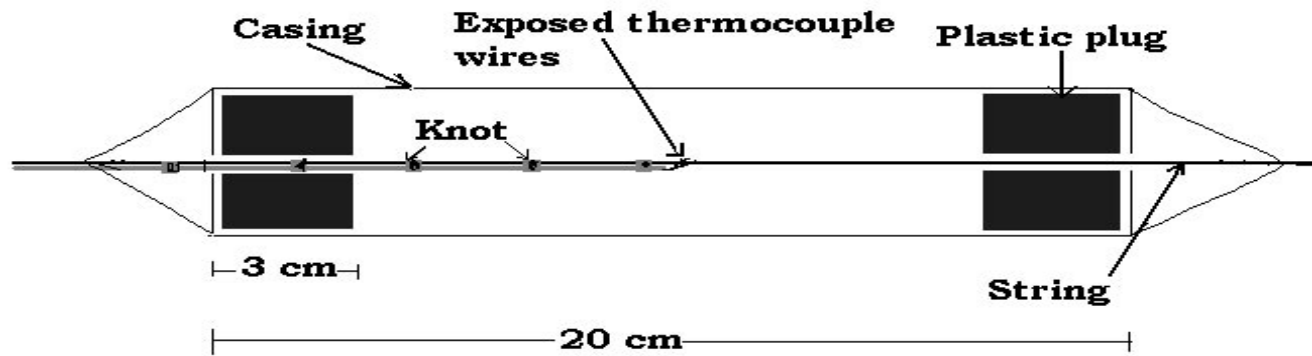


Figure 1-Thermocouple wire inserted into the center of casing

Table 1-Treatment combination, ingredients, and approximate usage levels¹ in the production of fat-free turkey-beef frankfurters

Independent variable ²	Treatment No.											
	1	2	3	4	5	6	7	8	9	10	11	12
Added water (%)	30	30	30	30	30	30	40	40	40	40	40	40
NaCl (%)	1	1	1	2	2	2	1	1	1	2	2	2
MPH (%)	1	2	3	1	2	3	1	2	3	1	2	3

Ingredients ³	Sausage Batter (%)											
	Turkey (1% fat)	48.80	48.06	47.33	47.99	47.25	46.52	40.72	39.98	39.24	39.91	39.17
Beef (3% fat)	2.45	2.41	2.37	2.41	2.37	2.33	2.04	2.00	1.97	2.00	1.96	1.93
Water & ice	45.78	45.56	45.34	45.63	45.41	45.19	54.31	54.09	53.87	54.17	53.97	53.72
NaCl	0.88	0.88	0.88	1.88	1.88	1.88	0.90	0.90	0.90	1.90	1.90	1.90
Dextrose	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Seasoning mix	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Modified starch	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Corn syrup solid	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
STP	0.26	0.25	0.25	0.25	0.25	0.25	0.21	0.21	0.21	0.21	0.21	0.20
Cure mix	0.13	0.13	0.13	0.13	0.12	0.12	0.11	0.11	0.10	0.11	0.10	0.10
MPH	1.00	2.00	3.00	1.00	2.00	3.00	1.00	2.00	3.00	1.00	2.00	3.00

¹ average usage level of all 3 replications

² Independent variable: Added water = %moisture – (4 x %meat protein); MPH = milk protein hydrolysate.

³ Ingredients; Modified starch = modified waxy maize starch (Thermax, National Starch Co., Bridgewater, NJ); STP = Sodium tripolyphosphate (added on meat weight basis); Cure mix contains 6.25% NaNO₂ (added on meat weight basis).

