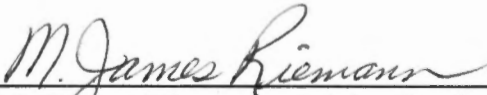


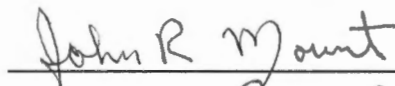
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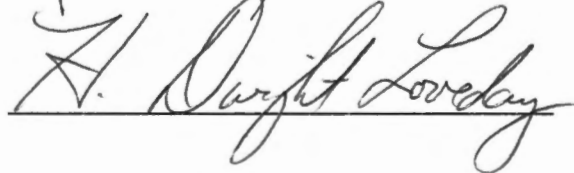
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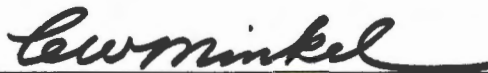
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**A
COMPARISON OF COOKED BEEF ROLLS
MADE FROM
FLAKED PRE-RIGOR AND POST-RIGOR BEEF**

**A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville**

**Ola Marie Archer
August, 1987**

AG-VET-MED.

Thesis
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.A733

DEDICATION

In memory of my father, William Arthur (Bunk) Archer (July 19, 1903 - June 15, 1967), who will always be my inspiration.

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ABSTRACT

This study was conducted to determine the effect of pre-rigor (PRR) and combinations of pre- and post-rigor (POR) beef on (1) selected processing characteristics and (2) shelflife and textural traits of cooked beef rolls.

Forty pounds of U.S. Utility cow carcass semimembranosus muscle (pre- and post-rigor) were flaked (.75 inch), vacuum tumbled 2 hours with 1.0% salt and 0.5% STPP and formulated into 8 lb. beef rolls consisting of 10 or 20% fat (fat source - boneless beef plates- U.S. Choice carcasses). After stuffing in an E-Z smoke casing, the beef rolls were cooked to an internal temperature of 62.8°C.

The results showed that treatments 3, 4 and 5 (increasing percentages of PRR beef from T3 to T5) had lower ($P<.05$) tensile strength than the other seven treatments. Treatments 4 and 5 (25% POR/75% PRR and 100% PRR, 10% fat, respectively) were the least tender and had the least amount of bind.

Treatment 2 (75% POR/25% PRR, 10% fat) had the highest ($P<.05$) bind and cooking yields. Even though treatment 2 had relatively high raw TBA values, after cooking this treatment had the lowest value and increased slightly to 30 days of storage.

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CHAPTER 1

INTRODUCTION

In recent years the segment of the meat industry that has experienced the most growth is that in which value-added meat products are produced. Production of value-added meat products may be characterized as the application of processing technology to raw materials thereby improving utilization of raw materials through manufacturing products that are more desirable and have greater value. Some meat plants have no slaughter capability but simply receive chilled raw materials for further processing. These plants manufacture some meat products that are restructured and formed by reducing the particle size of the raw materials, extracting as much protein as possible (by adding salt) to bind the particles together, and then forming the particles into a desired shape. However, the processor must remember some factors that may determine whether the sectioned and formed products will be accepted. Restructuring will not improve low quality meat. Connective tissue will remain relatively undisturbed and objectionable. Fat must be removed or it will show up in a very undesirable way in the sliced product. Fresh meat with a low bacteria count will produce a finished product with good appearance and shelflife. Color uniformity will be improved, but wide differences in muscle color can not be modified sufficiently to produce an attractive product. Restructuring does not require a sizeable investment in equipment and

management must be set up for product quality control, production supervision and marketing of the final product (Schmidt, 1978).

Those plants with slaughter capability have the advantage of being able to use pre-rigor meat to achieve greater bind than that possible with post-rigor meat. Advantages of using pre-rigor meat, besides greater bind, include greater energy efficiency by eliminating the need to chill whole carcasses, higher yields since shrinkage during chilling is avoided, safer products as there is less time for bacteria to grow before products are formed and frozen and quicker movement of meat through the plant. Also, hot-boning offers tremendous possibilities in labor, space and increased marketing efficiency (Henrickson, 1975). However, problems of hot-boning include textural changes, color differences and shelf life (Cross *et al.*, 1979a). Further advantages of restructuring include portion control, a boneless product, control of fat content, control of texture, product differentiation and intermediate value (Mandigo, 1974; Coon, 1982).

Some of the reasons for the lack of market acceptance of restructured pork products has been: (1) lack of uniform portion control, (2) lack of uniform quality to include juiciness, tenderness and flavor, and (3) improper preservation of quality (Mandigo, 1974). However, sensory analyses have indicated that sectioned and formed steaks are acceptable to the consumer (Dalton, 1979) and may even be preferred over intact muscles (Huffman and Cordray, 1979).

The objectives of this study were to: (1) determine the effect of pre-rigor and combinations of pre- and post-rigor beef on selected processing characteristics of cooked beef rolls, and (2) determine the effect of pre-rigor and combinations of pre- and post-rigor beef on shelflife and textural traits of cooked beef rolls.

