

**Effects of Physiological State, Temperature, Water, and
Extended Mixing on Low-Fat, High Added Water Frankfurters**

by

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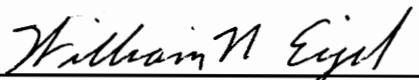
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ABSTRACT

Frankfurters with 15% fat and 25% USDA added water were formulated with either prerigor or postrigor lean meat and postrigor fat using typical manufacturing practices. These frankfurters were compared to others produced using a 30 min extended mixing process (EM) on the lean component at either 2° or 16°C and either 30 or 100% of the formulation water. Results indicated that prerigor lean offered no advantages in the cooking yield nor reduction in fluid accumulation in vacuum packaged product stored (5°C) for 30 days. In addition, prerigor treatments had lower ($P<0.05$) Instron hardness and distance to fracture values than postrigor treatments. EM with 30% of the formulation water resulted in lower distance to fracture ($P<0.05$), cohesiveness ($P<0.05$), springiness ($P<0.05$), and hardness ($P<0.07$) values compared to those with 100%. In general, the texture of EM frankfurters was not significantly different from traditionally processed products, though independent variables beyond physiological state could not be separately tested. Traditional mixing resulted in higher L^* , a^* , and b^* values than EM treatments. Within EM treatments, mixing with only 30% of the water resulted in significantly lower CIE a^* values, but increased L^* and b^* values.

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Chapter 1

INTRODUCTION

Many reduced fat foods are now being manufactured as a result of consumer demand for healthier, lower calorie products. Comminuted meats such as bologna and frankfurters are no exception. Historically, comminuted meats were manufactured with fat levels up to 30%. Research often has focused on fat emulsification as the primary factor in the stability of the finished product (Acton et al., 1983).

Fat reduction in sausages results in a higher cost of formulation (Rust and Olson, 1988) due to the use of additional leaner, more expensive raw materials (Claus et al., 1989). Fat reduction can affect texture (Lee et al., 1987; Rust and Olson, 1988; Park et al., 1989). Rust and Olson (1988) stated that reducing the fat content and compensating by adding additional salt-soluble proteins (lean meat) may yield a product that is too tough for the consumer.

Prior to 1988, the United States Department of Agriculture (USDA) restricted cooked sausages to a maximum of 10% added water (AW = % moisture - 4 x % protein), but currently allows up to 40% (fat plus AW) with fat being limited to 30% (USDA, 1988; CFR, 1991). Studies utilizing this higher limit have shown that some undesired effects associated with fat reduction can be at least partially offset by using additional formulation water (Claus et al., 1989; Park et al., 1990). When manufacturing products with less fat and increased AW, problems with poor cooking yields, fluid accumulation in the package (purge), and soft texture are often encountered (Rust and Olson, 1988; Claus et al., 1989), particularly when reducing the fat content to less than 15% (Rust and Olson, 1988).

Prerigor meat has been shown to prevent or reduce fat losses in a

variety of products (Trautman, 1964; Acton and Saffle, 1969; Froning and Neelakantan, 1971). This is believed to be due to the increased extractability of salt-soluble myofibrillar proteins (SSP) and the higher pH of prerigor meat (Goll et al., 1964; Trautman, 1964; Solomon and Schmidt, 1980). Higher cooking yields may be obtained in products using prerigor meat which indicates an increased water holding capacity (Cross et al., 1979; Ockerman and Wu, 1990).

The chopping method and final temperature also affect the properties of comminuted meats. The reported range of optimum final chopping temperatures for fat holding ability varies from 15° to 21°C (Hansen, 1960; Swift et al., 1961; Helmer and Saffle, 1963; Brown and Toledo, 1975; Webb et al., 1975), with other factors such as chopping speed, fat source (Ackerman et al., 1971), and order of ingredient incorporation (Barbut, 1990) also having an affect. The water binding ability was also optimized in this temperature range (Brown and Toledo, 1975). Studies examining the effects of chopping at controlled temperatures have indicated that lower temperatures, typically reported in the range of 5 to 7°C, may improve fat and water binding (Webb et al., 1975; Deng et al., 1981; Ockerman and Wu, 1990). Protein extractability may have been a factor as this is maximized at 7.2°C (Gillett et al., 1977).

Increasing the ionic strength through addition of higher amounts of salt is another means of increasing SSP extraction (Gillett et al., 1977; MacFarlane et al., 1977). Many studies have indicated that water holding capacity (WHC) and cooking yields are higher with increased ionic strength (Hamm, 1975b; Aberle et al., 1980; Poulanne and Terrell, 1983; Hand et al., 1987; Trout and Schmidt, 1987; Barbut, 1988; Girard et al., 1990; Ockerman and Wu, 1990).

Restricting water during the initial chopping or mixing period effectively increases the ionic strength by concentrating the soluble components within the system. However, when the SSP's are concentrated,

they tend to aggregate, thereby limiting interactions with water and fat (Mahler and Cordes, 1971).

Because of the need for acceptable low fat products, the objectives of this study were to establish the effects of producing 15% fat, 25% USDA AW frankfurters from prerigor and postrigor lean using conventional manufacturing procedures compared to alternative processing techniques that combined mincing then mixing for an extended period of time with:

- (1) temperatures of 2 or 16°C during the mixing process and
- (2) 30% or all of the formulation water

on the cooking yield, instrumental texture and color, and storage properties.

Chapter 2

LITERATURE REVIEW

2.1 Comminuted Meats

Products such as frankfurters and bologna are often referred to as meat emulsions or fine cut sausages. These are created by comminuting meat and water with sodium chloride to a fine homogenate, then heat processed to achieve fat and water binding (Schmidt, 1987). Comminuted meats are not true emulsions as the stability of these products depends primarily upon the formation of a protein matrix physically entrapping the liquid phase, as well as emulsification of the fat and water by proteins (Lee, 1985). The properties of this matrix, which is different for each class of processed meats, give the product its characteristic texture and bite (Schmidt et al., 1981). The major concern is proper stabilization of fat and water within the matrix (Lee, 1985).

2.2 Reduced-fat Products

Consumers have become increasingly concerned with their fat intake because of alleged adverse effects on health. Many foods being marketed have undergone a fat reduction or reformulation to meet the increased demand for lower calorie or healthier products, and comminuted meats are no exception, as these products may contain up to 30% fat.

Most of the earlier low-fat research was based on using less fat in comminuted meat product formulations. This may have been due to legal restrictions on composition, and resulted in a variety of changes including increased firmness and springiness (Hand et al., 1987; Lee et al., 1987; Park et al., 1989; Rust and Olson, 1988), decreased juiciness (Park et al., 1989), and higher cost due to the use of leaner cuts of meat (Rust and Olson, 1988). Other effects include a darker color with

increased redness (Claus et al., 1989; Ahmed et al., 1990).

Some of these changes are simply due to less fat, though other factors are likely to be involved. From a composition standpoint, lowering the fat results in an increase in the protein and moisture content (Claus et al., 1989). Partial research data from Claus et al. (1989), using the legal limit prior to 1988 of 10% USDA AW, demonstrated that a "typical" product with 28.1% fat, 10.9% protein, and 53.7% moisture undergoing an approximate 33% reduction in fat content became 18.5% fat, 13.1% protein, and 61.0% moisture. Note that the AW content of 8.6% is 1.4% below the targeted 10%. The percentage increase for protein and water are 20% and 14%, respectively. Proteins are known to be the main factor in determining the structure and texture of meat products, and therefore some of the changes that occur in low-fat comminuted meats may be due to this marked increase in protein content (Claus et al., 1989; Park et al., 1989).

At present, processors can formulate products to contain 40% fat plus AW, with the fat being restricted to its previous maximum of 30% (USDA, 1988; CFR, 1991). In effect, this allows manufacturers previously restricted to 10% AW to exchange water for fat (USDA, 1988) with no increase in the protein concentration. The original petition submitted to the USDA proposed a minimum protein content of 11.5% and a maximum fat content of 22.5% in "lite" frankfurters and cooked sausages, with no restrictions on AW (USDA, 1988).

Some of the physical and sensory changes associated with low-fat formulations may be reduced or eliminated by increasing the level of AW (Claus et al., 1989; Ahmed et al., 1990; Park et al., 1990). Claus et al. (1989) developed regression equations that indicated reduced fat products can be produced with a texture similar to that of a high-fat, 10% AW product by substituting AW for fat, though at less than a 1:1 ratio. This would suggest that an increase in protein content may be necessary. Data from Park et al. (1990) seems to support this

observation, as 10% to 15% fat, high moisture (20% to 23% AW) frankfurters had instrumental and sensory texture values that were similar to those of a traditional 30% fat, 10% AW product.

These low-fat, high-moisture comminuted meats have problems with WHC, and it has been stated that the product's water-binding capacity will now replace its fat-binding capacity as the critical issue in production (Rust and Olson, 1988). As the fat content decreases and the moisture content increases, higher cooking losses are encountered (Claus et al., 1989), though Park et al. (1990) reported equal yields when using less than the maximum allowed AW. Increased amount of purge is another problem encountered when substituting water for fat (Rust and Olson, 1988; Claus et al., 1989; Claus et al., 1990).

With vacuum packaging, there is a constant pull [push] on the product by the package, which increases purge (Rust and Olson, 1988). This generally is a greater problem with products containing increased levels of water (Rust and Olson, 1988)

Color changes associated with fat reduction are slightly lessened with higher levels of AW. By incorporating additional water, meat pigments are diluted lowering the redness values while increasing product lightness (Claus et al., 1989; Ahmed et al., 1990).

2.3 Effects of Ingredients in Comminuted Meats

2.3.1 Lean meat

Lean meat is the ingredient that supplies the majority of the proteins to the comminuted product. There are three major classes of proteins found in meat: myofibrillar, sarcoplasmic, and stromal proteins. Of the three, myofibrillar proteins have the greatest effect on product characteristics (Acton et al., 1983), though both stromal and sarcoplasmic proteins have been shown to have some influence under certain conditions.

Myofibrillar proteins

The myofibrillar fraction, consisting of mostly high-molecular weight, salt extractable fibrous proteins, is largely responsible for the functional responses within a comminuted meat mass (Acton et al., 1983). The principal myofibrillar proteins are myosin in prerigor meat and actomyosin in postrigor meat (Acton et al., 1983). Most studies conducted on rheological properties of extracted muscle protein gels have investigated myosin, actomyosin and their interaction with other myofibrillar protein fractions (Camou et al., 1989).

The binding abilities of myosin heavy chains, actomyosin, and myosin are not significantly different, but are increased by the presence of salt and phosphate (Siegel and Schmidt, 1979). The binding strength of myosin is not affected by salt concentrations above 0.2M whereas actomyosin binding ability increased markedly at salt levels above 0.6M, possibly due to myosin being more soluble at lower salt concentrations (Macfarlane et al., 1977).

The gel formed by heating crude myosin, actomyosin, or myosin heavy chains in the presence of 6% salt and 2% tripolyphosphate revealed that the protein had coagulated to form a three-dimensional network of protein fibers. This contributed to harboring of water as well as gel strength due to the occurrence of a greater number of molecular interactions (Siegel and Schmidt, 1979). When salt and phosphate were absent, the protein coagulated to form a spongelike framework less suited to harbor water or attain an appreciable gel strength (Siegel and Schmidt, 1979). Protein concentration effects gel strength as indicated by Ishioroshi et al. (1979) whose model system demonstrated a linear relationship between the log of myosin concentration and the log of gel rigidity in the concentration range of 0.1-1.0% myosin.

Early research often focused on fat emulsification as the primary factor in the stability of the finished product (Acton et al., 1983). Myofibrillar proteins play an important role in the fat holding/

emulsification abilities of meat. The salt soluble or myofibrillar protein fraction of muscle form a far more stable emulsion than the water soluble protein fraction (Trautman, 1964). Hansen (1960) reported that myosin and actomyosin appeared to concentrate at the fat globule surfaces forming an emulsifying protein matrix that enclosed the dispersed fat globules. In timed emulsification procedures, both myosin and actomyosin were removed rapidly from solution, whereas actin was less rapidly removed during the interfacial area increase (Galluzzo and Regenstein, 1978). Similar results for emulsifying capacity have been reported by Tsai et al. (1972). When the actomyosin complex was dissociated by adenosine triphosphate (ATP) or pyrophosphate addition, myosin was preferentially adsorbed as compared to actin (Galluzzo and Regenstein, 1978). A myofibrillar protein complex, tropomyosin-troponin, had some fat emulsifying ability, but these emulsions were not heat stable (Tsai et al., 1972).

The thermal denaturation of myosin and actomyosin, unlike actin, is highly pH dependent (Wagner and Anon, 1985) as is the protein-protein interactions of actomyosin (Ziegler and Acton, 1984). The maximum rate of conformational changes for both myosin and actomyosin were observed at $43^{\circ} \pm 2^{\circ}\text{C}$, with any conformational changes below this point being considered mostly reversible (Jacobson and Henderson, 1973). Ziegler and Acton (1984) reported an additional transition region at 56 to 57.5°C .

Sarcoplasmic proteins

The muscle fiber proteins that are not associated with the contractile apparatus either functionally or mechanically represent the sarcoplasmic proteins and include enzymes, hemoglobin, myoglobin, and other proteins that are soluble at a low ionic strength and neutral pH (King and Macfarlane, 1987). These proteins may be extracted by simply homogenizing muscle in water (King and Macfarlane, 1987).

An important function of sarcoplasmic proteins is the effect of myoglobin and hemoglobin on meat color (King and Macfarlane, 1987). They are not likely to be important binding agents since these proteins yield poor cohesion between ground meat particles that have been simply pressed together and then cooked (King and Macfarlane, 1987). However, at salt concentrations of less than 0.2 M, the addition of sarcoplasmic proteins to myosin are reportedly beneficial to binding ability (Macfarlane et al., 1977). The opposite is true for their fat emulsifying ability as salt enhances the tendency of water soluble proteins to stabilize emulsions (Swift et al., 1961; Swift and Sulzbacher, 1963; Tsai et al., 1972).