Table 2-Chemical and physical properties of fat-free turkey-beef frankfurters

Independent variable ¹	Cooking Loss (%)	Purge Loss (%)	Chemical analysis			CIE values		
			Moisture (%)	Protein ² (%)	Fat (%)	L*	a*	b*
NaCl (%)								
1	1.49 ^a	3.12 ^a	78.61 ^a	12.59 ^a	0.38 ^a	72.49 ^a	8.49 ^a	5.89 ^a
2	1.30 ^b	3.11 ^a	78.28 ^b	12.50 ^b	0.35 ^a	71.96 ^b	8.42 ^a	5.86 ^a
SE	0.03	0.05	0.07	0.02	0.003	0.08	0.04	0.03
Added water (%)								
30	1.02 ^b	2.82 ^b	77.29 ^b	13.51 ^a	0.39 ^a	71.17 ^b	9.07 ^a	5.81 ^a
40	1.76 ^a	3.40 ^a	79.60 ^a	11.58 ^b	0.34 ^b	73.28 ^a	7.84 ^b	5.94 ^a
SE	0.03	0.05	0.07	0.02	0.003	0.08	0.04	0.03
MPH (%)								
1	1.62 ^a	3.07 ^a	78.85 ^a	12.14 ^c	0.35 ^b	72.70 ^a	8.79 ^a	5.45 ^c
2	1.37 ^b	3.18 ^a	78.49 ^b	12.55 ^b	0.35 ^b	72.20 ^b	8.46 ^b	5.83 ^b
3	1.18 ^c	3.09 ^a	78.00 ^c	12.95 ^a	0.39 ^a	71.77 ^c	8.12 ^c	6.34 ^a
SE	0.04	0.06	0.08	0.02	0.003	0.10	0.05	0.04
EPT (°C)								
71.1	1.25 ^b	3.18 ^a	78.46 ^a	12.54 ^a	0.37 ^a	72.06 ^b	8.42 ^a	5.84 ^a
76.7	1.53 ^a	3.04 ^a	78.43 ^a	12.56 ^a	0.36 ^b	72.39 ^a	8.50 ^a	5.91 ^a
SE	0.03	0.05	0.07	0.02	0.003	0.08	0.04	0.03

¹ Independent variables; added water (AW) = %moisture - (4 x %meat protein), milk protein hydrolysate (MPH), end-point temperature (EPT). The following independent variable interactions were determined (P<0.05): NaCl x AW (moisture, protein, CIE L*); NaCl x AW x EPT (CIE a*).

² the percentage of protein from the chemical analysis represents total protein (meat and non-meat proteins).

^{abc} means within an independent variable and column with unlike superscript letters are different (P<0.05).

Table 3-Interaction between NaCl and added water for various physical properties

Dependent variable ¹	Added water ² (%)	
	30	40
<u>CIE L*</u>		
1 %NaCl	71.14 ^{bx}	73.84 ^{ax}
2 %NaCl	71.19 ^{bx}	72.72 ^{ay}
<u>Shear stress (kPa)</u>		
1 %NaCl	130.72 ^{ax}	87.29 ^{by}
2 %NaCl	131.83 ^{ax}	98.38 ^{bx}
<u>Shear strain</u>		
1 %NaCl	1.46 ^{by}	1.51 ^{ax}
2 %NaCl	1.57 ^{ax}	1.48 ^{by}
<u>Shear modulus³ (kPa)</u>		
1 %NaCl	90.10 ^{ax}	58.44 ^{by}
2 %NaCl	84.34 ^{ay}	66.48 ^{bx}

¹ Dependent variable: standard errors for the dependent variables were 0.12, CIE L*; 0.58, shear stress; 0.008, shear strain; 0.66, shear modulus.

² Added water (AW) = %moisture - (4 x %meat protein).

³ Shear modulus (G) = shear stress/shear strain.

^{ab} means within a dependent variable and row with unlike superscript letters are different (P<0.05).

^{xy} means within a dependent variable and column with unlike superscript letters are different (P<0.05).

Table 4-Effect of independent variables on instrumental texture analysis of fat-free turkey-beef frankfurters