CHAPTER 2

REVIEW OF LITERATURE

Transforming meat cuts of lower economic value into uniform, consumer-ready products can provide greater variety, increased convenience and maintain food budget economy (Chesney *et al.*, 1978). By restructuring lower quality cuts, the meat industry has been able to create a product with improved quality (Anonymous, 1974). The concept of restructured meat is to produce a uniform and completely edible product which resembles an intact muscle in textural properties (Booren *et al.*, 1981a).

I. PROCESSING VARIABLES

Particle Reduction

Development of a portion controlled product that would meet certain specifications of size, shape and composition as well as simulating intact muscle structure has been the goal of efforts to produce restructured meat products (Dalton, 1979). Various procedures are available for preparing meat products that have the appearance and consistency of intact muscle (Siegel *et al.*, 1978a). Some products consist of meat that has been flaked, formed and sectioned (Mandigo, 1974 and 1975) and researchers have utilized chunks of meat or entire muscle systems (Anonymous, 1971, 1977; Schmidt, 1977; Siegel *et al.*, 1978a) to make restructured products.

Comminution - flake cutting - is done by an uniquely designed, stationary cutting head which is made up of a continuous ring of cutting surfaces. The meat is forced across the cutting edges by a high speed impeller, producing thin, cleanly cut flakes without crushing or varying particle sizes and texture (Ferren, 1972; Pietraszek, 1972; Anonymous, 1973). The advantages of flaking include: (1) uniformly sized flakes of meat, (2) improved texture, (3) retention of juices, (4) improved binding and cohesive properties, (5) less cooking losses, (6) improved sensory characteristics, and (7) elimination of cylindrical pellets of gristle and connective tissue so often associated with grinding (Ferren, 1972, Anonymous, 1973). However, Acton (1972a) claimed some of the same advantages for ground meat particles over flaking as he stated that grinding provided: (1) greater ease of extracting surface soluble proteins, (2) more product yield through reduced cooking loss, and (3) increased binding strength between meat particles for maintaining an intact loaf or loaf slice (Acton, 1972a).

By reducing meat particle size, meat surface area is increased with an increase in the availability of myofibrillar proteins for binding. This increase in surface area promotes the release of muscle fiber contents which 1) form a moist surface to surface exudate, 2) can be solubilized in the presence of salts, and 3) can form a bond between similar surfaces (Acton, 1972a). Acton (1972a) reported that cook yield and binding strength were directly proportional to meat particle surface area. However, Pepper and Schmidt (1975) stated that the effect of increased surface area from a 25.4 mm grind as compared to a 9.5 mm grind did not appear to increase either binding strength or cook yield.

Cross *et al.* (1979a) showed that percent total cooking loss, height change, thaw loss and degree of doneness of beef patties were not significantly affected by the method of grinding. They also reported that grinding method did not affect significantly the pH values of frozen, thawed, and cooked patties or raw and cooked fat and water percentages. Flaked meat had significantly less drip than ground meat; however, the method of comminution had little effect upon cooking losses (Randall and Larmond, 1977; Chesney *et al.*, 1978). Randall and Larmond (1977) found that drip after thawing and bacterial contents on the patties (ground vs flaked) were similar. Samples containing meat flaked with the smaller 3.0 mm head had significantly less cooking loss than those flaked through the larger 12.7 and 6.9 mm cutting heads (Acton, 1972a,b; Chesney, 1973; Popenhagen *et al.*, 1973; Chesney *et al.* 1978; Mandigo, 1975).

When comparing flake sizes using 2.2°C meat, sensory panel results showed that non-blended products made with 6.9 mm and 12.7 mm flakes were more acceptable for all traits than those made with 3.0 mm flakes. However, when -5.6°C meat was used, no significant differences existed among the three flake sizes for juiciness, cohesiveness, and overall acceptability (Popenhagen *et al.*, 1973). In contrast, Chesney (1973) reported that juiciness and tenderness scores were higher for smaller sizes and decreased as the particle size increased. Trained sensory panels found that ground patties had a finer grind, were more tender, less rubbery and were more juicy and greasy than the flake-cut product. (Randall and Larmond, 1977). Cross *et al.* (1979a) stated that method of grinding had no significant effect on any palatability trait except the flavor intensity. Chesney *et al.* (1978) showed that panelists preferred flaked over ground

products, however, Randall and Larmond (1977) stated that a consumer panel gave higher scores to the ground patties.

Patties prepared from hot-boned beef were more tender and juicy than patties prepared from chilled beef (Cross *et al.*, 1979a). Pre-rigor grinding and salting reduced the rate of autoxidation (TBA number) as contrasted to sausage that was salted post-rigor after pre-or post-rigor grinding (Drerup *et al.*, 1981). This agrees with work by Judge and Aberle (1980) done on either light or dark semitendinosus muscle and the work of Hamm (1977a). Pre-rigor grinding reduced the extent of postmortem pH decline, improved binding properties and resulted in less shrink loss during cooking and higher juiciness scores on cooked patties (Drerup *et al.*, 1981). Substantially greater extractability occurred as a result of grinding. Coarse grinding (8 mm plate) increased the amount of soluble protein by 154%; fine grinding (4 mm plate) resulted in 182% more soluble protein (Acton, 1972a).