Stromal proteins

In whole meats, stromal proteins play an important role in meat tenderness, but their function in comminuted systems is less well defined. Connective tissue, consisting mostly of collagen, appears to have very little fat emulsifying power (Trautman, 1964), and is not an effective water binder compared to SSP (Rust and Olson, 1988).

In a frankfurter mixture, connective tissue elements contribute a great deal towards creating structure and giving a firm "bite" (Wirth, 1987). However, to do this, some connective tissue integrity must remain (Wirth, 1987).

2.3.2 Sodium chloride

Prior to widespread use of mechanical refrigeration, sodium chloride (salt) was one of the primary means used to preserve meat from microbial spoilage. With widespread refrigeration, the role of salt as a preservative has decreased, though today it is still widely used for different reasons. Salt has a complex effect on the flavor of meats and other products, not only imparting a "salty" flavor, but serving to enhance other flavor characteristics (Mickelsen, 1982). While

important, flavor is not the major function of salt in comminuted products.

Effect of salt on protein extraction

The primary objective for using salt in meat processing is to form a product with low moisture loss and no fat coalescence into lakes or loss through rendering (Acton et al., 1983). Other important reasons include producing a firmer texture and increasing shelf life (Terrell and Brown, 1981). Comminution of meat in the presence of sufficient salt induces a partial extraction of the myofibrillar protein components (Acton et al., 1983; Wirth, 1987). Another effect is that myofibrils swell quickly to about twice their original volumes in the presence of salt at concentrations which are widely used in the meat industry (Offer and Trinick, 1983; Wirth, 1987). 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).

The effects of salt are primarily ionic (Siegel and Schmidt, 1979). Early studies indicated that meat proteins (actomyosin in postrigor meat) probably absorb both anions and cations from neutral salt solutions leading to a reduction in the internal forces of attraction between oppositely charged groups within the protein molecules (Alexander and Johnson, 1950). Hamm (1960) and Schut (1976) stated that effect is primarily due to the chloride ions which are 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 WHC. Hamm (1960) reported that salt produced an apparent shift in the pI of the myofibrillar proteins to a lower pH value creating a larger net negative charge at the existing pH from the ionizable carboxyl groups of the protein. Aside from increased protein extraction, salt enhances the dissociation of actomyosin to actin and myosin in the presence of ATP

(Hamm, 1975a; Wirth, 1987). Changes in the structure and charge of the salt soluble proteins have a destabilizing effect on these proteins evidenced by a lowering of denaturation temperatures (Quinn et al., 1980; Samejima et al., 1983).

The precise degree of swelling of the protein network depends on the concentration of ions absorbed (Sherman, 1962). Higher levels of salt increased the extractability of proteins in meat (Gillett et al., 1977) and levels up to about 5% increased the viscosity of muscle homogenates (Hamm, 1975a).

Many studies have indicated that WHC and cooking yields are higher with increasing salt levels (Hamm, 1975a; Aberle et al., 1980; Poulanne and Terrell, 1983; Hand et al., 1987; Trout and Schmidt, 1987; Barbut, 1988; Girard et al., 1990; Ockerman and Wu, 1990), though there is some variation (generally 2% to 3%) in reported optimum concentration. The minimum level of salt required for a significant increase in the WHC of preblended prerigor pork sausage has been reported to be greater than 1%. However, at levels above 2%, the increase in benefits decline rapidly (Poulanne and Terrell, 1983). Similar results were obtained for fat holding ability (Swift and Sulzbacher, 1963; Hand et al., 1987).

Effect of salt and physiological state

Salted prerigor meat is superior to postrigor in fat and water holding capacity, though benefits decreased rapidly with increasing time of postmortem salt addition (Honikel et al., 1981b), whereas rigor mortis did not influence the fat and water holding capacities of unsalted meat (Honikel et al., 1981a). Hamm (1975a) stated that prerigor salting is important because it prevents the strong decrease in WHC postmortem. The effect of NaCl on the prerigor tissue has been attributed to increased solubilization of myofibrillar proteins caused by the combined effects of ATP, high pH and high ionic strength (Hamm, 1975a; Honikel et al., 1981a; Choi et al., 1987a). Once salted, the

desirable sausage making qualities of prerigor beef can be maintained for up to 28 days (Abu-Bakar et al., 1982), although Wirth (1987) stated the limit to be three days due to microbial considerations..

Adverse effects of salt

Salt is considered a prooxidant and contributes to the acceleration of rancidity in meat products. Numerous studies indicate a direct relationship between the percentage of salt and increasing degrees of rancidity during storage as evidenced by higher thiobarbituric acid (TBA) or peroxide values (Ellis et al., 1968; Waldman et al., 1974; Judge and Aberle, 1980; Drerup et al., 1981; Choi et al., 1987b). Waldman et al. (1974) stated that above 1.5% salt, no significant increase in the TBA values were observed, though other studies indicated that rancidity increased through higher salt levels (Ellis et al., 1968; Choi et al., 1987a). The physiological state at which salt is added has been reported to have an effect on TBA values, as susceptibility to autoxidation was reduced in prerigor ground and salted sausages due to higher pH compared with control which was salted post-rigor (Judge and Aberle, 1980; Drerup et al., 1981).

Excessive intake of sodium is a concern as it is related to an increased incidence of hypertension (Dahl, 1972). In North America, dietary intake of salt was estimated to be 10 to 12 g per person per day. This is equivalent to 3,900 to 4,700 mg of sodium, and is many times greater than the minimum adult requirement of 100 to 200 mg per day (Anonymous, 1980). Of this quantity, salt from commercially processed foods may represent 4 to 6 g of the total intake (Anonymous, 1980).

2.3.3 Phosphates

The primary purpose of using phosphates in cured meat products is to increase the water holding capacity thereby reducing cooking losses and the degree of purge (Sherman, 1962; USDA, 1982; 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.

There are three classes of phosphates: neutral, acidic, and basic. Schmidt (1987) reported that only the alkaline phosphates are effective in improving water binding since acid phosphates may lower the pH and cause greater shrinkage, but Barbut (1988) reported that all classes offer at least some benefit. Of the alkaline phosphates, sodium tripolyphosphate is the most commonly added to processed meats, poultry, and seafood (Fennema, 1985), though it has been reported that pyrophosphates are more effective at increasing the cook yield (Fukazawa et al., 1961; Knipe et al., 1990).

The mechanism by which phosphates and polyphosphates enhance meat hydration is not clearly understood despite extensive studies (Fennema, 1985). Phosphates may adsorb onto proteins or react with charged groups in polypeptides to form complexes, thereby exerting direct effects on protein characteristics such as hydration and swelling, gelation, thermal denaturation, and protein-protein interactions (Molins, 1991). Alkaline phosphate addition results 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 because of an increase in the electrostatic repulsion between protein molecules. This results from an increased net negative charge associated with higher pH (Molins, 1991). Phosphate addition also increases the ionic strength (Siegel and Schmidt, 1979).

Salt and phosphate have a synergistic effect for altering meat

properties. 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, 1987; Molins, 1991) and water binding (Seman et al., 1980; Trout and Schmidt, 1987; Girard et al., 1990). Seman et al. (1980) reported that by lowering the ionic strength of bologna from 0.42 to 0.21 resulted in less stable emulsions with lower hardness values, but adding small amounts (0.13%) of phosphate to low ionic strength (0.21) bologna, yielded products similar to high ionic strength (0.41) treatments.

There may be an ionic strength threshold as pyrophosphate had a positive effect on both cook yield and tensile strength at ionic strengths above 0.25M, 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 low ionic strength which destabilized the protein structure making the proteins more heat labile. In contrast, at high ionic strength, pyrophosphate affected hydrophobic interactions 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 the positive hydrophobic effects (Trout and Schmidt, 1987). Other studies indicated that this was not the case (Seman et al., 1980; Knipe et al., 1990). Addition of 0.3% sodium pyrophosphate or tripolyphosphate increased the cooking yields of low salt (0.75%) comminuted meat emulsions, though 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, 1975a; Siegel and Schmidt, 1979). However, phosphates cannot exert this effect on salted prerigor tissue as actin and myosin will not be associated

(Hamm, 1975a).

2.3.4 Nitrite

The main value of nitrite in stabilizing canned, cured, or shelf-stable meats appears to reside in its ability to aid in the prevention of microbial outgrowth of spores that survive heat processing and germinate during post-processing storage (Pivnick et al., 1970, Cassens, 1990). Nitrite's bacteriostatic action is affected by pH as its effect is believed to be due to undissociated nitrous acid which is greater at reduced pH (Castellani and Niven, 1955). It has been shown that preblending beef with salt and nitrite lowers the total plate counts (Abu-Bakar et al., 1982), though Waldman et al. (1974) reported increased aerobic and anaerobic bacteria compared to preblends mixed only with salt.

Effect of nitrite on color

Meat cured color is the product of nitrite being reduced to form nitric oxide, which in turn reacts with heme proteins. Upon heating, extremely stable, bright red complexes called nitrosylhemochromes are formed "imparting" color by giving the meat a cured color that it would not otherwise possess (Cassens, 1990).

The color of cured meats is dependent on three factors: concentration of pigment in the tissues, degree of conversion to the nitrosyl pigment, and state of the heme proteins in meat (Townsend and Olson, 1987). In ham or frankfurters, the pigment concentration is low and the proteins are denatured, therefore these products are opaque. The reflected light is brighter and the color is a pale pink (Townsend and Olson, 1987). Pigment conversion is important to the observed hue, and conversions of 60 to 80% are normal. Less than 50% conversion results in brownish hues, and over 80% results in bluish-red hues (Townsend and Olson, 1987). Pigment conversion to the cured form in

frankfurters was more efficient when sodium nitrite was added at the time of manufacture rather than when preblending (Waldman et al., 1974). Species differences apparently affect residual sodium nitrite concentrations, as beef had lower levels than pork probably due to the higher myoglobin content in the former (Waldman et al., 1974).

Effects of nitrite on oxidative changes

Nitrites have been shown to delay the development of oxidative rancidity in cured meats. This effect was observed even in the presence of sodium chloride, a promoter of lipid oxidation (Abu-Bakar et al. 1982). The effect of nitrite on rancidity is probably due to the same reaction that is responsible for color development. Reaction of the heme iron with nitrate [nitric oxide] to form cured pigments retained the iron within the heme molecule, and in its reduced (Fe^{++}) form, rendering it inactive as a catalyst for lipid oxidation (Watts, 1954).

Adverse effects of nitrite

Under extreme heating conditions, residual nitrites have been shown to be potential precursors for carcinogenic nitrosamines. As a result, limitations have been placed on the use of nitrates and nitrites in meat products (Townsend and Olson, 1987). Although nitrosamine formation in meat does not occur if the concentration of nitrite does not exceed U.S. Federal regulations, commercial samples of frankfurters have occasionally been found that contain this compound at low levels (Fennema, 1985). In some instances, it was suspected that improper mixing may have resulted in high local concentrations of nitrite, thereby favoring the formation of nitrosamines.

2.3.5 Effects of ascorbate/erythorbate

The primary use of ascorbates, including sodium erythorbate, in the meat industry is to accelerate the cure reaction and color development of meat products (Townsend and Olson, 1987; Cassens, 1990). Ascorbic and erythorbic acid react very rapidly in solution with nitrates and nitrites causing the release of gaseous nitrogen oxides which then reacts with heme pigments in meat leading to the formation of nitrosylhemochromes on heating. The USDA has required the use of ascorbates in cured products such as bacon (Townsend and Olson, 1987; Cassens, 1990) since they reduce the conversion of nitrites to nitrosamines in cured meat (Mirvish et al., 1972; Fennema, 1985).

2.3.6 Fat

Fat has an important impact on tenderness, juiciness, flavor, appearance, cost, and processing characteristics of meat products (Cross et al., 1980; Rust and Olson, 1988; Claus et al., 1989; Allen and Foegeding, 1981). Townsend et al. (1968) suggested that the melting characteristics of meat fats could be the basis for differences in the maximum temperatures at which meat formulas should be chopped. Reported melting temperatures for beef fat are 41 to 48°C, pork fat 38 to 47°C, and chicken fat 31 to 33°C (Acton et al., 1983). Generally, meat batters prepared with higher melting temperature fats had to be chopped to higher temperatures to obtain maximum fat holding ability (Townsend et al., 1971). Frankfurter texture also was affected by the use of harder or more saturated fats resulting in increased firmness, springiness, and cohesiveness (Townsend et al., 1971; Lee et al., 1987; Park et al., 1989; Sams and Diez, 1990).

Cooking yields or shrinkage also varied with the type of fat, as frankfurters formulated with pork fat had less shrinkage than those with beef fat or cottonseed oil (Townsend et al., 1971). Physiological state of the fat also seems to play a role as Bentley et al. (1988) found a

significant increase in the cooking yield by using prerigor pork fat in luncheon loaves produced from postrigor lean.

Increased levels of fat have been directly related to increases in cooking yield and water binding ability in comminuted products (Townsend et al., 1971; Haq et al., 1973; Cross et al. 1980; Poulanne and Turkke, 1984), though Trout and Schmidt (1986) reported little effect on the water binding ability in canned meat. Fat prevents the protein structure from shrinking too much when heat denatured during heat treatment (Wirth, 1987). To do this, the fat particles must be well distributed and the fat tissue must be sufficiently well comminuted. Frankfurter products with a low fat content are more likely to deposit jelly and are less resistant to heat than high fat content ones (Wirth, 1987). Varying levels of fat did not have an effect on the percentage of extractable meat protein (Saffle and Galbreath, 1964). Increases in fat content resulted in increased batter viscosity at low temperatures when the fat would typically be in a solid state (Haq, 1973; Hamm 1975; Payne and Rizvi 1988), but the opposite was true as temperatures increased (Toledo et al., 1977). Shear force and firmness of frankfurters also showed a direct relationship to the fat content when comparing 17 and 25% fat products (Hand et al., 1987). However, Sams and Diez (1990) reported that chicken frankfurters using only or mostly chicken fat had very little difference in the firmness values for 22 vs. 27% levels.