Torsion test Independent variable ¹	Torsion test		Torsion test Shear modulus ² (kPa)	Instron TPA ³	
	Peak force (g)	Total energy (kg x mm)		Hardness (kg)	Cohesiveness (TE2/TE1)x100
NaCl (%)					
1	279 ^a	1.61 ^a	74.27 ^a	11.03 ^a	58.29 ^a
2	259 ^b	1.51 ^b	75.41 ^a	10.59 ^a	58.20 ^a
SE	5.30	0.03	0.47	0.24	0.20
Added water (%)					
30	323 ^a	1.92 ^a	87.22 ^a	13.42 ^a	57.65 ^b
40	215 ^b	1.21 ^b	62.46 ^b	8.20 ^b	58.84 ^a
SE	5.30	0.03	0.47	0.24	0.20
MPH (%)					
1	278 ^a	1.60 ^a	69.14 ^c	11.25 ^a	58.71 ^a
2	271 ^a	1.58 ^a	73.27 ^b	10.57 ^a	58.03 ^a
3	258 ^a	1.51 ^a	82.12 ^a	10.62 ^a	57.99 ^a
SE	6.48	0.04	0.58	0.29	0.25
EPT (°C)					
71.1	286 ^a	1.61 ^a	71.81 ^b	10.75 ^a	58.65 ^a
76.7	252 ^b	1.52 ^b	77.87 ^a	10.87 ^a	57.84 ^b
SE	5.30	0.03	0.47	0.24	0.20

¹ Independent variable: added water (AW) = %moisture - (4 x %meat protein), milk protein hydrolysate (MPH), end-point temperature (EPT). The following independent variable interactions were determined (P<0.05): NaCl x AW (shear modulus); NaCl x MPH (shear modulus, cohesiveness); NaCl x EPT (shear modulus); AW x MPH (shear modulus); AW x EPT (shear modulus, cohesiveness); MPH x EPT (shear modulus); NaCl x AW x MPH (shear modulus); NaCl x AW x EPT (shear modulus); NaCl x MPH x EPT (shear modulus); AW x MPH x EPT (shear modulus).

² Shear modulus (G) = shear stress/shear strain.

³ Instron TPA: hardness measured on a single compression to 25% of the original sample height; cohesiveness determined from sequential compression to 50% of the original sample height and defined as the ratio (TE2/TE1 x 100) of the total energy of the second compression (TE2) to the first (TE1) x 100.

^{abc} means within an independent variable and column with unlike superscript letters are different (P<0.05).

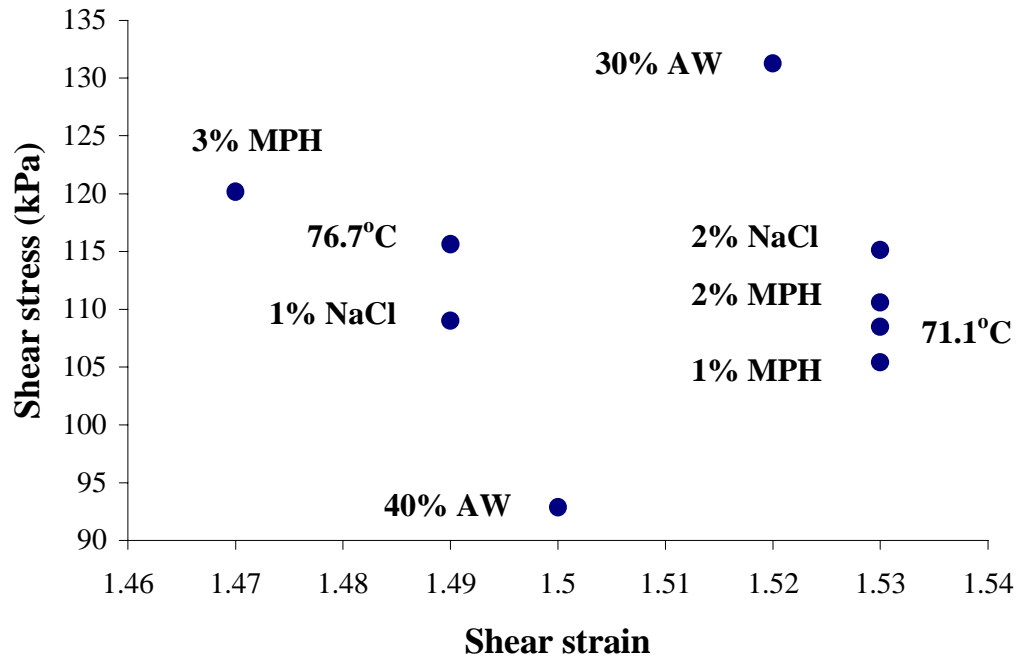


Figure 2-The relationship between shear stress and shear strain of fat-free frankfurters for independent variables¹.