Particle size had no significant influence on water holding capacity of restructured meat products (Chesney *et al.*, 1978; Popenhagen and Mandigo, 1978) but flaked products had greater water holding capacity than ground products.

When comparing sectioned and formed steaks to intact top sirloin or flaked and formed steaks, a sensory panel rated the sectioned and formed steaks as more desirable (Booren *et al.*, 1981c). However, meat chunks (2-3 cm) and slices (1-2 mm) gave the restructured pork chops a bite and mouthfeel more typical of muscle meat than can be obtained from either ground or flaked products (Huffman and Cordray, 1979).

Blends of different flake sizes are more desirable than single flake sizes of meat (Popenhagen and Mandigo, 1974; Popenhagen and Mandigo, 1978) to form a higher quality product. Popenhagen and Mandigo (1978) suggested blending a small flake with a large flake but Chesney (1973) suggested medium sized flakes were preferred over very fine or coarse flakes.

Meat Temperature

Meat temperature is a critical factor at nearly every stage of the restructuring process. Coon (1982) stated that meat temperature during flaking and blending affected the final product stability and color. The temperature of the trimmings and meat ingredients as they were flaked was extremely important with respect to texture and appearance of the finished products (Mandigo, 1974).

Chesney *et al.* (1978) reported that cooking loss increased ($P < .01$) as the processing temperature (32.2, 2.2 or -5.6°C) of the fabricated pork product decreased which is in agreement with the findings of Miller *et al.* (1968) and Popenhagen *et al.* (1973). The percent cooking loss for restructured pork from blended and non-blended treatments containing -5.6°C meat was significantly greater than the cooking loss from treatments containing 2.2°C meat (Popenhagen *et al.*, 1973; Popenhagen and Mandigo, 1978). Samples containing 2.2°C meat flaked through the 3.0 mm head, had less cooking loss than those flaked with the 6.9 or 12.7 mm heads (Popenhagen and Mandigo, 1978).

Chesney *et al.* (1978) reported lower ($P < .01$) water holding capacity in fabricated product made from -5.6°C meat compared to products made

from 2.2 or 32.2°C meat which agrees with reports by Chesney and Mandigo (1974) and Popenhagen and Mandigo (1978).

Hansen and Mandigo (1972) compared flaked pre-rigor pork to conventionally chilled flaked pork and found that as the proportion of warm pork increased, when blending with chilled meat, a decrease in percent fat occurred in the uncooked samples. Hot processed patties changed significantly less in diameter than chilled patties which would be of great importance for institutional use (Cross *et al.*, 1979b).

Taste panel results showed products made from 2.2°C meat had significantly higher juiciness, cohesiveness, and overall acceptability scores than products made from -5.6°C meat (Chesney and Mandigo, 1974; Popenhagen and Mandigo, 1978). Panelists found the chilled (2.2°C) product to be more cohesive than either the pre-rigor (32.2°C) or tempered (-5.6°C) pork products (Chesney and Mandigo, 1974). They also reported that the panel preferred the chilled products (2.2°C) over the tempered (-5.6°C) for overall acceptability (Chesney and Mandigo, 1974) as did Popenhagen *et al.* (1973). The raw product acceptability for pre-rigor products was higher ($P < .05$) than the two lower processing temperatures (2.2°C and -5.6°C) (Chesney and Mandigo, 1974). Mandigo *et al.* (1972) concluded that the processing temperature of flaked, formed and sectioned meat products did not appear to influence consumer preference. But, Chesney (1973) reported that organoleptic panel acceptability scores indicated chilled products were preferred over pre-rigor and tempered products.

Myofibrillar proteins in the exudate were higher for all treatments than had been previously reported for sectioned and formed steaks (Booren

et al., 1979). This was explained by the lower processing temperature of -2°C which was closer to the reported optimum temperature for myofibrillar protein extraction (Bard, 1965). Cold flakes (-4.4°C) were important in providing the "bite" or texture of the finished product (Mandigo, 1974). Mandigo (1974) further reported that when the fat component is flaked through fine flaking heads, the fat content is not readily discernable in the finished product. However, if the marbled effect is desired fat flaked through coarser heads at colder temperature (-4.4 vs 2.2°C) will accomplish this objective (Mandigo, 1974).

Research has shown that the use of two different temperatures of meat ingredients offers certain advantages over a single temperature (Mandigo, 1974; Popenhagen and Mandigo, 1974; Popenhagen and Mandigo, 1978). Mandigo (1974) reported that 2.2°C tempered meats are excellent for the emulsion component of the flaked, formed or sectioned product. He further stated that this temperature would usually be used for the fat source component and would be used with the finer flake sizes. The colder, tempered meat, -4.4°C , is used for the leaner meat components as well as the coarser flake sizes (Mandigo (1974). However, Popenhagen and Mandigo, (1974) stated that a flaking temperature of -5.5°C is more desirable than 2.2°C based on product performance and chemical analysis. Popenhagen and Mandigo (1978) also reported that a 50:50 temperature mixture had greater ($P<.01$) binding ability and produced a higher quality product than the sample composed of 100% -5.6°C or 100% 2.2°C meat as indicated by the Warner-Bratzler shear force values. Panel members also found the 50:50 samples to be more cohesive (Popenhagen and Mandigo, 1978). The type of product desired should dictate the processing temperature, since the

exact temperature to insure the optimal cohesion varies from product to product (Farrington, 1975).