2.3.7 Water

Typically, water is the principal component in fresh meat and in processed meat products, and has an important influence on product characteristics. The amount of water present has an important role in emulsion stability. Evaluation of emulsions with widely varying compositions indicated that the lean and fat percentages could be altered over wide ranges without significantly affecting emulsion

stability, but the range of moisture content was narrow and critical to stability (Morrison et al., 1971). For example, it was found that at the 30% fat level, there was a sharp decrease in fat emulsion stability as the amount of water added to a meat batter was reduced to 16% for fresh beef and 21% for frozen (Morrison et al., 1971). Similar findings were reported by Swift and Sulzbacher (1963) when restricting or eliminating the amount of water in a salted meat batter. Other reported effects of decreasing moisture level include increases in hardness, fracturability, apparent moduli, stress at 20% compression, mechanical hysteresis loss, and strain energy, as well as thermal conductivity and decreases in springiness and the degree of elasticity (Ziegler et al. 1987). Moisture had no significant effect on cohesiveness (Ziegler et al. 1987).

Mahler and Cordes (1966) developed a theory that protein-protein interactions increased with higher protein concentration decreasing their emulsification effectiveness. In a relatively dilute system, such as those in sausage-type emulsions which have higher levels of added water, greater stability was obtained. Apparently, the opposite occurs when limited water is available.

2.4 Physiological State

2.4.1 Rigor development

The cessation of blood flow is needed to initiate the chain of events culminating in rigor as oxygen no longer enters the tissues and no waste products leave (Marsh, 1981). The cells now produce ATP anaerobically leading to the production and accumulation of lactic acid in the tissue, attaining a concentration of 1% or more accounting for the decline in muscle pH (Marsh, 1981). Except in rather special circumstances, a rapid decline in ATP levels does not occur due to the presence of creatine phosphate (Marsh, 1981). Creatine phosphate (CP) along with the enzyme creatine phosphokinase promotes the

rephosphorylation of adenosine diphosphate to ATP as long as the supplies of CP last. However, once the CP reserve is exhausted, the initial level of ATP can no longer be maintained, initiating the rapid onset phase of rigor mortis (Marsh, 1981). The depletion of ATP postmortem causes an association of actin and myosin into the actomyosin complex, thus producing a loss of extensibility of the muscle fiber or the fiber fragments (Hamm, 1975a; Honikel et al., 1981a). A number of studies showed that prerigor muscle tissue had considerably higher percentages of salt-soluble proteins compared to postrigor tissue (Goll et al., 1964; Saffle and Galbreath, 1964; Trautman, 1964; Acton and Saffle, 1969; Solomon and Schmidt, 1980).

The development of rigor mortis has an effect possibly due to different types of intermolecular or interfilamental cross-linking that occurs postmortem during pH decline as the myofibrillar proteins are approaching the pI (Hamm, 1975b). As the pI is approached, there is an increase of oppositely charged groups and therefore, an increase of intermolecular ionic cross-linkages. As the network of myofibrillar proteins tightens, less water can be immobilized compared to that of the loose network which exists at higher pH values, resulting in a decrease of WHC (Hamm, 1975b). The formation of interfilamental cross-linkages also hinders the ability of salt to shift the pI, therefore, the WHC-raising effect of NaCl in muscle homogenates is continuously diminished with decreasing pH of the prerigor muscle (Hamm, 1960; Hamm, 1975b).

2.4.2 Advantages and disadvantages of prerigor meat

Hot boning before chilling has been reported to offer advantages of savings in energy, space, labor, materials and supplies (Bowling, 1981; Reagan, 1983; Choi et al., 1987a; Eikelenboom and Smulders, 1987). A conflicting account was given by Saffle (1968) who stated that the use of prerigor meat had largely been discontinued because of excessive refrigeration and labor requirements. There are problems associated

with prerigor meat, especially when considering whole muscle cuts. Early attempts at hot boning resulted in problems with toughness and shape distortion caused by uncontrolled muscle contraction associated with prerigor excision of muscle (West, 1983b). There are also problems in establishing carcass grade as the U.S. livestock and meat industry relies heavily on USDA grading as a marketing tool (Cross et al., 1981), though pork carcasses are generally not graded (Cross and Seideman, 1985). Other disadvantages include difficulties in working with and packaging the soft meat and fat (Jacobs and Sebranek, 1980; Bowling, 1981; Cross et al., 1981; Reagan, 1983).

It has been known that prerigor meat can improve certain properties of processed meats, as Trautman (1964) and Froning and Neelakantan (1971) stated that prerigor meat was often included in formulations to prevent excessive fat separation. Photomicrographs of emulsions utilizing prerigor turkey muscle showed uniform and round fat globules, whereas nonuniform emulsions with some very large fat globules resulted from postrigor muscle (Froning and Neelakantan, 1971). Mixed results have been obtained for cooking losses, with some research indicating that better yields were obtained when using prerigor meat (Cross and Tennes, 1981; Drerup et al., 1981; Van et al., 1980; Kijowski et al., 1982; Huffman et al., 1985), others reported no significant differences (Aberle et al., 1980; Van Laack et al., 1989).

Hot processing procedures designed to maintain the functional advantages of prerigor meat during storage require special handling procedures like the addition of salt to the coarsely ground muscle (Froystein et al., 1984; Honikel and Reagan, 1987). In such operations, the time course of rigor mortis and thus, the time available for boning, grinding, and blending becomes of great practical importance (Honikel et al., 1981a; Froystein et al., 1984). Processing must be conducted within one hour postmortem when glycolysis is fast such as in porcine muscle (Wirth, 1987; Van Laack et al., 1989). The time frame for beef

is considerably longer as prerigor properties might be partially preserved by blending with salt up to 6 hours postmortem (Froystein et al., 1984).

Conformational changes in protein structure caused by prerigor salting are apparently irreversible because the WHC of this meat remains high irrespective of the postmortem breakdown of ATP and the fall of pH (Hamm 1977). Therefore, preblending of prerigor meat with salt is advantageous because slaughtering and boning operations do not have to be synchronized with the sausage kitchen (Acton and Saffle, 1969).

The high WHC of salted meat may be due to a strong electrostatic repulsion between the dissociated myofibrillar proteins myosin and actin caused by the combined influence of ATP, high pH, and increased ionic strength resulting from salt addition (Hamm 1977; Honikel and Hamm, 1978). Prerigor muscle pH is known to be higher than that of postrigor (Jacobs and Sebranek, 1980; Van et al., 1980; Bentley et al., 1987) and higher pH is often associated with increased water and fat holding ability. In the period after slaughter, whether intact or homogenized with or without salt, muscle has a WHC that decreases gradually with decreasing pH, though for salted meats, the decrease is less apparent (Honikel et al., 1981b).

Mixed results have been reported when comparing prerigor to postrigor meat after standardizing the pH to prerigor levels. Readjusting the pH of postrigor beef muscle homogenates to that of prerigor muscle caused an increase in both protein solubility and WHC. However, results were still lower than those of prerigor muscle homogenates, which indicated that this effect was not simply due to pH differences (Saffle and Galbreath, 1964; Honikel et al., 1981a). With postrigor turkey meat, adjustment of the pH restored the original high emulsifying ability of prerigor muscle (Froning and Neelakantan, 1971).

2.4.3 Effects of postmortem temperature

Postmortem temperature is an important factor to be considered when dealing with meat in the prerigor state. A "cold shortening" phenomenon has been attributed to the influence of low temperatures on the membrane system of the sarcoplasmic reticulum (Kanda et al., 1977). Lowering the temperature below approximately 15°C resulted in an increase in ATP degradation decreasing the time of rigor onset and sarcomere length (Bendall, 1973). Salting of prerigor beef decreased the rate of ATP hydrolysis with falling temperature until the meat is frozen (Honikel and Hamm, 1978). The rate of lactate formation (glycolysis) follows a similar pattern (Honikel and Hamm, 1978).

Ground prerigor meat can be frozen and still maintain its advantage over postrigor product provided the meat is frozen rapidly and is cooked or further processed from the frozen state (Honikel and Hamm, 1978; Jacobs and Sebranek, 1980; West, 1983b). Thawing frozen prerigor muscle resulted in a very rapid drop in both ATP and glycogen content leading to "thaw rigor" and a loss of fat and WHC (De Fremery and Pool, 1960; Acton and Saffle, 1969; Jacobs and Sebranek, 1980; West, 1983b), though some researchers indicated that thawed ground prerigor meat had better properties than postrigor meat, possibly due to the muscle structure being disrupted to the point that thaw rigor changes were not evident (Cross et al., 1979 ; Jacobs and Sebranek, 1980). Freezing and thawing had very little effect on postrigor meat (de Fremery and Pool, 1960).

2.5 Physical manipulation

2.5.1 Mixing

Mixing is a relatively gentle way of physically providing a uniform dispersion of various components in a mixture. Several studies have been performed using extended mixing time or "massaging". Extended mixing time increased the concentration of protein extracted from ground

meat slurries, though the highest rate was 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) reported that massaging of low-fat, high added water bologna formulations tended to increase Instron hardness and fracturability values and decrease purge compared to preblended or nonpreblended bolognas. 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.

2.5.2 Grinding, mincing, chopping

Particle size reduction for rupture of muscle cells is necessary 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 to an extent determined by particle size (Hamm, 1975a, Schut, 1976). 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 (Hamm, 1977; 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).

Prolonged chopping resulted in changes in fat and water binding irregardless of temperature control (Brown and Toledo, 1975). 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). Comminuted meat batters lose their binding capacity for water earlier than fat with longer periods of chopping (Brown and Toledo, 1975, Barbut, 1990, Ockerman and Wu, 1990). Increased chopping time with its further reduction of the lean meat particle and fat globule size, results in lower hardness values (Barbut, 1988 and 1990), though Lee et al. (1987) stated that underchopping the batter resulted in poorer protein extraction and lower firmness, chewiness, and elasticity scores.

The effects of overchopping may possibly be reversed by first cooling then rechopping the meat batter, indicating that no irreversible protein denaturation occurred (Helmer and Saffle, 1963). Brown and Toledo (1975) and Deng et al. (1981) concluded otherwise (partially reversible) when using more current evaluation techniques. Rechopping also reduces the size of the fat globules (Helmer and Saffle, 1963).

Emulsification temperature also has a profound effect on product characteristics such as water and fat holding as well as texture. There is extensive information available stating optimum and maximum temperatures. Research from the 1960's to mid-1970's often focused on

fat emulsification values which reported optimums usually in the 15 to 21°C range and exceeding these temperatures resulted 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, though Helmer and Saffle (1963) believed that protein denaturation was not the factor. Increasing 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), though 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 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 is a direct relationship between temperature and protein-protein interaction of actomyosin (Deng et al., 1976), however any protein-protein interaction and molecular aggregation that occurs is 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 7.2°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 (Ockerman and Wu, 1990). Low temperature (5.2°C) chopping with minimal fat, then adding cold fat and rapidly adjusting the temperature to 23°C was shown to produce

higher cook stability and physical property scores than chopping with minimal fat at 19 or 29°C (Webb et al., 1975). Similar findings are reported by Barbut (1990), who also stated that chopping all ingredients together to the desired temperature resulted in a higher cooking loss. Note that these temperatures are 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 temperatures (76.7°C) produced higher cook stability and physical property scores than fat added at 1.7 or 20°C. Faster rates of molten fat addition have been shown to lead to higher emulsification values, possibly due to reduced damage to protective membranes with decreased mixing (Swift et al., 1961).

Product particle size affects its ability to bind with other pieces of meat and prevent fat and water losses. Fat separation in very coarsely chopped products such as salamis and some luncheon loaves is almost never a problem as compared to finely comminuted systems (Acton et al., 1983). Other binding and stabilizing factors include the development of a strong protein exudate in the saline phase at the surface of the coarse lean particles, and the lower endpoint chopping and mixing temperatures preventing fat "smearing" through liquefaction (Acton et al., 1983). Prevention of fat rendering may also be related to the lack of extensive fat cell rupture with less chopping, as Tinbergen and Olsman (1979) suggested that the final integrity of the fat cells rather than the availability of released fat from ruptured cells was the determining factor in heat stability. Greater reduction of the lean meat particle size also resulted in lower hardness values (Barbut, 1988; Barbut, 1990).

2.6 Chemical Manipulation of the Meat Batter

2.6.1 Effects of preblending

Grinding and mixing of raw materials several hours before batter production is known as preblending (Judge et al., 1989). Various sources list different ingredients, but all include salt and most include phosphates and/or some water and nitrite (Acton and Saffle, 1969; Hand et al., 1987; Judge et al., 1989). Preblending allows 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). Though it has previously been mentioned that ground prerigor meat requires the addition of salt for maintaining its properties, preblending has not been shown to alter its functional value (Acton and Saffle, 1969). Preblending is of particular value in postrigor meats (Acton and Saffle, 1969).

Preblending has been reported to enhance binding ability, color, and water and fat holding capacity (Acton and Saffle, 1969). However, preblending did not significantly affect the color or texture of frankfurters (Hand et al., 1987). When preblending with very low salt levels (0.75%), no differences were observed in these traits (Knipe et al., 1990). An interesting finding was that preblending had an equalizing effect on perceived saltiness between low vs. high fat frankfurters with the same salt content (Hand et al., 1987). Without preblending, high fat frankfurters were perceived as being more salty than low fat frankfurters.

Another important result of preblending was the reduction of the total bacterial count, most probably due to the adverse effects of the added salt on bacteria (Acton and Saffle, 1969).