¹Footnotes: Independent variable: added water (AW) = %moisture - (4 x %meat protein), milk protein hydrolysate (MPH), end-point temperature (EPT). The following independent variable interactions were determined (P<0.05): NaCl x AW (shear stress, shear strain); NaCl x MPH (shear stress, shear strain,); NaCl x EPT (shear stress); AW x MPH (shear stress, shear strain); AW x EPT (shear stress); MPH x EPT (shear stress, shear strain); NaCl x AW x MPH (shear stress, shear strain); NaCl x AW x EPT (shear stress, shear strain); NaCl x MPH x EPT (shear stress, shear strain); AW x MPH x EPT (shear stress, shear strain).

Table 5-Interaction between NaCl or end point temperature, and milk protein hydrolysate for various physical properties

Dependent variable ¹	Milk protein hydrolysate (%)		
	1	2	3
<u>Shear stress (kPa)</u>			
1 %NaCl	96.76 ^{cy}	108.52 ^{by}	121.74 ^{ax}
2 %NaCl	114.06 ^{bx}	112.68 ^{bx}	118.58 ^{ay}
71.1°C	98.09 ^{cy}	106.01 ^{by}	121.38 ^{ax}
76.7°C	112.74 ^{cx}	115.18 ^{bx}	118.94 ^{ay}
<u>Shear strain</u>			
1 %NaCl	1.49 ^{aby}	1.51 ^{ax}	1.46 ^{bx}
2 %NaCl	1.58 ^{ax}	1.54 ^{bx}	1.47 ^{cx}
71.1°C	1.54 ^{ax}	1.53 ^{ax}	1.52 ^{ax}
76.7°C	1.53 ^{ax}	1.52 ^{ax}	1.42 ^{by}
<u>Shear modulus² (kPa)</u>			
1 %NaCl	66.01 ^{cy}	73.14 ^{bx}	83.67 ^{ax}
2 %NaCl	72.27 ^{bx}	73.40 ^{bx}	80.56 ^{ax}
71.1°C	64.37 ^{cy}	70.93 ^{by}	80.14 ^{ay}
76.7°C	73.91 ^{bx}	75.61 ^{bx}	84.10 ^{ax}
<u>Cohesiveness³</u>			
1 %NaCl	58.21 ^{ax}	57.75 ^{ax}	58.91 ^{ax}
2 %NaCl	59.21 ^{ax}	58.31 ^{ax}	57.08 ^{by}

¹ Dependent variable: standard errors for the dependent variables were 0.71, shear stress; 0.01, shear strain; 0.81, shear modulus (shear stress/shear strain); 0.35, cohesiveness.

² Shear modulus (G) = shear stress/shear strain.

³ Cohesiveness determined from sequential compression to 50% of the original sample height and defined as the ratio (TE2/TE1 x 100) of the total energy of the second compression (TE2) to the first (TE1) x 100.

^{abc} means within a dependent variable and row with unlike superscript letters are different (P<0.05).

^{xy} means within a dependent variable and column with unlike superscript letters are different (P<0.05).

Table 6-Interaction between added water and milk protein hydrolysate on torsion values.

Dependent variable ¹	Milk protein hydrolysate (%)		
	1	2	3
<u>Shear stress (kPa)</u>			
30% Added water ²	124.26 ^{cx}	132.67 ^{bx}	136.89 ^{ax}
40% Added water	86.56 ^{by}	88.52 ^{by}	103.43 ^{ay}
<u>Shear strain</u>			
30% Added water	1.53 ^{ax}	1.52 ^{ax}	1.50 ^{ax}
40% Added water	1.54 ^{ax}	1.53 ^{ax}	1.43 ^{by}
<u>Shear modulus³ (kPa)</u>			
30% Added water	81.98 ^{cx}	87.92 ^{bx}	91.76 ^{ax}
40% Added water	56.29 ^{by}	58.62 ^{by}	72.47 ^{ay}

¹ Dependent variable: standard errors for the dependent variables were 0.71, shear stress; 0.01, shear strain; 0.81, shear modulus (shear stress/shear strain).