Mixing

Mixing action has been shown to have a vital role in the restructuring of meat products. In restructured meat products, mixing has two purposes: (1) it is essential to provide a uniform distribution of fat particles, salt and other additives, and (2) the mechanical action enhances protein extraction, thus contributing to the final product texture (Coon, 1982).

Water holding capacity (WHC) is most affected by mixing time and is reduced with increased mixing time (Belohlavy and Mandigo, 1974) to a low at 14 minutes mixing time. They further stated that the WHC then increased from the 14 to 20 minutes mixing time for beef, lamb and pork with the 20 minutes mixing time resulting in the greatest WHC for all mixing times studied (2, 8, 14 and 20 minutes). However, Siebert (1978) and Wiebe and Schmidt (1982b) reported there was no improvement of WHC by using a vacuum chopper as opposed to an open bowl chopper.

Mixing time did not cause differences ($P < .05$) in percentages of moisture (Belohlavy and Mandigo, 1974; Wiebe and Schmidt, 1982b), protein (Belohlavy and Mandigo, 1974; Solomon and Schmidt, 1980), ash or ether extract (Belohlavy and Mandigo, 1974).

Pepper and Schmidt (1975) reported that in most cases the binding strengths and cook yields of beef rolls increased with mixing times (5, 10, 20 or 30 minutes). Booren *et al.* (1981a) showed that mixing for 16 minutes increased binding as well as improved tenderness in sectioned and formed

beef steaks. However, no effect of mixing treatment on the binding strength of restructured beef steaks was shown by Wiebe and Schmidt (1982a).

Mixing for 24 minutes resulted in greater cooking yields according to Booren *et al.* (1981a) and Belohlavy (1975) who found greater cooking yields up to 26 minutes blending of flaked beef. Similar results have been reported with the tumbling and massaging of hams (Schmidt, 1978).

Based on Lee Kramer shear, mixing improved tenderness ($P < .01$) by 20% after 18 minutes while an 8% improvement occurred after 6 minutes (Booren *et al.*, 1981a,b). However, sensory evaluation failed to fully substantiate this tenderness difference (Booren *et al.*, 1981a).

Thiobarbituric acid (TBA) values in sectioned and formed beef steaks were consistent over mixing times after 0 and 90 days storage at -30°C (Booren *et al.*, 1979; Booren *et al.*, 1981a,b).

Myofibrillar proteins in the exudate were higher for all treatments than previously reported for sectioned and formed steaks (Booren *et al.*, 1979). This can possibly be explained by the lower processing temperature of -20°C which was closer to the reported optimum temperature for myofibrillar protein extraction (Bard, 1965). However, Solomon and Schmidt (1980) reported that mixing time had a linear effect on the amount of crude myosin produced from post-rigor meat ($P < .01$). There was an average increase of 2.29 g protein of crude myosin extracted for each hour of mixing (Solomon and Schmidt, 1980). Booren *et al.* (1981a) reported that juiciness and flavor were not influenced by mixing time while Booren *et al.* (1981b) stated that mixing increased sensory juiciness ($P < .01$) and flavor ($P < .05$). Color scores significantly increased over mixing times which would suggest that the lower the mixing time the more desirable the color of

the finished steaks (Booren *et al.*, 1981b). However, when surface color was monitored spectrophotometrically over mixing times there were no apparent changes (Booren *et al.*, 1981b).

In the past few years, an extensive amount of research has been done on vacuum mixing of meat particles and its affect on all attributes of restructured meat items. Wiebe and Schmidt (1982b) stated that the advantage of vacuum mixing is a firmer texture. This firmer texture can be attributed to the enhanced protein extraction during vacuum mixing (Anonymous, 1978 ; Siebert, 1978). Siebert (1978) and Anonymous (1978) stated that 20-30% more protein is extracted in a vacuum chopper as opposed to an open bowl chopper. Furthermore, vacuum had a significant effect of increasing the amount of crude myosin ($P<.05$) produced with increased time of mixing ($P<.01$) (Belohlavy and Mandigo 1974; Solomon and Schmidt, 1980). The increase in crude myosin determined by the fact that the total protein did not increase due to vacuum but the crude myosin content did increase (Solomon and Schmidt, 1980). Therefore, increased mixing time is associated with the generation of crude myosin. Solomon and Schmidt (1980) also compared pre- and post-rigor vacuum minced meat and found the former produced greater crude myosin yields over time ($P<.01$).

There was no improvement in WHC by using vacuum mixing as opposed to no vacuum (Anonymous., 1978; Siebert, 1978; Wiebe and Schmidt, 1982b). Vacuum mixing was responsible for increased binding strength of restructured steak but had no effect on the cook yield (Wiebe and Schmidt, 1982b). Also, Booren *et al.* (1981 a,c) stated that sensory analyses indicated vacuum processed steaks had superior bind ($P<.01$). Adhesion

measurements did not change when meat pieces were mixed under vacuum which conflicts with sensory evaluation of adhesion (Booren *et al.*, 1981c).