2.6.2 pH effects

The pH of comminuted products is important to texture, bind, microbial stability, fat and water holding abilities, and it affects the batter rheology as well as the thermal denaturation characteristics of both myosin and actomyosin. Increasing the pH away from the pI results in less actomyosin protein-protein interaction vs. time at a given temperature (Deng et al., 1976). Some adjuncts used for sausage manufacturing can alter the pH. A higher product pH is obtained when using prerigor meat (Lin et al., 1979; Abu-Bakar et al., 1982; Ockerman and Wu, 1990). Salt also produced a slight, but significant increase in the pH (Waldman et al., 1974; Neer and Mandigo, 1977). Phosphates also can affect the pH with the direction being based on whether an acid or alkaline form is used (Townsend and Olson, 1987). In whole muscle products such as hams where a higher pH is desired, the use of sodium hydroxide is allowed at a ratio of 1 part sodium hydroxide to 4 parts phosphates (Schmidt, 1987).

Any rise in the pH away from the myofibrillar proteins pI (5.0 and 5.5 for actomyosin and myosin, respectively) resulted in an increase in the amount of protein which can be extracted (Saffle and Galbreath, 1964) and sharply increased muscle homogenate viscosity (Hamm, 1975a). Increased pH also improved the ability of the raw material to emulsify fat and moisture (Swift and Sulzbacher, 1963; Miller et al., 1968; Froning and Neelakantan, 1971), however the two former studies reported there was little difference above pH 6.0. A similar effect was observed for the effects of pH on the binding ability of a crude myosin extract since there was no significant difference between pH 6 and 8 (Siegel and Schmidt, 1979).

The strength of a myosin gel containing 0.6M potassium chloride was reported to be at a maximum at pH 6.0 with rigidity values decreasing at pH values above and rapidly decreasing at values below 6.0 (Ishioroshi et al., 1979; Yasui et al., 1980). This is very similar to

the optimum "least protein concentration" gelation pH of 5.8 to 6.1 for postrigor SSP (Trautman, 1966). By adding increasing levels of actin to the myosin solutions, the optimal pH shifts from 6.0 to 5.5 (Yasui et al., 1980).

2.7 Thermal Processing

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 system from the end of comminution (18°C) to the final product temperature (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.

2.7.1 Effect of temperature

Cheng and Parrish (1979) reported that myofibrillar proteins of bovine longissimus muscle denatured as follows: alpha-actinin 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). Calorimetric investigations have shown that myosin had several unfolding domains, but these were influenced by salt (Quinn et al., 1980; Samejima et al., 1983).

For a myosin system, heating to temperatures of less than 35°C resulted in only minor increases in the shear modulus (Ishioroshi et al., 1979) while there was no binding ability below 45°C and only a

modest increase from 45 to 50°C (Siegel and Schmidt, 1979). Further temperature increases up to a generally reported 60 to 70°C range resulted in maximum textural strength and binding ability (Ishioroshi et al., 1979; Siegel and Schmidt, 1979; Foegeding et al., 1986a and 1986b; Trout and Schmidt, 1987; Barbut and Mittal, 1990). Foegeding et al., (1986a and 1986b) speculated that the trend of increasing gel strength from 50 to 70°C could have been due to an unfolding of the myosin tail thereby resulting in an increase in the length of the protein available to form a gel matrix.

Water binding ability of cooked meat products was at its maximum at low temperatures and progressively decreased as the cooking temperature increased above approximately 55°C (Hamm and Deatherage, 1960; Trout and Schmidt, 1986), though increasing levels of salt (0.72 to 2.52%) raised the minimum temperature for significant water loss (Trout and Schmidt, 1986). Cooking water losses may result from shrinkage or aggregation and coalescence of the filament lattice (Offer and Trinick, 1983; Hermansson, 1985). A chemical basis for this was given 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 $pH > pI$, this decrease lessened the electrostatic repulsion between the peptide chains causing a tighter protein structure network and decreased water holding capacity. At $pH < pI$, a decrease of negative protein charges disrupted salt cross linkages, resulting in 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 temperatures. Basic groups appeared to be unaffected during heating.

2.7.2 Effect of the rate of temperature increase

The rate of temperature increase affects the type of protein-protein interactions that occur during cooking. Protein-protein

interactions may be more complete at a slower heating rate, resulting in an extensive, uniform 3-dimensional gel structure of the protein molecules (Hermansson, 1978; Foegeding et al., 1986a; Camou et al., 1989). A more ordered denaturation leading to gelation, rather than aggregation, results in a higher degree of elasticity and a finer gel network (Hermansson, 1978). This contributed to increased gel strength, WHC, and fat emulsifying capacity (Foegeding et al., 1986a; Camou et al., 1989) as well as increased hardness, springiness, and cohesiveness (Mittal et al., 1987; Barbut and Mittal, 1990). Under smokehouse conditions, faster rates of heating decreased moisture losses (Lee et al., 1987; Mittal et al., 1987; Barbut and Mittal 1990).

2.7.3 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. 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 levels in the air (Saffle et al., 1967). Higher fat emulsion stability values occurred with higher rates (1.1 to 3.9% per minute) of RH increases (Mittal et al., 1987). In some cases, higher RH may increase the cooking time, as moist surfaces delayed heating due to evaporative losses (lack of case hardening) (Judge et al., 1989).

2.8 Product Characteristics

2.8.1 Water holding capacity and cook yield

Water holding ability contributes to product texture, cooking yields, and purge during storage and contributes to a complex series of protein-protein and protein-water interactions (Lubuza and Busk, 1979). Acton et al. (1983) stated that WHC is influenced by the (1) ionization and charge density of the protein which is increased through salt and

phosphate addition, and through increased tissue pH being more alkaline than protein's pI; (2) extent of tissue physical disruption allowing protein extraction and/or exposure to a higher ionic strength environment and to create more proteinaceous surface and capillary pore areas, and; (3) distance of water location from the protein surface. On the second, there is considerable disagreement as reduction in the particle size through prolonged chopping was reported to decrease WHC and/or cooking yields (Brown and Toledo, 1975; Payne and Rizvi, 1988; Barbut, 1990; Ockerman and Wu, 1990). Bacteria also have an effect as Rust and Olson (1988) stated that excessive microbial growth can greatly diminish WHC.

The effects of WHC on cooking yield are not always apparent. As previously mentioned, muscle in the prerigor state has a higher WHC. Some have indicated that the use of prerigor meat increased the cooking yield (Cross et al., 1979; Ockerman and Wu, 1990) while others reported no significant difference (Aberle et al., 1980; Abu-bakar et al., 1982). A conflicting factor is the rate of heating, which at slower rates enhanced WHC in isolated protein gels (Foegeding et al., 1986a; Camou et al., 1989), but at the same time allowed for increased moisture loss in cooked comminuted meat products (Lee et al., 1987; Mittal et al., 1987; Barbut and Mittal, 1990).

Higher levels of fat increased the cooking yield (Rongey and Bratzler, 1966; Townsend et al., 1971; Claus et al., 1989). Higher levels of water have the opposite effect (Claus et al., 1989; Claus et al., 1990).

2.8.2 Fat-holding capacity

Considerable literature dealing with fat in comminuted meat products is available. Early research refers to "fat emulsification ability" which is the volume of oil added to a homogenized system at the point of visible emulsion breakdown during high speed blending in a

blender (Carpenter and Saffle, 1964). It has previously been mentioned that comminuted meats are not true emulsions because the stability of these products depends primarily upon the formation of a protein matrix (Lee, 1985). Schut (1976) suggested the term "fat-holding capacity" as more adequately describing the stability of the comminuted meat system against fat separation during heat processing which appears to be well below a collapse point range for typical fat emulsification studies.

As with water holding capacity, fat holding or emulsification depends primarily upon the salt soluble proteins myosin and/or actomyosin (Hansen, 1960; Trautman, 1964; Galluzo and Regenstein, 1978). Other salt soluble proteins had little effect (Tsai et al., 1972; Galluzo and Regenstein, 1978).

Prerigor meat and its proteins are known to be more effective than those of postrigor meat. (Trautman, 1964; Acton and Saffle, 1969; Froning and Neelakantan, 1971). In fact, frankfurters formulated with prerigor meat could support high levels of fat that would be unacceptable to consumers (Acton and Saffle, 1969). Photomicrographs of emulsions utilizing prerigor turkey muscle showed uniform and round fat globules, whereas postrigor muscle resulted in a nonuniform emulsion with some very large fat globules (Froning and Neelakantan, 1971).

Salt, with its increasing effect on protein solubility, has a positive effect on emulsion stability (Swift and Sulzbacher, 1963; Hand et al., 1987), though increases above a concentration of 0.3M had only minimal effect (Swift and Sulzbacher, 1963).

pH also has an affect on fat emulsification. For turkey muscle, adjustment of the pH of postrigor muscle to that of prerigor restored the original high emulsifying ability of prerigor muscle (Froning and Neelakantan, 1971). Swift and Sulzbacher (1963) reported that fat emulsification values increased sharply from pH 5 to 6 and were at a maximum from pH 6 to 8.

Moisture content is another factor affecting emulsification.

Morrison et al. (1971) concluded that decreasing the amount of water added to a meat batter to 16 to 21% decreased fat emulsion stability in comminuted products with 30% fat. Protein-protein interactions may increase with increasing protein concentration decreasing their emulsification effectiveness (Mahler and Cordes, 1966).

Numerous studies have been performed to determine the optimum final comminution temperature. Typically reported optimums ranged from 15 to 21°C (Hansen, 1960; Swift et al., 1961; Helmer and Saffle, 1963; Brown and Toledo, 1975; Webb et al., 1975). Work by Webb et al. (1975) and Deng et al. (1981) indicated differently. These researchers, using controlled temperatures, indicated that optimum chopping temperatures were in the range of 1.7 to 6°C. Deng et al. (1981) attributed this to reduced protein-protein interaction in the temperature range used.

The highest fat emulsion stability was obtained at the lowest rate of smokehouse temperature and highest rate of relative humidity increases (Mittal et al., 1987). This could possibly have been due to the stronger and more uniform protein gels that are known to form at lower rates of temperature increase (Hermansson, 1978; Foegeding et al., 1986a; Camou et al., 1989).

2.8.3 Effects of microorganisms on comminuted meats

Microbial growth prior to and during processing has little effect on the subsequent growth of microorganisms in packaged comminuted meat product as many of these products are vacuum packaged, limiting bacterial growth to anaerobic microorganisms (Warnecke et al., 1966). The anaerobic bacteria in vacuum packaged bologna did not have as great an effect on the flavor and color deterioration as comparable numbers of bacteria grown in an aerobic packaged product (Warnecke et al., 1966).

Inoculated ground pork samples maintained a lower emulsifying capacity and a lower extract release volume than control samples which had lower bacterial counts (Borton et al., 1968). Excessive microbial

growth in the raw meat material can diminish the WHC (Rust and Olson, 1988). Increasing amounts of water may have an undesirable effect by increasing bacterial growth during storage as reported microbial counts were directly proportional to the level of added water present (Abu-Bakar et al., 1989).

The physiological state appears to have an effect on microbial numbers. Hot-boned or prerigor meats were usually reported as having higher numbers of bacteria (mesophilic and/or psychrotrophic) than their postrigor counterparts (Davidson et al., 1968; Judge and Cousin, 1983; Bentley et al., 1987; Choi et al., 1987b). This was attributed by Corte et al. (1980) to an initial superficial contamination due to handling in an environment favorable to microbial growth, though subsequent chilling reduces the difference. Not only did the hot-boned meat have higher numbers of bacteria, but it also had a wider variety of species (Bentley et al., 1987). Work by Abu-Bakar et al. (1982) does not agree with these findings as they reported significantly lower counts for frankfurters formulated with prerigor meat.

Preblending with salt decreased the total bacterial count in sausage emulsions (Acton and Saffle, 1969; Waldman et al., 1974; Choi et al., 1987b). This condition was attributable to the adverse effects of the added salt on bacteria that were not salt tolerant, namely *Achromobacter*, *Pseudomonas*, and *Flavobacterium* (Acton and Saffle, 1969).

2.8.4 Analysis of texture

Texture is an important aspect of food acceptability (Bourne, 1978). Szczesniak (1963) originally described five primary parameters for the mechanical characteristics of texture (hardness, cohesiveness, viscosity, elasticity or springiness, and adhesiveness), and three secondary parameters (brittleness or fracturability, chewiness, and gumminess).

Sensory evaluation is a scientific discipline used to evoke,

measure, analyze and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch and hearing (Anonymous, 1975). Unfortunately, sensory panels may require extensive time and expense, and are subject to a number of human variations in perception (Stone and Sidel, 1985).

It is of value to develop instruments to minimize total reliance on panel tests for routine evaluation of products (Stone and Sidel, 1985). This imitative testing should be performed by a device which imitates the way in which the property is assessed and correlates with the way in which humans respond to its perceived studies (Stone and Sidel, 1985).

The General Foods Texturometer was the first instrument capable of providing information that could be correlated with a number of sensory ratings (Friedman et al., 1963). Terms for the Texture Profile Analysis (TPA) parameters during sequential compressions to 75% of a 1.27 cm sample were defined by Friedman et al. (1963). For the texturometer, these are (1) hardness: the height of the first chew; (2) fracturability: the height of the first significant break in the curve; (3) cohesiveness: the ratio of the positive force area during the second compression to that during the first compression; (4) springiness: the height that the food recovers during the time that elapses between the end of the first bite and the start of the second bite; (5) adhesiveness: the negative force area for the first bite, representing the work necessary to pull the compressing plunger away from the sample; (6) gumminess: the product of hardness x cohesiveness; (7) chewiness: the product of hardness x cohesiveness x springiness. Note that more modern terms have replaced some from the original paper, though the definitions are unchanged.

Bourne (1978) indicated that previous studies demonstrated that an Instron Universal Testing Machine could successfully be adapted to texture profile analysis. Both the terms and definitions, as well as

75% compression from the texturometer procedure were retained by Bourne (1978) when using an Instron, though peak heights are reported as force. This appears to be the most commonly used procedure. Correlations between sensory analysis and Instron TPA values ranged from 0.66 for springiness to 0.81 for cohesiveness (Montejano et al., 1985)

The majority of studies in current literature have used the Instron for TPA, though a lack of consistency in procedures (percentage compression, speed of compression) was observed as others have modified the terms or procedures. Montejano et al. (1985) redefined springiness as the proportion of the compression distance recovered between the first and second compressions. Claus et al. (1989) determined cohesiveness at 25% compression. In a later study, Claus et al. (1990) determined both springiness and cohesiveness at 50% compression. This reduction in compression was done in order to obtain values from partially fractured samples, though Montejano et al. (1985) indicated that maximum force during 50% compression was poorly correlated with sensory results.