² Added water (AW) = %moisture - (4 x %meat protein).

³ Shear modulus (G) = shear stress/shear strain.

^{abc} means within a dependent variable and row with unlike superscript letters are different (P<0.05).

^{xy} means within a dependent variable and column with unlike superscript letters are different (P<0.05).

Table 7-Interaction between NaCl or added water and end point temperature (EPT) for various physical properties

Dependent variable ¹	End point temperature	
	71.1°C	76.7°C
<u>Shear stress (kPa)</u>		
1% NaCl	103.74 ^{by}	114.27 ^{ay}
2% NaCl	113.25 ^{bx}	116.97 ^{ax}
30% Added water ²	126.15 ^{bx}	136.40 ^{ax}
40% Added water	90.83 ^{by}	94.84 ^{ay}
<u>Shear modulus³ (kPa)</u>		
1% NaCl	70.27 ^{by}	78.28 ^{ax}
2% NaCl	73.36 ^{bx}	77.46 ^{ax}
30% Added water	83.36 ^{bx}	91.08 ^{ax}
40% Added water	60.26 ^{by}	64.66 ^{ay}
<u>Cohesiveness</u>		
30% Added water	57.64 ^{ay}	57.66 ^{ax}
40% Added water	59.66 ^{ax}	58.01 ^{bx}

¹ Dependent variable: standard errors for the dependent variables were 0.58, shear stress; 0.66, shear modulus; 0.29, cohesiveness.

² Added water (AW) = %moisture - (4 x % meat protein).

³ Shear modulus (G) = shear stress/shear strain.

^{ab} means within a dependent variable and row with unlike superscript letters are different (P<0.05).

^{xy} means within a dependent variable and column with unlike superscript letters are different (P<0.05).

APPENDIX

Table 1- Effect of independent variables on shear stress and shear strain of fat-free turkey-beef frankfurters

Independent variable ¹	Torsion test	
	Shear stress (kPa)	Shear strain (mm/mm)
NaCl (%)		
1	109.01 ^b	1.49 ^b
2	115.11 ^a	1.53 ^a
SE	0.41	0.01
Added water (%)		
30	131.28 ^a	1.52 ^a
40	92.84 ^b	1.50 ^a
SE	0.41	0.01
MPH (%)		
1	105.41 ^c	1.53 ^a
2	110.60 ^b	1.53 ^a
3	120.16 ^a	1.47 ^b
SE	0.50	0.01
EPT (°C)		
71.1	108.49 ^b	1.53 ^a
76.7	115.62 ^a	1.49 ^b
SE	0.41	0.01

¹ Independent variable: added water (AW) = %moisture - (4 x %meat protein), milk protein hydrolysate (MPH), end-point temperature (EPT). The following independent variable interactions were determined (P<0.05): NaCl x AW (shear stress, shear strain); NaCl x MPH (shear stress, shear strain); NaCl x EPT (shear stress); AW x MPH (shear stress, shear strain); AW x EPT (shear stress); MPH x EPT (shear stress, shear strain); NaCl x AW x MPH (shear stress, shear strain); NaCl x AW x EPT (shear stress, shear strain); NaCl x MPH x EPT (shear stress, shear strain); AW x MPH x EPT (shear stress, shear strain).

^{abc} means within an independent variable and column with unlike superscript letters are different (P<0.05).

Table 2-Interaction between NaCl and added water on the chemical analysis

Dependent variable ¹	Added Water ² (%)	
	30	40
<u>Moisture</u>		
1% NaCl	77.28 ^{bx}	79.94 ^{ax}
2 %NaCl	77.30 ^{bx}	79.26 ^{ay}
<u>Protein</u>		
1% NaCl	13.51 ^{ax}	11.68 ^{bx}
2 %NaCl	13.52 ^{ax}	11.48 ^{by}

¹ Dependent variable: standard errors for the dependent variables were 0.09, moisture; 0.02, protein.

² Added water (AW) = %moisture - (4 x %meat protein).

^{ab} means within a dependent variable and row with unlike superscript letters are different (P<0.05).

^{xy} means within a dependent variable and column with unlike superscript letters are different (P<0.05).