Sensory analyses indicated vacuum processed steaks remained unchanged for juiciness, flavor, tenderness, and connective tissue (Booren *et al.*, 1981c). This agrees with cooking yield and Instron Lee Kramer shear analyses.

Subjective and spectrophotometric color analyses indicated vacuum mixing resulted in less desirable color in the finished steaks, vacuum mixing did not decrease rancidity as indicated by TBA values; however, TBA values were lower in steaks with no salt (Booren *et al.*, 1981c).

Cooking Properties

Cooking properties of restructured meat products entering the consumer market have been studied quite extensively. The first effect of heat is to activate a contractile process if the primary filaments have not yet "locked" completely in rigor (Cia and Marsh, 1976).

The binding strength of poultry loaves increased ($P < .05$) from temperatures of 35-82°C with maximum binding strength occurring at 82°C (Acton, 1972b). Further heating to an internal temperature of 94°C caused a reduction ($P < .05$) in the binding strength when compared to that observed at 82°C. However, salt treated beef rolls had the greatest binding strength at 68°C but binding strength in the salt-phosphate treated rolls increased with temperature (61°C, 68°C, 75°C) (Pepper and Schmidt, 1975). Hamm and Deatherage (1960) reported the most extensive binding changes occur in the temperature range of 40-65°C. Pre-cooked reheated steaks had significantly higher binding strength but lower yield than steaks

cooked from the frozen, raw state. Acton (1972b) summarized that stronger binds were developed when the meat was heated for long periods at low temperatures.

Cia and Marsh (1976) showed that meat cooked early postmortem was found to be more tender relative to that cooked after rigor onset. They suggested that the tenderness of meat cooked in the pre-rigor state was largely a consequence of a shattering of fiber structure in some areas brought about by extreme shortening in others. The fractured zones offer little resistance to cleavage and shear very readily despite the great shortening which occurred in nearby sarcomeres (Cia and Marsh, 1976). Parrish (1974) reported that toughness increased with higher cooking temperatures at least within the range 60-80°C.

The amount of connective tissue in the muscle also plays a role in how tough or tender meat may be. Connective tissue in muscle is made up of collagen, elastin, reticulin and the ground substance (Cover *et al.*, 1962). Of these, the one present in largest amount is collagen, which is heat labile. Cover *et al.* (1962) studied connective tissue in the Longissimus dorsi (LD) and Biceps femoris (BF) and found that the connective tissue in the LD was scored tender at 61°C by a sensory panel and became only slightly more tender with an increase in temperature. Furthermore, in the BF the connective tissue was scored tough at 61°C and became progressively more tender at 80 and 100°C. In both the LD and BF, the collagen content decreased with increasing internal temperature as determined by the hydroxyproline procedure.

Acton (1972b) found the percent cooking loss increased ($P < .05$) as the internal temperature of the chicken loaves increased (55-94°C) with a

120% increase between 82-94°C. This agrees with reports by Wierbicki *et al.* (1957) and Hamm (1960) who showed that drip loss is temperature dependent. For both salt and salt-phosphate mixtures, the highest cook yield in a restructured beef roll occurred at 68°C, not 61 or 75°C (Pepper and Schmidt, 1975). Huffman *et al.* (1981) stated that retention of moisture due to salt addition was a factor in determining cooking yields. Furthermore, the release of juices from meat on heating has been shown to be dependent on temperature (Hamm, 1960). Wiebe and Schmidt (1982b) reported increased binding strength and cook yields for pouched restructured meat products at 121°C as opposed to 110°C. However, there was no significant influence of processing temperature on binding strength or cook yield of the canned product.

As fat content of patties increases cooking time decreases (Cross *et al.*, 1980a; Costello *et al.*, 1985). Cross (1977) reported that as the percentage of intramuscular fat increased the cooking time decreased because of differences in heat transfer of lean versus fat. Cross *et al.* (1980a) also showed that as percent fat increased in raw patties, fat loss during cooking also increased.

Cia and Marsh (1976) reported small changes in pH during cooking. Samples cooked at a high initial pH suffered appreciably smaller cooking losses than those cooked after rigor onset, despite the much greater shortening which occurred in the pre-rigor material.

Cover *et al.* (1962) reported no significant differences in sensory panel scores or shear-force values between cooking of LD and BF steaks to 80°C by dry heat and to 85°C by moist heat. This seems to confirm that the important consideration in tenderness and juiciness is meat temperature

rather than moist or dry heat. The level of phosphorus (Pepper and Schmidt, 1975) and protein (Acton, 1972b; Pepper and Schmidt, 1975) in salt treated beef rolls and chicken loaves was significantly reduced as higher internal temperatures were attained during the cooking process.

Brady and Hunecke (1985) stated that as endpoint temperature was increased (60°, 70° and 80°C), time to reach the designated temperature also increased and heating losses increased significantly between 60° and 70°C but were not different between 70°C and 80°C. This is in contrast to Cross *et al.* (1979a) who found heating losses increased as end point temperatures were increased in 10°C increments between 60° and 90°C and increased significantly between 70° and 80°C. Laakkonen *et al.* (1970) found that the weight loss of various beef muscles was dependant on the final temperature attained during the cooking process.