Texture and Palatability

Product composition has considerable effect on the texture of comminuted meats. Protein is the main factor as it is responsible for gelation as well as emulsification ability, and by altering it, one may affect several characteristics as discussed previously. By increasing the protein content, one increases the perceived hardness or firmness (Claus et al., 1989). Fat content has the opposite effect as increasing levels decreased firmness (Rongey and Bratzler, 1966; Hand et al., 1987; Lee et al., 1987; Ahmed et al., 1990), though some of these effects may have been due to decreased levels of protein (Rongey and Bratzler, 1966; Park et al., 1989). The same effect is true for higher levels of water (Lee et al., 1987; Claus et al., 1989; Ahmed et al., 1990). Higher rates of relative humidity increases during cooking lowered hardness

values in wieners, which may have been due to a higher moisture content attributed to increased cooking yields (Mittal et al., 1987).

Substituting water for fat on a 1:1 basis results in decreased hardness values (Claus et al., 1990). The species of fat also has a significant effect as frankfurters formulated with harder fats were firmer than those using softer fats or oils (Townsend et al., 1971; Lee et al., 1987; Park et al., 1989; Sams and Diez, 1990).

Prerigor meat used in the formulation may result in a more tender product as it did for ground beef (Cross et al., 1979), though higher cooking yields (more moisture and fat) may have influenced these results. For frankfurters, use of prerigor raw materials resulted in a firmer product with similar cooking losses (Abu-Bakar et al., 1982; Choi et al., 1987a). No significant difference was reported for tenderness when using prerigor meat in restructured pork chops (Marriott et al., 1983).

Differences in fracturability appear to parallel those of hardness as data indicated that increases in protein and/or decreases in fat or moisture tended to result in an increase in the distance or force required for fracture (Claus et al., 1989 and 1990; Park et al., 1990). Again, water seems to have more of an effect as fracturability values decrease when replacing fat on a 1:1 basis (Claus et al., 1989 and 1990).

By simply reducing the fat (and increasing the protein) springiness values increased (Park et al., 1989; Park et al., 1990). Similar effects were observed by sensory panels when using less water (more protein) at the same fat levels (Claus et al., 1989). The use of firmer fats also increased springiness in frankfurters (Townsend et al., 1971; Lee et al., 1987; Park et al., 1989; Sams and Diez, 1990). When substituting water for fat in bologna, no differences for springiness were observed over a wide range of fat and moisture concentrations (Claus et al., 1989). An interesting finding was that the reduction of

salt from 2.5% to 1.25% decreased springiness even though the protein content was increased due to higher cooking losses (Barbut and Mittal, 1990). Data for cohesiveness values appear to follow the same trends as firmness and springiness with respect to protein, fat, and moisture content (Claus et al., 1989; Park et al., 1989; Claus et al., 1990; Park et al., 1990) and fat type (Lee et al., 1987; Park et al., 1989) when using normal levels of salt .

Juiciness is another characteristic that is highly dependent upon the composition. Frankfurters formulated with less fat have lower sensory juiciness scores (Rongey and Bratzler, 1966; Hand et al., 1987; Park et al., 1989). Partially compensating fat reduction with increased AW can enhance juiciness levels to those of more traditional products (Claus et al., 1989; Park et al., 1990) but with a 1:1 substitution, higher juiciness scores were obtained with decreasing fat content (Claus et al., 1989). Reduced salt may have a negative effect on juiciness as scores were highest for frankfurters with 2.5% salt and decreased with 2% and 1.5% salt levels (Hand et al., 1987), though the final composition was not given and further inferences could not be made. Lower moisture and higher protein content may have been a factor as Barbut and Mittal (1990) reported much higher cooking losses for low salt (1.25% vs. 2.5%) beef patties.

Prerigor raw materials have been shown to produce higher juiciness scores in sausage (Lin et al., 1979), beef patties (Cross et al., 1979; Jacobs and Sebranek, 1980) and wieners (Abu-Bakar et al., 1982) than those made using postrigor meat. In most cases, higher cooking yields resulting in increased moisture and/or fat content may have been responsible.

Fat reduction in frankfurters from 31% to 17% resulted in no difference in desirability (Lee et al., 1987), nor did fat replacement with limited (less than 1:1) additional water (Park et al., 1990). Lee et al. (1987) found that simply adding additional water (increasing

moisture from 61 to 71%) while not changing the amounts of other ingredients decreases overall desirability. Product desirability has been shown to be increased when using prerigor meat for beef patties (Jacobs and Sebranek, 1980), sausage (Lin et al., 1979), meat loaves (Van et al., 1980) and wieners (Abu-Bakar et al., 1982).

2.8.5 Analysis of color

Color and appearance are two properties that are evaluated by the eye and form the first impression to the consumer. Any specific color has three attributes, known as hue, chroma, and value (Judge et al., 1989). Hue describes that which one normally thinks of as color, yellow, green, blue, or red. Chroma (purity or saturation) describes the intensity of a color relative to the amount of white light that is mixed with it. The value of a color is an indication of the overall light reflectance (brightness) of the color.

Color can be measured either subjectively using visual standards, or objectively by using one of several instruments to measure hue, saturation, lightness, and brightness (Kauffman and Marsh, 1987). These instruments provide information concerning the stimulus equivalents (CIE, Hunter) needed to match the meat color, but do not provide information on the state of the myoglobin pigment (Hunt, 1980). Information on the myoglobin properties can be obtained through the use of transmission and reflectance spectrophotometry (Hunt, 1980).

The pink color seen in frankfurters, bologna, and cured meats is the result of nitrite having been reduced to nitric oxide which reacts with the meat pigments and, upon heating, forms extremely stable, bright red complexes called nitrosylhemochromes (Townsend and Olson, 1987). Some spices and their oleoresins (i.e. paprika) are other sources of color. Prolonged time at higher temperatures increased the percentage of pigment conversion to the cured form (Okayama et al., 1991). Saffle et al. (1967) reported that lower relative humidities during the cooking

process increased both the intensity and uniformity of frankfurter color. Another factor is the concentration of myoglobin which varies with species (Townsend and Olson, 1987). Perceived redness or instrumental "a" values have been shown to decrease when "diluting" the system using higher moisture levels (Claus et al., 1989; Ahmed et al., 1990). Increasing levels of fat also decreased the red intensity (Hand et al., 1987; Claus et al., 1989; Ahmed et al., 1990). Fat reduction appears to have a greater effect on red color than increased moisture as a 1:1 replacement of fat results in higher redness values (Claus et al., 1989).

Different chopping methods also alter the color as Barbut (1990) reported that the red color was most pronounced when the lean and fat were chopped together all at once rather than gradually adding the fat or adding prechopped fat in the final stage. This same procedure also results in a darker product. Unlike redness, lightness or instrumental "L" values vary directly with the fat and/or water content as increasing levels result in a lighter product (Hand et al., 1987; Claus et al., 1989; Ahmed et al., 1990).

Blueness, represented by lower instrumental "b" values, appears to be dependent upon the system's fat level. Frankfurters formulated with reduced fat are less yellow (more blue) in color (Hand et al., 1987; Claus et al., 1989). Claus et al. (1989) indicated that increases in AW tend to decrease "b" values. Ahmed et al. (1990) reported the same trends in pork sausage with respect to fat and moisture content, though no significant differences were found.

Chapter 3

MATERIALS AND METHODS

Ten 15% fat, 25% AW frankfurter treatments were studied in which eight of these utilized an extended mixing procedure while the remaining two followed more traditional processing procedures. Frankfurters were manufactured from either prerigor or postrigor lean tissue. The extended mixing treatments were subjected to two additional variables: mixing temperature (2 or 16°C), and the amount (30 or 100%) of formulation water present during the extended mixing (Table 1).

3.1 Preparation of Lean Pork Tissue

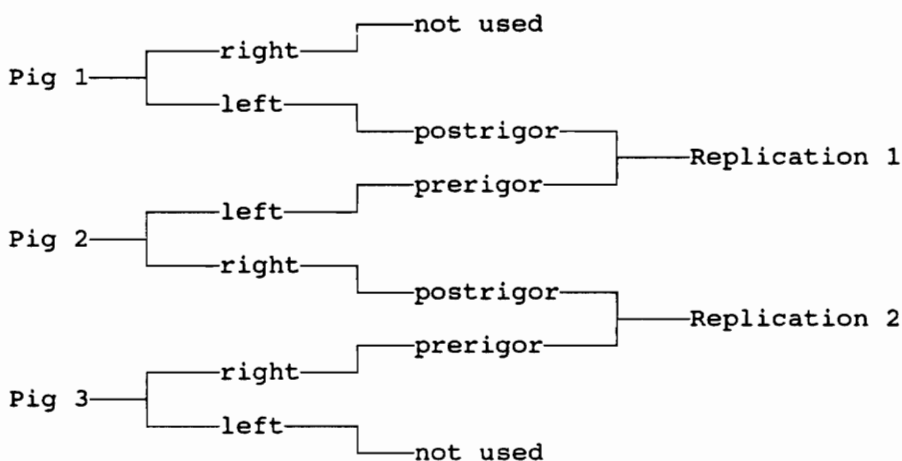
Three U.S. #1 pigs (90 to 95 kg) were obtained from the VPI&SU swine farm and one animal per day was slaughtered in the muscle food's abattoir three to four days apart. After scalding, dehairing, and evisceration, each carcass was split longitudinally with one side being stored in a 2°C cooler for later use as a source of postrigor lean while the other side was incorporated immediately as a source of prerigor lean. The initial prerigor side from the first pig was not utilized (Figure 1). Closely trimmed lean was removed from the ham, loin, Boston butt, and picnic.

For carcasses boned postrigor, the lean tissue was removed 16 hr prior to the next slaughter replication. After removal, the lean tissue was ground twice (Hobart Grinder 4532, Hobart Manufacturing Co., Troy, Ohio) through a 6.6 mm plate, mixed (Hobart Mixer A-200, Hobart Manufacturing Co., Troy, Ohio) for 2 min, sampled for proximate analysis, vacuum packaged (Inauen Maschinen VC999/01, Inauen Maschinen AG, Herisau, Switzerland) in moisture impermeable bags (type B620, Cryovac Division W.R. Grace & Co., Duncan, S.C.), and refrigerated 16 hr

Table 1-Treatment combinations used to manufacture 15% fat, 25% added water frankfurters

Treatment number	Physiological state	Mixing (min)	Batter temp.	Formulation water
1	prerigor	30	2°C	30%
2	prerigor	30	2°C	100%
3	prerigor	30	16°C	30%
4	prerigor	30	16°C	100%
5	postrigor	30	2°C	30%
6	postrigor	30	2°C	100%
7	postrigor	30	16°C	30%
8	postrigor	30	16°C	100%
9	prerigor	--	conventional procedures	
10	postrigor	--	conventional procedures	

Fig. 1-Animal and carcass assignment per replication



at 2°C. For carcass halves boned prerigor, the removal of the lean, grinding, and mixing (30 sec) were performed as with the postrigor samples.

The pH of the prerigor lean meat was determined immediately after grinding in an isoionic strength, pH 7 sodium iodoacetate solution (5mM sodium iodoacetate, 150mM potassium chloride) as listed in Bendall (1973), to confirm the absence of PSE pork. Ten grams of sample was mixed with 100 mL of the above sodium iodoacetate solution for 2 min using a Stomacher 400 Lab Blender (Teckmar Co., Cincinnati, Ohio). Samples were analyzed for pH using a pH electrode (Corning model 576570, Corning, Inc., Corning, N.Y.) and an Accumet pH Meter Model 950 (Fisher Scientific Co., Medford, Md.).

The prerigor pork was salted to a concentration of 3%, mixed (Hobart Mixer A-200, Hobart Manufacturing Co., Troy, Ohio) for 2 min, and sampled (for subsequent fat and protein analysis) within 1 hr postmortem. This product was stored in a 2°C cooler for 2 hr. Acton and Saffle (1969) indicated that salt added to ground meat in the prerigor state and stored for a period of time (preblending) had little effect on the functional characteristics other than maintaining the physiological state of the meat when compared to salt added during meat batter processing. The same is not true for ground meat in the postrigor state, thus all salt for postrigor treatments was added during meat batter processing.

3.2 Preparation of Pork Fat

Refrigerated pork backfat was used as the fat source, and was obtained from Dinner Bell, Inc. (Lynchburg, Va.) one week prior to the beginning of this study. The pork backfat was partially frozen, ground (Hobart Grinder 4532, Hobart Manufacturing Co., Troy, Ohio) through a 9.5 mm plate then reground through a 3.2 mm plate, mixed (Leland Food Mixer 100DA, Leland Detroit Mfg. Co., Detroit, Mich.) for 3 min, sampled

for proximate analysis, and vacuum packaged (Inauen Maschinen VC999/01, Inauen Maschinen AG, Herisau, Switzerland) in moisture impermeable bags (type B620, Cryovac Division W.R. Grace & Co., Duncan, S.C.). The fat was then frozen and stored at -23°C until the day prior to use.

3.3 Proximate Analyses of Meat Block Components

Moisture, fat, and protein analyses of the raw materials were performed according to AOAC (1990) procedures in triplicate for the postrigor lean meat and pork fat. For the prerigor lean, fat and protein analyses were performed, while moisture was estimated by difference due to time limitations.