Table 3-Interaction between NaCl, added water and milk protein hydrolysate on torsion values.

Dependent variable ¹	Added water ² (%)					
	30			40		
	milk protein hydrolysate (%)			milk protein hydrolysate (%)		
	1	2	3	1	2	3
Shear stress (kPa)						
1% NaCl	120.80 ^{by_m}	135.02 ^{ax_m}	136.34 ^{ax_m}	72.72 ^{cy_n}	82.02 ^{by_n}	107.15 ^{ax_n}
2% NaCl	127.72 ^{bx_m}	130.33 ^{by_m}	137.45 ^{ax_m}	100.41 ^{ax_n}	95.02 ^{bx_n}	99.71 ^{ay_n}
Shear strain						
1% NaCl	1.45 ^{ay_n}	1.45 ^{ay_n}	1.48 ^{ay_m}	1.52 ^{bx_m}	1.58 ^{ax_m}	1.45 ^{cx_m}
2% NaCl	1.60 ^{ax_m}	1.60 ^{ax_m}	1.53 ^{bx_m}	1.56 ^{ax_m}	1.48 ^{by_n}	1.41 ^{cx_n}
Shear modulus³ (kPa)						
1% NaCl	84.06 ^{bx_m}	93.19 ^{ax_m}	93.06 ^{ax_m}	47.95 ^{by_n}	53.08 ^{by_n}	74.28 ^{ax_n}
2% NaCl	79.91 ^{bx_m}	82.65 ^{by_m}	90.47 ^{ax_m}	64.64 ^{bx_n}	64.16 ^{bx_n}	70.66 ^{ax_n}

¹ Dependent variable: standard errors for the dependent variables were 1.00, shear stress; 0.014, shear strain; 1.15, shear modulus (shear stress/ shear strain).

² Added water (AW) = % moisture - (4 x % meat protein).

³ Shear modulus (G) = shear stress/shear strain.

^{abc} means within a dependent variable and row with unlike superscript letters are different (P<0.05).

^{xy} means within a dependent variable and column with unlike superscript letters are different (P<0.05).

^{mn} means within the same NaCl and milk protein hydrolysate level with unlike superscript letters are different (P<0.05).

Table 4-Interaction between end point temperature (EPT), added water and NaCl for various physical properties.

Dependent variable ¹	NaCl (%)			
	1		2	
	added water ² (%)		added water (%)	
	30	40	30	40
<u>CIE a*</u>				
71.1°C	9.00 ^{aym}	7.84 ^{bxm}	9.09 ^{axm}	7.77 ^{bxm}
76.7°C	9.33 ^{axm}	7.81 ^{bxm}	8.87 ^{axn}	7.96 ^{bxm}
<u>Shear Stress (kPa)</u>				
71.1°C	127.69 ^{aym}	79.79 ^{byn}	124.61 ^{ayn}	101.88 ^{bxm}
76.7°C	133.74 ^{axn}	94.80 ^{bxm}	139.05 ^{axm}	94.88 ^{bym}
<u>Shear strain</u>				
71.1°C	1.46 ^{bxn}	1.55 ^{axm}	1.60 ^{axm}	1.51 ^{bxn}
76.7°C	1.46 ^{axn}	1.48 ^{aym}	1.55 ^{aym}	1.46 ^{bym}
<u>Shear modulus³ (kPa)</u>				
71.1°C	88.02 ^{axm}	52.51 ^{byn}	78.71 ^{ayn}	68.01 ^{bxm}
76.7°C	92.19 ^{axm}	64.37 ^{bxm}	89.97 ^{axm}	64.96 ^{bxm}

¹ Dependent variable: standard errors for the dependent variables were 0.09, CIE a*; 0.81, shear stress; 0.011, shear strain; 0.94, shear modulus (shear stress/ shear strain).

² Added water (AW) = %moisture - (4 x %meat protein).

³ Shear modulus (G) = shear stress/shear strain.

^{ab} means within a dependent variable and row with unlike superscript letters are different (P<0.05).

^{xy} means within a dependent variable and column with unlike superscript letters are different (P<0.05).