Packaging Properties

Over the past several decades the character of the meat packaging industry and the retail food business has changed (Apple, 1981). Apple (1981) further stated that packaging materials for food products have a number of necessary purposes such as acting as a cover to prevent soiling and physical damage, providing a convenient and economical means of transporting the product and dispensing the product to its final consumer.

The gases that are of most concern in packaging meat are oxygen and water vapor (Perdue *et al.*, 1975). They found that an O₂ transmission rate of 50 cc per meter squared/24 hours/at 22.8°C was acceptable to prevent the degradation of fresh meat pigments under the conditions of vacuum packaged storage up to 28 days at 2.2°C.

Hess *et al.* (1980) showed a reduction in the growth of Pseudomonas by the use of films of lower permeabilities (10 cc's) but the cost makes the material uneconomical. However, Seideman *et al.* (1976) suggested that a tight fitting vacuum package with little residual air could have a greater CO₂ concentration earlier from the conversion of O₂ to CO₂. This higher CO₂ concentration could have an inhibiting effect on gram-negative aerobic spoilage bacteria.

Perdue *et al.* (1975) found that package design had an effect on the amount of purge found in the vacuum package of fresh beef. The packages where the film surface area is equal to the product surface area had approximately 1% lower purge than packages where the film surface area is significantly greater than the meat product area. Schwartz and Mandigo (1976) stated that packaging loss increased ($P < .01$) with increased salt in restructured pork. Packaging loss was not changed with the addition of STPP except at the two highest levels (0.375 and 0.5%), where the 0.375% level had the least packaging loss (Cross *et al.*, 1979b).

Cross and Tennet (1980) and Cross *et al.* (1979b) all mentioned that whiter fat was found in vacuum packaged hot-processed product. Cross *et al.* (1979b) attributed the difference to discoloration of fat during the chilling period (48 hr) for cold-boned cuts and the greater amount of purge they found in the vacuum package.

Cross *et al.* (1979b) found that lean color of vacuum packaged hot-boned and cold-boned meat did not differ significantly. However, Lawrie (1979) suggests that hot boning could produce cuts with a more uniform lean color.

Apple (1981) reported that vacuum packaging of hot processed meat was difficult. Some of the difficulties stated were: (1) distortion of muscle to an unconventional shape, (2) inconsistent appearance because of muscle separation during sawing, and (3) difficulty of sawing and handling "hot" meat. However, Cross *et al.* (1979b) found that cold-boned cuts were rated higher on appearance than hot-boned cuts before and after storage but the differences were not significant.

Storage Characteristics

The storage characteristics of restructured products were not studied until 1976 when Schwartz and Mandigo first addressed the situation. Many factors like freezer yield, cook yield, oxidative rancidity, color and organoleptic properties needed to be determined for the effect of frozen storage on restructured meat products since most restructured meat items are handled frozen.

Cooking yields for restructured meat products decreased over storage time (Neer and Mandigo, 1974b; Schwartz and Mandigo, 1976; Neer and Mandigo, 1977) and the cooking yield decrease was more dramatic with higher levels of salt and tripolyphosphate (Neer and Mandigo, 1974b). Neer and Mandigo (1974b) showed that as time of frozen storage was increased, freezer yields decreased. Wierbicki *et al.* (1957) stated that when sodium chloride was added to meat prior to freezing, less drip was encountered on thawing.

Rancidity has been shown to increase significantly ($P < .01$) during frozen storage (Schwartz and Mandigo, 1976; Neer and Mandigo, 1977). Neer and Mandigo (1974b) reported iodine values decreased (increased

rancidity) over time, however, products with no salt were slower to go rancid than those with salt. Furthermore, the presence of tripolyphosphate retarded the increased oxidation effect of salt (Neer and Mandigo, 1974b).

TBA values indicated that a 0.5% salt level in steaks will increase rancidity slightly after 90 days storage (Booren *et al.*, 1981a) and in patties to a significant extent by day 60 (Huffman *et al.*, 1981), but the rancidity could not be detected by a sensory panel. Booren *et al.* (1981b) showed TBA values were low and did not change after 90 days storage at -30°C which is consistent with Booren *et al.* (1979).

Pre-rigor grinding pork muscle reduced the rate of lipid oxidation during storage at 2°C (Judge and Aberle, 1980) and at 0°C (Drerup *et al.*, 1981). Salt (2% and 0.5%) had a pro-oxidant effect in both pre-rigor and post-rigor ground muscle but pre-rigor ground and salted pork oxidized slower than did muscle that was ground and salted post-rigor (Judge and Aberle, 1980; Drerup *et al.*, 1981, respectively). This agrees with work reported by Hamm (1977b).

WHC of frozen restructured pork was lower ($P < 0.10$) than that of cuts made from pre-rigor and chilled meat according to Chesney *et al.* (1978). However, Schwartz and Mandigo (1976) reported an increase in WHC with frozen storage. The high WHC of pre-rigor material can be preserved for months by rapid freezing of the muscle and processing without prior thawing (Hamm, 1978). If frozen in a strictly pre-rigor state, the tissue shortens greatly when thawed and loses a lot of fluid, but if frozen at rigor onset both shortening and exudation were quite small (Marsh and Leet, 1966b).