3.4 Formulation of Frankfurter Batters

Least-Cost FormulatorTM (LCF; Least Cost Formulations LTD., Inc., Virginia Beach, Va.) was used to formulate 2.0 kg treatment batches utilizing the raw material proximate analyses results, a projected cook loss of 6.5%, and finished product specifications of: 15% fat, 25% USDA AW, 2.3% salt, 0.5% sodium tripolyphosphate (Stauffer Chemical Co., Shelton, Conn.), 2% granulated sugar; and based on meat block weight, 156 ppm sodium nitrite (incorporated as prague powder; 6.25% sodium nitrite and salt carrier; Heller Co., Bedford Park, Ill.), 0.042% sodium erythorbate, and 1% paprika-free seasoning.

3.5 Further Pre-Treatment of the Lean Component

Approximately 1.5 kg of both prerigor salted and postrigor lean was set aside at 2°C for treatments that did not utilize extended mixing. To the remainder of the ground lean meat, water (postrigor treatments) or ice (prerigor treatments) was added to a level equivalent to 30% of all of the formulation water required per batch. This meat plus water (or ice) blend was mixed (Hobart Bowl Mixer A-200, Hobart Manufacturing Co., Troy, Ohio) for one min, minced (Mincemaster[®] GL 86,

Griffith Design and Equipment Co., Chicago, Ill.) through a 1.7 mm plate, and remixed for an additional min to ensure homogeneity. The usual post-mincing temperature was 14 to 17°C for both prerigor and postrigor. The minced meat was then allowed to equilibrate (approximately 20 min) to treatment temperature in either an ice bath or a 16°C cooler.

3.6 Formation of Meat Batter

Treatments were mixed in Kitchen-Aid mixers (model K45SS or K50SS, Hobart, Inc., Troy, Ohio) operating at 72 orbital revolutions per min using a flat beater mixing head.

For the extended mixing treatments, a standard amount of product was placed in the mixing bowl for each treatment in an attempt to provide the same physical action irregardless of whether the blend contained 30 or 100% of the formulation water. These were mixed in either 2 or 16°C coolers.

For the extended mixing treatments with all formulation water present, the temperature equilibrated comminuted lean containing 30% of the required water was mixed for 25 min with the balance of the water (2 or 16°C) plus salt, phosphate and prague powder. Sugar, seasoning, and erythorbate were added to the batter and mixed for 2 min prior to incorporating the fat (42°C). Mixing was continued for an additional three min.

The extended mixing treatments containing 30% of the required formulation water were mixed for 25 min as above, except that the balance of the formulation water was not added. The quantities of the remaining ingredients were scaled up to compensate for the weight difference. After this 25 min mixing period, the excess mass was removed, and the balance of the formulation water was added as was the sugar, seasoning, and erythorbate. Mixing was resumed for 2 min, then

fat (42°C) was added and mixed for 3 min.

For the traditional processing method treatments, the refrigerated ground lean was mixed for 3 min with salt, phosphate, and prague powder while gradually adding all of the water. Pieces of refrigerated, ground fat were added, and mixed for 3 min prior to adding and mixing (2 min) in sugar, seasoning, and erythorbate. After mixing, these batters were minced (Mincemaster[®] GL 86, Griffith Design and Equipment Co., Chicago, Ill.) through a 1.7 mm plate.

3.7 Other Pre-Stuffing Treatments

After all ingredients were incorporated (extended mixing treatments) and minced (traditional treatments), a slurry pH measurement (25°C) was accomplished by mixing 10 g of sample with 100 mL distilled water for 2 min using a Stomacher 400 Lab Blender (Teckmar Co., Cincinnati, Ohio). Samples were analyzed for pH using a pH electrode (Corning model 576570, Corning, Inc., Corning, N.Y.) and an Accumet pH Meter Model 950 (Fisher Scientific Co., Medford, Md.). One sample from each treatment and replication was used to determine pH.

All batters were vacuum treated to remove air pockets by spreading the batter out in a plastic container, and twice evacuating in a vacuum packager. Batters were refrigerated (2°C) until stuffing.

Frankfurters were formed by stuffing 25 mm casings (E-Z Peel Nojax Casings C25 x 125, Viskase Sales Corp., Chicago, Ill.) with a hand stuffer (Vogt Ideal 9L, Vogt-Werre Hessen, Germany) and linking at 20 cm using a hand operated sausage linker (Koch Supplies, Inc., Kansas City, Mo.). All frankfurters were weighed and allowed to temperature equilibrate (13°C) for 15 min after being hung on a smokehouse truck. The stuffed products were heat processed to an internal temperature of 70°C in a smokehouse (Alkar Rasmussen 2160 A-T, Alkar Engineering Corp., Lodi, Wisc.) using the following cycle and then refrigerated for 2 hr at

2°C prior to further handling.

<u>Time (min)</u>	<u>Dry-bulb (°C)</u>	<u>Wet-bulb (°C)</u>	<u>Relative humidity (%)</u>
15	60	49	55
10	68	57	58
10	74	63	60
10	79	71	70
to finish	82	74	71
7	cold shower		

3.8 Analyses of Product

3.8.1 Cooked-chilled yield

The cooked-chilled yield was determined as the weight of the cooked product (several continuous linked frankfurters) after chilling (2°C) for 2 hr divided by the weight of the uncooked string of frankfurters and multiplied by 100%. Where multiple strings for a treatment were produced, the recorded value was the average yield.

3.8.2 Proximate analysis

Moisture, fat, and protein determinations (AOAC, 1990) were performed in duplicate within 48 hr of cooking.

3.8.3 Purge determination

Three frankfurters from each treatment were weighed and then placed into CryovacTM bags (type B540, Cryovac Division W.R. Grace & Co., Duncan, S.C.) and vacuum packaged (17 kPa). Vacuum packaged products were stored for thirty days in a 5°C retail display case (Tyler Commercial Refrigerator and/or Freezer Model CGS8M, Tyler Refrigeration Corp., Niles, Mich.) under continuous lighting (1076 lux). 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%.

3.8.4 Color and pigment state analyses

Instrumental color evaluation was performed three days after production using a Minolta Chroma Meter (model CR-200; Minolta Camera Co., Ltd., Osaka, Japan). The instrument was referenced against a standard Minolta calibration plate (CIE $L^* = 97.91$, $a^* = -0.70$, $b^* = +2.44$). CIE L^* a^* b^* values were obtained from six repeated readings from the inner surface of longitudinally split frankfurters.

Spectrophotometric reflectance readings (Shimadzu 2101PC U.V.-Visible Scanning Spectrophotometer, Shimadzu Corp., Kyoto, Japan) were obtained in the visible region between 500 and 700 nm on the third day after production. The instrument was baselined with the same reference tile used for the Minolta color analysis and was set for a sampling interval of 1.0 nm, slit width of 1.0 nm, and a medium scan speed. Cure color was evaluated as the ratio of the reflectance readings at wavelengths 650 nm/570 nm (Erdman and Watts, 1957).

3.8.5 Texture analysis

Textural characterization of the products was performed using an Instron Universal Testing Instrument (model 1011, Instron Corp., Canton, Mass.). Samples tested by compression utilized a 19 mm by 19 mm cylindrical core and a crosshead speed of 100 mm/min. Coring involved manually cutting frankfurters to lengths of 19 mm and removing a 19 mm core. Cores were prepared and stored in a 2°C cooler.

Both distance to fracture and hardness were determined during a single compression to 25% of the original sample height. Hardness was reported as the maximum force observed during the compression cycle (Bourne, 1978), whereas distance to fracture was reported as the compression distance where the first significant drop in force occurred. Fracturability, the typically reported term, is the force at the first significant decrease in compression force during 75% compression (Bourne, 1978), but in this study, hardness and fracturability were one

in the same. Distance to fracture is an original term used to provide more information for physical characterization of the product.

Springiness, cohesiveness, and chewiness were determined from sequential compressions to 50% of the original sample height. Springiness is a unitless value defined as the peak width of the second compression divided by the peak width of the first compression. Cohesiveness is another unitless value defined as the ratio of the total energy of the second compression to the first. Chewiness is the product of (springiness) x (cohesiveness) x (peak force of the first compression), and has units of force (kgf).

The Instron was also used with a Warner-Bratzler shear apparatus operating 200 mm/min for determining the total energy required to shear through a 2°C frankfurter. Again, six repeated measures were taken.

3.9 Statistical Analysis

Data from dependent variables were analyzed by treatment using the General Linear Model (GLM) procedure of SAS[®] (1989) in a randomized block design. If the model was found to contain significant differences, mean values were separated using the Least Significant Difference procedure of SAS. Data were analyzed by the GLM procedure using a 2x2x2 factorial (physiological state, temperature, and percentage water present) split-split plot design generating the F statistic and P values for the main effects of the extended mixing treatments. An additional 2x2 factorial (physiological state and mixing procedure) split plot design was also performed.

Chapter 4

RESULTS AND DISCUSSION

Preliminary studies indicated that when using an extended mixing treatment after comminution of the lean component, fat must be added to the meat batter in a molten state in order to achieve the dispersion required. In addition, the fat must have been previously ground through a plate smaller than 6.4 mm as fat particle definition was still apparent after melting with this grinding size. Data from Webb et al. (1975) indicated that fat added at 42°C should yield a batter stability essentially equal to a batter in which cold fat was added, though their study added fat during the comminution process.

4.1 Composition of Raw Materials

Means of the proximate analyses for the two lean sources were: 69.56% moisture, 6.97% fat, and 19.49% protein for the 3% salted prerigor lean and 72.50% moisture, 5.51% fat, and 20.35% protein for the postrigor lean. The pork fat contained 8.3% moisture, 89.60% fat, and 0.39% protein. Data from proximate analyses of raw materials were not statistically analyzed as frankfurter batter formulation was designed to compensate for any differences in raw material composition.

4.2 Batter pH, Cooking Yield, and Purge Accumulation

The pH (Table 2) of the prerigor batters averaged 6.41 just prior to stuffing and was consistently higher than that of the postrigor treatments (average 6.18). These values are 0.29 and 0.35 pH units higher, respectively than those reported by Choi et al. (1987a), possibly due to the use of a more alkaline phosphate in this study. Ground and salted prerigor meat is known to have a higher pH than

Table 2-Raw batter pH, cooking yield, and vacuum packaged purge relative to low-fat, high added water frankfurters^d

Treatment number	Independent variables			Batter pH	Cooking yield (%)	Package Purge (%)
	Rigor state	Temp. (°C)	Formula water (%)			
<u>Extended mixing</u>						
1	prerigor	2	30	6.43 ^{ab}	93.3	4.87
2	prerigor	2	100	6.39 ^{ab}	93.6	3.45
3	prerigor	16	30	6.38 ^{ab}	93.6	3.06
4	prerigor	16	100	6.36 ^{ab}	94.2	3.66
5	postrigor	2	30	6.16 ^c	93.8	3.40
6	postrigor	2	100	6.18 ^c	93.4	3.82
7	postrigor	16	30	6.24 ^{bc}	93.8	3.40
8	postrigor	16	100	6.16 ^c	93.7	3.86
<u>Controls (Normal mix)</u>						
9	prerigor	--	--	6.51 ^a	93.9	3.30
10	postrigor	--	--	6.18 ^c	93.5	3.51
Standard error				0.09	0.27	0.30

^{abc}Batter pH: means within a column with at least one common superscript are not different (P>0.05).

^dMeans within a column without superscripts are not different (P>0.05).

postrigor meat (Hamm 1977; Honikel and Hamm, 1978). Treatment pH values were generally separable by physiological state, with the exception of treatment 7 which was not different ($P>0.05$) from some prerigor treatments. No differences were found relative to mixing temperature or amount of formulation water.

The high relative humidity cook cycle used appeared to limit cooking losses (average yield 93.7%; Table 2) compared to cooking yields of 89% reported by Park et al. (1990) for frankfurters of similar composition. This may be significant because low-fat, high moisture comminuted sausages are known to have higher losses than comparable high fat products (Claus et al., 1989; Park et al., 1989; Claus et al., 1990). No differences ($P>0.05$) in cooking yield were observed among the treatments.

Percentage purge in the vacuum packaged frankfurters (Table 2) ranged from 3.06 to 4.87%, but were not different ($P>0.05$) among treatments. Lack of difference may be due to some air pockets that remained despite efforts to evacuate the batter prior to stuffing. These pockets were observed to have filled with fluid during vacuum packaged storage, and may have resulted in artificially low purge volumes.

4.3 Cooked Product Composition

Finished frankfurter composition for moisture, fat, and protein (Table 3) was very consistent ($P>0.05$) among treatments. All treatments contained slightly less fat (average 14.5%) than the specified 15% fat. Rendered fat was observed in EM frankfurters mixed at 16°C, and appeared to be more abundant in those formulated with postrigor lean tissue.

All frankfurter treatments contained slightly less than 25% USDA AW (average 22.6%), which was surprising since the moisture content was generally slightly higher than predicted. By the formula for AW, these values are dependent on both moisture and protein content, and the

Table 3-Frankfurter composition^a

Treatment number	Independent variables			Chemical analyses			USDA AW(%) ^b
	Rigor state	Temp. (°C)	Formula water (%)	Moisture (%)	Fat (%)	Protein (%)	
<u>Extended mixing</u>							
1	prerigor	2	30	68.0	14.6	11.4	22.3
2	prerigor	2	100	68.1	14.7	11.2	23.2
3	prerigor	16	30	68.4	14.3	11.4	22.8
4	prerigor	16	100	68.7	14.2	11.5	22.9
5	postrigor	2	30	68.1	15.0	11.2	23.2
6	postrigor	2	100	68.6	14.6	11.4	22.9
7	postrigor	16	30	68.5	14.4	11.6	22.0
8	postrigor	16	100	68.6	14.0	11.7	21.9
<u>Controls (Normal mix)</u>							
9	prerigor	--	--	68.3	14.9	11.3	23.0
10	postrigor	--	--	68.3	14.6	11.5	22.1
Standard error				0.2	0.3	0.2	0.7

^aComposition: means within columns are not different (P>0.05).