^{mnn} means within the same end-point temperature and added water level with unlike superscript letters are different (P<0.05).

Table 5-Interaction between end point temperature (EPT), NaCl and milk protein hydrolysate on torsion values

Dependent variable ¹	NaCl (%)					
	1			2		
	milk protein hydrolysate (%)			milk protein hydrolysate (%)		
	1	2	3	1	2	3
<u>Shear stress (kPa)</u>						
71.1°C	87.16 ^{cyn}	100.42 ^{byn}	123.64 ^{axm}	109.02 ^{bym}	111.60 ^{bxm}	119.13 ^{axn}
76.7°C	106.36 ^{cxn}	116.61 ^{bxm}	119.85 ^{aym}	119.11 ^{axm}	113.76 ^{bxm}	118.03 ^{axm}
<u>Shear modulus² (kPa)</u>						
71.1°C	60.61 ^{cyn}	68.58 ^{bym}	81.60 ^{axm}	68.13 ^{bym}	73.27 ^{abxm}	78.68 ^{axm}
76.7°C	71.40 ^{cxm}	77.69 ^{bxm}	85.75 ^{axm}	76.41 ^{bxm}	73.53 ^{bxm}	82.45 ^{axm}

¹ Dependent variable: standard errors for the dependent variables were 1.00, shear stress; 1.15, shear modulus.

² Shear modulus (G) = shear stress/shear strain.

^{abc} means within a dependent variable and row with unlike superscript letters are different (P<0.05).

^{xy} means within a dependent variable and column with unlike superscript letters are different (P<0.05).

^{mn} means within the same end-point temperature and milk protein hydrolysate level with unlike superscript letters are different (P<0.05).

Table 6-Interaction between end point temperature (EPT), added water and milk protein hydrolysate on torsion values

Dependent variable ¹	Added water ² (%)					
	30			40		
	milk protein hydrolysate (%)			milk protein hydrolysate (%)		
	1	2	3	1	2	3
Shear stress (kPa)						
71.1°C	115.78 ^{cym}	128.21 ^{bym}	134.46 ^{aym}	80.39 ^{cyn}	83.81 ^{byn}	108.30 ^{axn}
76.7°C	132.74 ^{bxm}	137.13 ^{axm}	139.32 ^{axm}	92.74 ^{bxn}	93.23 ^{bxn}	98.56 ^{ayn}
Shear strain						
71.1°C	1.53 ^{bxm}	1.48 ^{byn}	1.58 ^{axm}	1.55 ^{axm}	1.58 ^{axm}	1.45 ^{axn}
76.7°C	1.53 ^{axm}	1.56 ^{axm}	1.43 ^{bym}	1.53 ^{axm}	1.48 ^{byn}	1.41 ^{cxm}
Shear modulus³ (kPa)						
71.1°C	76.97 ^{bym}	87.83 ^{axm}	85.29 ^{aym}	51.77 ^{byn}	54.03 ^{byn}	74.98 ^{axn}
76.7°C	87.00 ^{bxm}	88.01 ^{bxm}	98.24 ^{axm}	60.81 ^{bxn}	63.22 ^{bxn}	69.96 ^{axn}

¹ Dependent variable: standard errors for the dependent variables were 1.00, shear stress; 0.014, shear strain; 1.15, shear modulus (shear stress/ shear strain).

² Added water (AW) = %moisture - (4 x % meat protein).

³ Shear modulus (G) = shear stress/shear strain.

^{abc} means within a dependent variable and row with unlike superscript letters are different (P<0.05).

^{xy} means within a dependent variable and column with unlike superscript letters are different (P<0.05).

^{mn} means within the same end-point temperature and milk protein hydrolysate level with unlike superscript letters are different (P<0.05).

VITA

The author, Bhundit Innawong, was born January 1, 1970 in Thailand. He graduated with a Bachelor of Science degree in Food Science from Kasetsart University in Bangkok, Thailand in 1992.

After graduation, Bhundit had opportunity to work with the Dole Company as project supervisor in the preparation department for 2 years. In 1994, he received scholarship from his government in 1995 to study in USA. He began pursuing the Master of Science degree in Food Science and Technology at Virginia Polytechnic Institute and State University.