Marsh *et al.* (1968) showed that L D muscles from lamb carcasses held for various periods at 20°C before being exposed to freezing conditions were more tender when the holding period exceeded 16 hrs. than holding times. However, McCrae *et al.* (1971) showed that lamb muscles varied widely in their response to pre-rigor carcass freezing and that increasing the holding period at 18°C from 10-16 hrs. before freezer entry greatly improved the tenderness of some muscles.

Huffman *et al.* (1981) reported that storage of beef patties up to 60 days had little effect on any of the sensory attributes. Both trained and consumer panel ratings revealed a non-significant storage effect. Neer and Mandigo (1974b) showed that products with low levels of salt and/or tripolyphosphate were rejected by taste panelists much sooner than those containing moderate amounts of either ingredient. High salt and/or tripolyphosphate levels were distasteful to panelists. Frozen storage has also been shown to decrease aroma, flavor, eating texture (Schwartz and Mandigo, 1976) and raw and cooked color (Schwartz and Mandigo, 1976; Neer and Mandigo 1977). But Neer and Mandigo (1977) showed that all products initially rated as acceptable were still scored acceptable after 18 weeks in frozen storage.

Massaging and Tumbling

The effects of massaging and tumbling on meat pieces have been studied quite extensively over the past few years. Some of the many advantages of tumbling and massaging are: (1) uniform color, shape, weight and sliceability, (2) meat becomes pliable and is therefore easily handled by the machinery, (3) controlled composition, shrinkage and

cooking losses, (4) muscle tissue from any part of the animal may be utilized to form cuts that resemble primal cuts, (5) increased tenderness, (6) improved additive concentration and distribution, (7) increased salt-soluble protein extraction.

Tumbling generally refers to placing meat into a drum that has baffles on the inside and rotating the drum about a horizontal axis (Schmidt, 1978). This impact of meat on meat as well as the friction of one portion abrading another portion has several functions. The agitation or tumbling of meat particles in the presence of a salt solution brings the salt-soluble proteins to the meat surface (Pepper and Schmidt, 1975; Schmidt, 1978). Krause *et al.* (1978a) reported better sliceability and yield in tumbled canned hams with the addition of STPP and the removal of most of the fat cover. Maesso *et al.* (1970a) suggested that mechanical action increased the surface area of the tissue, thus exposing a greater amount of protein for binding with both protein and non-protein moieties. The proteins interact and coagulate during heating, thus binding the meat surfaces (Woollen, 1971).

Krause *et al.* (1978b) found that STPP and tumbling independently increased the migration of salt and nitrite and resulted in an increase in color development. Krause *et al.* (1978a) determined that tumbling significantly improved canned ham external appearance, color, sliceability, taste, aroma and yield. However, three-hour continuous tumbling resulted in less improvement in product quality and yield than did 18-hour intermittent tumbling. Furthermore, Ockerman *et al.* (1978) determined that tumbling for 30 minutes did not increase yield, texture or sensory characteristics of canned hams.

The surface proteins reduced cook losses in chicken loaves and hams (Acton, 1972a,b;) and increased binding strength between meat pieces (Aref and Tape 1966; Maesso *et al.* 1970a,b; Schnell *et al.*, 1970; Vadehra and Baker, 1970; Acton 1972a,b). The amount of myofibrillar protein present in the exudate could be increased by increasing muscle destruction with a resultant increase in surface area (Acton, 1972a,b). Rahelic *et al.*, (1974) studied tumbling on pasteurized canned hams and found that tumbling for up to 320 minutes decreased released juice in cans and tumbling beyond 460 minutes increased juice loss in cans. Histologically, increased duration of tumbling caused a swelling and loosening of the structure of the sarcomeres (Rahelic *et al.*, 1974). After extensive tumbling, the sarcomere structure degraded completely with actin filaments and Z discs broken down most rapidly (Rahelic *et al.*, 1974).

The massaging process seems to facilitate the necessary salt-soluble protein extracting without the gross destruction of muscle structure that occurs in emulsion-type meat products (Weiss, 1974; Theno *et al.*, 1977). The massaging process serves to disrupt the normal muscle structure through the application of frictional energy, creating a greater surface area from which greater amounts of myofibrillar proteins may be extracted (Hamm, 1970a; Theno *et al.*, 1978a). These solubilized proteins are thought to be released either through extraction from muscle cells or by cellular destruction resulting in a release of intracellular materials into the exudate.

Theno *et al.* (1978a) stated that the addition of salt and phosphate in conjunction with massaging, contributes to the disruption of muscle fibers, with subsequent production of an exudate rich in solubilized myofibrillar proteins rather than just broken pieces of muscle. The exudate is principally

a solubilized protein suspension containing the myofibrillar proteins (Schnell *et al.*, 1970; Acton, 1972a,b). However, the exudate is not exclusively composed of solubilized myofibrillar protein, it also contains fat, water and pieces of broken muscle fibers (Hansen, 1960; Siegel *et al.*, 1978b). Hamm (1970a,b) and Theno *et al.* (1978a) further stated that samples without added salt or phosphates showed broken fibers and fragments from the disruption but samples with salt or phosphate showed both solubilized protein and fragments from fiber disruption. However, length of massaging enhanced the effects in all samples (Theno *et al.*, 1978a). Ham rolls prepared using no salt or phosphate failed to provide adequate binding even after 24 hours of massage (Theno *et al.*, 1978b). The addition of salt and phosphate dramatically increased binding and product quality (Maesso *et al.*, 1970a; Theno *et al.*, 1978b). Theno *et al.* (1978a) showed that the addition of 1% salt produces quite a noticeable increase in the amount of exudate produced as seen when compared to no salt (0.0%).