^bUSDA AW = (% moisture - 4 x % protein).

latter was higher than predicted by an average of 0.6%. This alone would lower predicted AW values by 2.4%. No explanation for this discrepancy could be determined. No differences ($P>0.05$) among treatments were found for the calculated AW. Statistical analyses for effects of independent variables on product composition indicated that temperature during mixing had a significant effect such that higher mixing temperature resulted in a higher moisture content ($P<0.005$). It is suspected that this can be at least partially explained through the observation of some fat rendered out in the 16°C EM treatments, particularly in the postrigor treatments. Mathematically, less fat could result in higher moisture and/or protein, but it appears that only moisture analyses produced a low enough standard error for the effect to be found significant. The mean fat contents of the 16°C mixing treatments were consistently lower, but not different ($P>0.05$) from those mixed at 2°C.

Studies where chopping was the comminution method have often reported that final temperatures of 15 to 18°C resulted in the optimum fat holding ability (Hansen, 1960; Swift et al., 1961; Helmer and Saffle, 1963; Brown and Toledo, 1975; Webb et al., 1975) and was believed to be dependent upon the fat melting characteristics (Townsend et al., 1968). By adding molten fat, melting characteristics become irrelevant. Observations from this study indicated that when molten fat was utilized, uniform dispersion was readily achieved, but temperatures of 16°C must be avoided as fat stabilization became difficult, particularly in postrigor treatments. With mixing temperatures of 2 to 5°C, no visible fat separation occurred. Therefore, temperatures that caused optimum fat holding ability in a chopped system resulted in higher fat losses with the extended mixing method used here, whereas lower temperatures enhanced product stability. Neither physiological state nor the amount of water present during extended mixing had a

significant effect on product composition. No fat rendering was observed in traditional mix then minced treatments, though it was noted that refrigerated lean meat and fat, and tap temperature water were used.

4.4 Color Evaluation of Frankfurters

Significant differences between treatments for instrumental color lightness (L^*) were found (Table 4). Both control treatments were lighter ($P < 0.05$) than their corresponding extended mixed prerigor or postrigor treatment, except for those mixed at 2°C with 30% of the formulation water. Treatments mixed with only 30% of the required water were lighter ($P < 0.003$) than those mixed with 100% (Table 5). This effect may have been more apparent in postrigor treatments as independent variable effect analysis indicated a possible interaction ($P < 0.10$) between physiological state and amount of formulation water present. The mean L^* value (68.01) for the prerigor EM treatments was higher but not different ($P > 0.16$) than those of postrigor (67.21). Physiological state and mixing temperature did not have a significant effect on lightness.

The mixing technique also affected lightness ($P < 0.10$), with treatments mixed in a traditional manner having higher L^* values (69.18) than those utilizing EM (67.61). Although not formally evaluated, observations were made that frankfurters utilizing EM appeared to have a more homogenous appearance both externally and in the interior. Traditional mixing followed by mincing (1.7 mm) left distinct particles of lean and fat. These observations agree with those reported by Gregg (1992).

No significant differences between treatments were found for a^* (redness) values (Table 4). Restricting formulation water during extended mixing lowered ($P < 0.04$) a^* values (Table 5), but the difference was slight (12.38 vs. 12.25). Postrigor frankfurter redness values were

Table 4-Instrumental Color Values^e of low-fat, high added water frankfurters

Treatment number	Independent variable			CIE values			Cure Color ^f
	Rigor state	Temp. (°C)	Formula water (%)	L*	a*	b*	
<u>Extended mixing</u>							
1	prerigor	2	30	68.55 ^{abc}	12.09	7.08 ^{abc}	1.98
2	prerigor	2	100	67.97 ^{bcd}	12.01	6.84 ^c	1.96
3	prerigor	16	30	67.84 ^{bcd}	12.04	6.86 ^c	1.97
4	prerigor	16	100	67.70 ^{cd}	12.19	6.85 ^c	2.00
5	postrigor	2	30	67.82 ^{bcd}	12.31	6.74 ^c	2.04
6	postrigor	2	100	66.70 ^d	12.52	6.58 ^c	2.08
7	postrigor	16	30	67.37 ^{cd}	12.56	6.97 ^{bc}	2.02
8	postrigor	16	100	66.93 ^d	12.80	6.90 ^c	2.03
<u>Controls (Normal mix)</u>							
9	prerigor	--	--	69.44 ^a	12.37	7.59 ^a	1.96
10	postrigor	--	--	68.92 ^{ab}	12.85	7.48 ^{ab}	2.01
Standard error				0.47	0.29	0.02	0.02

^{abcd}Means within a column with at least one common superscript are not different (P>0.05).

^eMeans within a column without superscripts are not different (P>0.05).

^fCure color evaluated as the ratio of the percentage reflectance readings at wavelengths 650nm/570nm.

Table 5-Effects of independent variables on instrumental color of low-fat, high added water frankfurters

Independent variable	CIE Values			Cure color ^a
	L*	a*	b*	
Comparisons within extended mixing treatments:				
Physiological state				
Prerigor	68.01	12.08	6.91	1.98
Postrigor	67.21	12.55	6.80	2.04
(P-value)	(0.159)	(0.549)	(0.769)	(0.355)
Mixing temperature				
2°C	67.76	12.23	6.81	2.01
16°C	67.46	12.40	6.90	2.00
(P-value)	(0.404)	(0.145)	(0.542)	(0.432)
Formulation water				
30%	67.89	12.25	6.91	2.00
100%	67.33	12.38	6.79	2.01
(P-value)	(0.003)	(0.040)	(0.036)	(0.216)
Comparisons averaged across mixing techniques:				
Physiological state				
Prerigor	68.72	12.27	7.25	1.97
Postrigor	68.07	12.70	7.14	2.02
(P-value)	(0.432)	(0.524)	(0.515)	(0.375)
Mixing technique				
Traditional	69.18	12.61	7.53	1.98
Extended	67.61	12.32	6.86	2.01
(P-value)	(0.102)	(0.151)	(0.040)	(0.079)

^aCure color evaluated as the ratio of the percentage reflectance readings at wavelengths 650nm/570nm.

consistently higher than prerigor values (Table 4), irregardless of mixing technique, however physiological state was not significant (Table 5).

The prerigor control had higher ($P < 0.05$) b^* (yellowness) values than all EM prerigor treatments except treatment 1 (Table 4). The postrigor control followed a similar pattern. Restricted water in extended mixing treatments (Table 5) resulted in higher ($P < 0.05$) b^* values (6.91 vs. 6.79). Physiological state and temperature during EM had a negligible effect.

Traditional mixing treatments resulted in higher ($P < 0.04$) b^* values (7.53 vs. 6.86) than those of EM treatments. Once again, particle definition, particularly fat particle definition, may have contributed to higher yellowness values.

No significant differences between treatments (Table 4) were observed for cure color as evaluated using the percentage reflectance ratio of 650nm/570nm. Within the extended mix treatments, the cure color mean for postrigor (2.04) treatments was higher than for prerigor treatments (1.98). For comparisons between mixing treatments, extended mixing resulted in slightly higher ($P < 0.08$) ratio values (2.01 vs. 1.98) than traditionally mixed frankfurters. This may have been due to a combination of reduction in particle size allowing the myoglobin to more fully react with nitric oxide, a more uniform dispersion of the pigment, and longer reaction time before heat processing.

4.5 Instrumental Texture Evaluation of Frankfurters

Prerigor treatments (1-4 and 9) appeared to be unaffected by various processing treatments (Figure 2). All had nearly equal hardness values which were generally lower than postrigor treatments (5-8 and 10). Treatment 7 had a significantly lower hardness value than all other postrigor treatments, with the exception of treatment 10. Analysis of independent variable effects (Table 6) indicated that

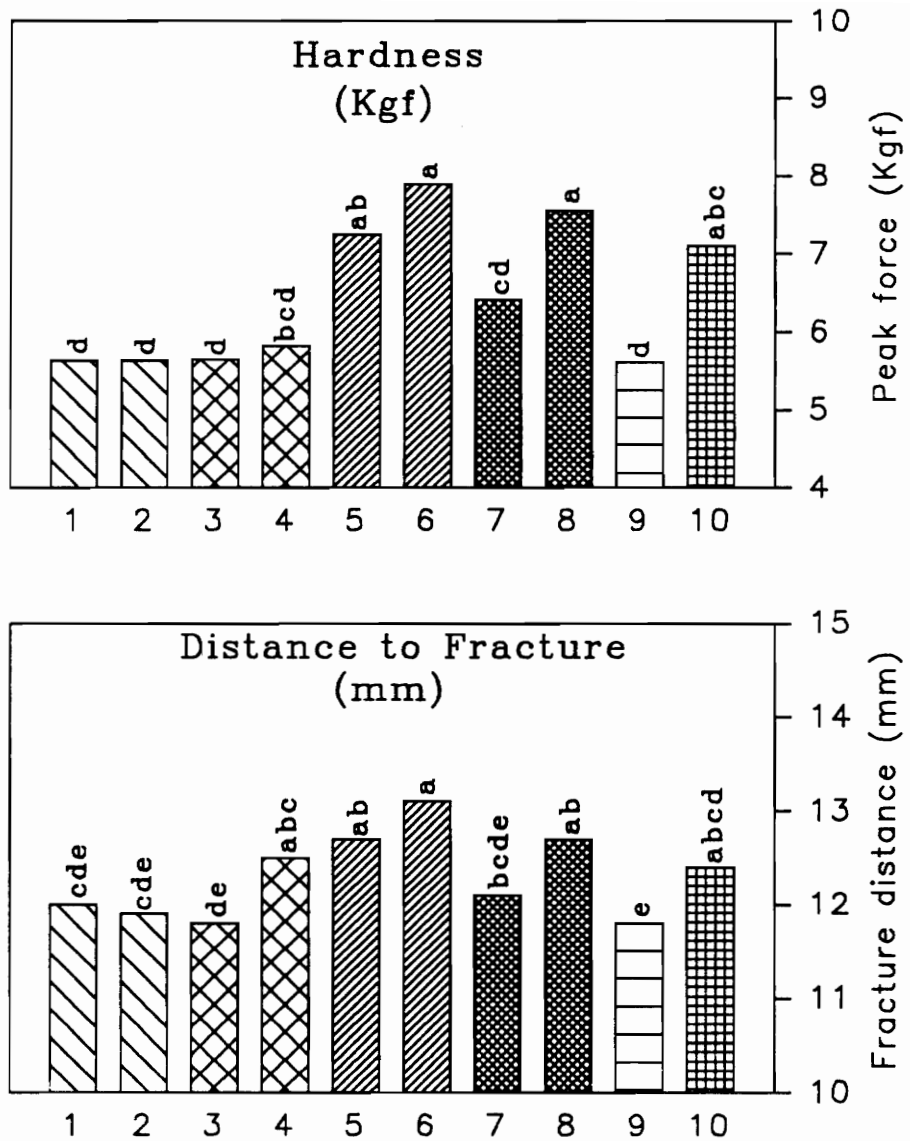


Figure 2-Intron texture profile analysis for low-fat, high moisture frankfurters

Treatment number	Physiological state	Mixing (min)	Batter temp.	Formulation water
1	prerigor	30	2°C	30%
2	prerigor	30	2°C	100%
3	prerigor	30	16°C	30%
4	prerigor	30	16°C	100%
5	postrigor	30	2°C	30%
6	postrigor	30	2°C	100%
7	postrigor	30	16°C	30%
8	postrigor	30	16°C	100%
9	prerigor	--	conventional procedures	
10	postrigor	--	conventional procedures	

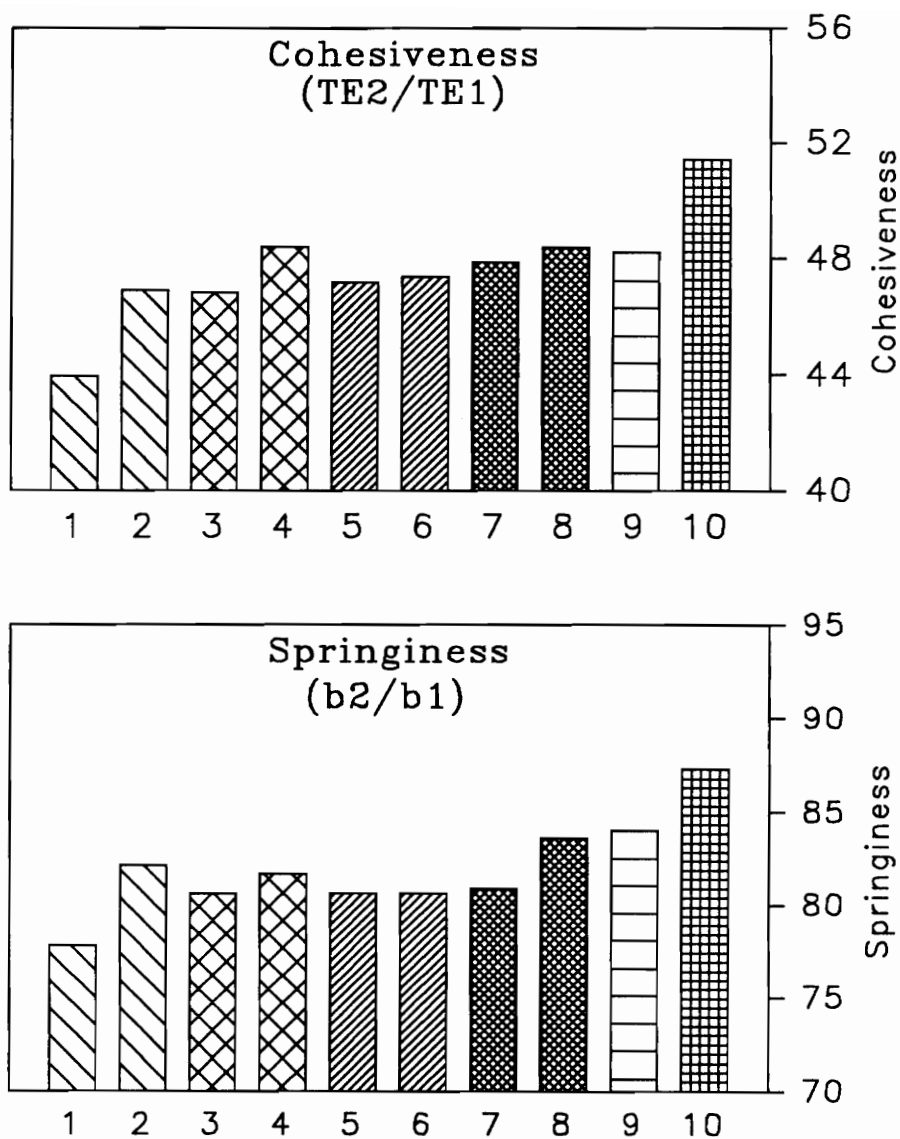


Figure 2-Instron texture profile analysis cont.

Treatment number	Physiological state	Mixing (min)	Batter temp.	Formulation water
1	prerigor	30	2°C	30%
2	prerigor	30	2°C	100%
3	prerigor	30	16°C	30%
4	prerigor	30	16°C	100%
5	postrigor	30	2°C	30%
6	postrigor	30	2°C	100%
7	postrigor	30	16°C	30%
8	postrigor	30	16°C	100%
9	prerigor	--	conventional procedures	
10	postrigor	--	conventional procedures	

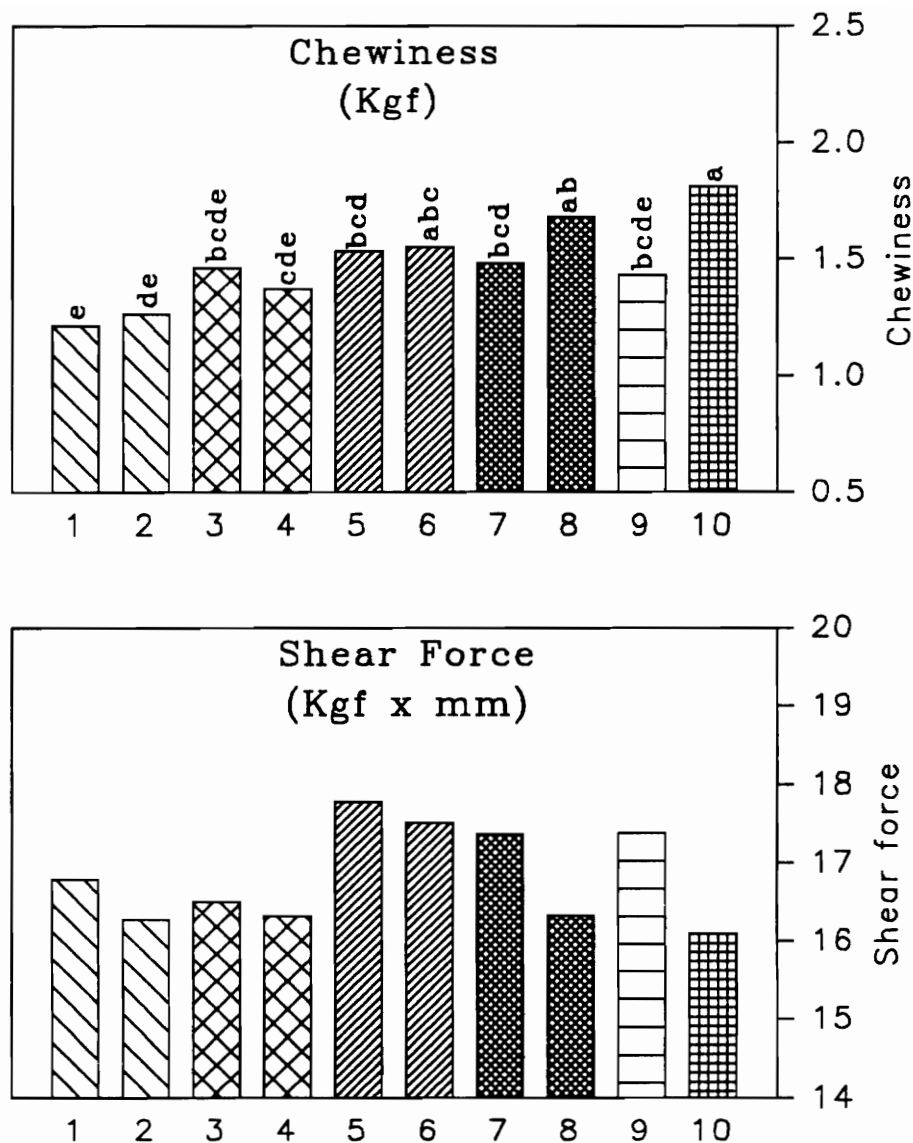


Figure 2-Instron texture profile analysis cont.

Treatment number	Physiological state	Mixing (min)	Batter temp.	Formulation water
1	prerigor	30	2°C	30%
2	prerigor	30	2°C	100%
3	prerigor	30	16°C	30%
4	prerigor	30	16°C	100%
5	postrigor	30	2°C	30%
6	postrigor	30	2°C	100%
7	postrigor	30	16°C	30%
8	postrigor	30	16°C	100%
9	prerigor	--	conventional procedures	
10	postrigor	--	conventional procedures	

Table 6-Effects of independent variables on instrumental texture of 15% fat, 25% added water frankfurters.

Independent variable	75% Compression		50% Compression		Shear (kgf*mm)
	Hardness (Kgf)	Distance to fracture (mm)	Springiness (b2/b1*100)	Cohesiveness (A2/A1*100)	
Comparisons within extended mixing treatments:					
Physiological state					
Prerigor	5.82	12.06	80.36	46.46	16.41
Postrigor	7.28	12.65	81.44	47.69	17.28
(P-value)	(0.030)	(0.064)	(0.796)	(0.225)	(0.118)
Mixing temperature					
2°C	6.62	12.43	80.11	46.30	17.09
16°C	6.48	12.28	81.70	47.85	16.60
(P-value)	(0.557)	(0.111)	(0.332)	(0.096)	(0.534)
Formulation water					
30%	6.25	12.16	79.81	46.41	17.09
100%	6.85	12.55	81.99	47.73	16.60
(P-value)	(0.076)	(0.047)	(0.042)	(0.041)	(0.292)
Comparisons averaged across mixing techniques:					
Physiological state					
Prerigor	5.78	11.97	81.11	46.87	16.61
Postrigor	7.24	12.60	82.63	48.46	17.03
(P-value)	(0.011)	(0.189)	(0.248)	(0.194)	(0.456)
Mixing technique					
Traditional	6.35	12.00	85.74	50.01	16.72
Extended	6.55	12.36	80.90	47.08	16.85
(P-value)	(0.424)	(0.342)	(0.123)	(0.319)	(0.118)

postrigor frankfurters were harder ($P < 0.03$) than prerigor counterparts, irregardless of the mixing treatment. Moisture and protein contents were essentially identical, and therefore do not explain the differences in frankfurters produced from the different physiological states. Higher pH in prerigor treatments was expected, but it is uncertain how this affected texture. Treatment 7 had a higher pH than other postrigor treatments (Table 2) and had several textural characteristics similar to prerigor treatments. Previous research has determined that prerigor meat resulted in more tender ground beef, but higher moisture content may have been responsible (Cross et al., 1979). High-fat (30%) frankfurters manufactured using prerigor raw materials had firmness and cooking loss values similar to postrigor controls (Abu-Bakar et al., 1982; Choi et al., 1987a).

Restricted water during extended mixing lowered ($P < 0.07$) hardness values (6.25 vs. 6.85 kgf) compared to treatments with 100% of formulation water present (Table 6). Claus et al. (1990) reported a similar trend in "massaged" postrigor low-fat, high moisture bologna, though that study added 50% of the formulation water and minced after extended mixing, possibly minimizing the differences. Mahler and Cordes (1966) theorized that concentrating proteins within the system would result in increased protein-protein interactions or aggregation. Another possibility is increased friction coupled with extended physical action may have increased protein denaturation. Either may have led to decreased gelation agility and a reduction in resistance to compression.

Hardness relative to extended mixing was not different than traditionally mixed products (Table 6) possibly due to insufficient replications. Solomon and Schmidt (1980) reported that protein functionality for both prerigor and postrigor beef slurries decreased with prolonged mixing time, though postrigor was more affected. However, Ockerman and Wu (1990) tumbled sausage batter for 0, 12, or 24 hr and found that firmness was not affected. Thermal emulsion stability

results from Gregg et al. (1992) indicated that extended mixing (up to a total of 40 min) of a comminuted batter may improve emulsion stability, but beyond this, losses increased sharply. Restricted water during EM resulted in values similar to or less than traditionally mixed treatments, whereas EM with all water consistently had higher firmness values (Figure 2). Claus et al. (1990) obtained significant results that support this observation. The design used in our study to analyze data could not differentiate temperature or water levels when comparing EM to traditional processing (Table 6). Temperature at which EM was conducted had no effect on hardness.

Data for fracturability was reported as distance to the first significant drop in force instead of the traditionally reported force at the first significant drop. For this study, the fracturability peak was, without exception, the same peak for hardness. By reporting distance to fracture, not force, more information was available.

In general, postrigor treatments fractured at a greater distance than corresponding prerigor treatment, except for treatment 7 (Figure 2). Within prerigor treatments, treatment 3 fractured at a shorter ($P < 0.05$) distance than treatment 4. Analysis of independent variable effects (Table 6) found postrigor fracturability distance in EM treatments to be greater ($P < 0.06$) than prerigor (12.65 vs. 12.06 mm), but physiological state comparisons across mixing techniques found no significance. Fracture distances were less ($P < 0.05$) for restricted water treatments compared with those mixed with all water. Claus et al. (1990) reported a similar trend. This possibly indicates a decreased ability of internal forces to maintain structural integrity for reasons previously discussed with hardness. EM at 2°C tended to result in greater distance to fracture. No differences were observed for mixing technique.

No significant differences between treatments were found for springiness, though controls appeared springier than EM treatments

(Figure 2). Treatment 1 appeared to be the least springy treatment. Extended mixing (Table 6) with all formulation water resulted in higher ($P < 0.05$) springiness than mixing with only 30% (81.99 vs. 79.81). There was a trend between mixing period and springiness as springiness values were higher (85.74 vs. 80.90) for traditionally mixed frankfurters.

Like springiness, no significant difference among treatments was observed for cohesiveness, control treatments appeared more cohesive than EM physiological state counterparts, and treatment 1 had a value noticeably lower than all others (Figure 2). EM treatments mixed with 100% formulation water (Table 6) were consistently more cohesive ($P < 0.04$) than those with 30% (47.73 vs. 46.41). Temperature also had an effect ($P < 0.10$) as the 16°C EM temperatures resulted in higher (47.85 vs. 46.30) cohesiveness values. Neither physiological state nor mixing technique had a significant effect. This agrees with Ockerman and Wu (1990) who found that prolonged physical action (tumbling) had no effect on cohesiveness.

The postrigor control was significantly chewier than all other treatments except for postrigor EM treatments mixed with 100% of formulation water (Figure 2). Postrigor treatments consistently had higher mean values than corresponding prerigor treatments. Postrigor treatments were chewier ($P < 0.04$) than prerigor when analyzed across mixing technique (Table 6). Extended mixing temperature and percentage formulation water had no effect, nor did mixing technique.

For Warner-Bratzler shear values, no significant difference among treatments (Figure 2) was found, though postrigor frankfurters in EM treatments tended to require more energy to shear through than prerigor EM treatments (Table 6). The opposite effect was observed in traditionally mixed treatments. No other independent variables had any effect.

Chapter 5

SUMMARY AND CONCLUSIONS

The use of prerigor lean did not decrease cooking losses or purge during storage, nor did it result in increased firmness in low fat, high moisture frankfurters. These results are contrary to previous research on high-fat comminuted products. In fact, firmness of prerigor treatments was significantly lower than that of postrigor frankfurters, particularly when extended mixing was applied.

Increasing ionic strength through the addition of salt and/or phosphate is generally recognized to result in greater extraction of myofibrillar proteins, which in turn produces a firmer, more cohesive product. Results from this study indicated that increasing ionic strength by restricting the amount of water present had a negative effect on texture. Frankfurters produced with an initially restricted water content during mixing were less firm, cohesive, and springy than corresponding treatments mixed with all of the water.

Temperature at which extended mixing was conducted had negligible effects on the product characteristics tested in this study, though it was observed that rendering occurred in those treatments mixed at 16°C. This would indicate that higher mixing temperatures are detrimental to fat holding ability and should be avoided.

Mixing procedure had no significant effect on the texture of low-fat, high moisture frankfurters, though by utilizing extended mixing techniques, particle definition was observed to have been greatly reduced over that of traditional techniques. This reduction in particle definition may have been responsible for the lower lightness, redness, and yellowness color scores received by EM treatments.

An interesting result was that in the prerigor treatments, texture tended to be less affected by treatment variables than postrigor

samples. Therefore, use of prerigor meat may be of benefit to some processors that are unable to have stringent processing controls necessary to produce a consistent product. In addition, processors that require longer mixing periods should incorporate all of the formulation water prior to mixing if firmer, more cohesive products are desired.

Further research should be investigated to establish if increased mince particle size can improve the water binding and firmness of low-fat, high moisture comminuted meat products. Additional studies involving the controlled incorporation of formulation water may be of benefit.

Chapter 6

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Vita

Stephen Frederick Sylvia was born on July 29, 1967 in Salisbury, Maryland, and is the son of Frederick and Barbara Sylvia of Bridgeville, Delaware. He received his high school diploma from Woodbridge Jr.-Sr. High School in Bridgeville, Delaware, and his Bachelor of Science degree in Food Science in May, 1990 from the University of Delaware. After graduation, Stephen performed his second summer internship with the McCormick Spice Company, then began pursuing the Master of Science degree in Food Science and Technology at Virginia Polytechnic Institute and State University. It was here where Stephen met his wife-to-be, Ruth Karina Espinel. The two were married on April 18, 1992, and currently reside in Fullerton, California.

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