Postmortem Shortening

Since tenderness is a major textural component of any meat item, the effects of muscle shortening upon tenderness and other properties should be considered when producing a restructured meat product. Meat tenderness is greatly affected by postmortem carcass handling (Moeller *et al.*, 1976). Cold shortening (Locker and Hagyard, 1963) has been recognized as a major determinant of tenderness in beef (Locker, 1960) and lamb (Marsh *et al.*, 1968).

Improvements in tenderness may be achieved by methods which minimize shortening either by the use of physical restraint (Locker, 1960;

Newbold and Harris, 1972; Hostetler *et al.*, 1975;) or by the use of high temperatures during the development of rigor mortis (Smith *et al.*, 1971; Fields *et al.*, 1975). Postmortem shortening and the rate of tenderization is dependent on temperatures of holding or ripening (Wierbicki *et al.*, 1954; Newbold and Harris, 1972) but not all muscles show the same temperature dependence (Newbold and Harris, 1972). Beef taken immediately at slaughter and before rigor mortis began was more tender than beef in rigor mortis (Wierbicki *et al.*, 1954). Studies of Locker (1960), Smith *et al.*, (1971), Fields *et al.* (1975), and Hostetler *et al.* (1975) all attribute improvements in tenderness to the prevention of muscle fiber shortening as shown by increased sarcomere lengths.

The increase in toughness with shortening is believed to be due to changes in the myofibrillar structure (Marsh and Leet, 1966b). Moeller *et al.* (1976) results indicate that some of the differences in tenderness produced by high temperature treatments are possibly associated with the increased level of free lysosomal enzymes the first 12 hr postmortem. However, low temperatures can cause a decrease in tenderness through cold shortening (Marsh *et al.*, 1968) and elevated temperatures during the early postmortem period produce marked tenderness improvements (Parrish *et al.*, 1969; Fields *et al.* 1975). The tenderness of meat, cooked after rigor onset, is determined largely by the extent of cold shortening (Locker and Hagyard, 1963) undergone by the muscle during the first few hours postmortem. Meat is relatively tender if shortening during this period was either relatively small or very considerable; at intermediate values, a marked toughening is observed (Marsh and Leet, 1966a).

Tissue at the 'peak' of toughness is uniformly shortened and shows no sign of structural weakness or damage, but with further shortening supercontraction and node formation takes place in an increasing proportion of the sarcomeres (Marsh *et al.*, 1974). They further state that when the length change has exceeded about 50% this disruption appears sufficient to account for the declining toughness which accompanies supraphysiological shortening. Moeller *et al.* (1976) reported that samples taken 18 hr postmortem contained a significant difference in the level of cathepsin C activity. This phenomena was not present in the 24 hr samples, again indicating that the effects of high temperature conditioning on tenderization resulting from enzyme action are more prominent in the early postmortem stages. After 24 hr, the only remaining differences reported between control and high temperature conditioned samples are differences in tenderness (Dutson *et al.*, 1975; Fields *et al.*, 1975). These differences in tenderness are probably brought about by subtle alterations in muscle structure associated with high free enzyme levels immediately postmortem. Dutson and Lawrie (1974) state that the acid hydrolases present in lysosomes could be responsible, at least partly, for the postmortem break down of proteins and other components in muscle, which is concomitant with tenderization of the meat during conditioning.

Newbold and Harris (1972) have shown that one way of reducing "processing toughness" is to hold the carcass for about 20 hrs in a room at 15-20°C before placing it in a freezer. A disadvantage to this method is that bacteria can grow well at this temperature and a distinct health risk may be introduced. If the humidity is reduced to a level which discourages the

growth of salmonellae, evaporative losses from the carcass can be high (Newbold and Harris, 1972).

Honikel *et al.* (1981b) have shown that neither shortening nor development of rigor (pH 5.9) have an immediate influence on WHC of muscle and unsalted homogenates; the small decrease of WHC postmortem is due to pH fall only and independent of temperature. At the onset of rigor mortis (pH 5.9), however, the WHC of the salted homogenate decreases strongly (Honikel *et al.*, 1981b).

The rate of pH fall in muscle depends on the incubation temperature (Honikel *et al.*, 1981b). High temperature samples (37°C vs 2°C) had significantly lower pH values at both 4 and 12 hr postmortem ($P < .05$ and $P < .01$, respectively) (Moeller *et al.*, 1977). This is in agreement with the results of Cassens and Newbold (1967). The combination of lower pH and elevated temperature approaches optimum conditions for lysosomal hydrolase activity (Barrett, 1972; Moeller *et al.*, 1976). Samples which had attained their ultimate pH usually shortened by 10-20% of their raw lengths (Cia and Marsh, 1976), while toughness increases with the extent of length change attaining a maximum value at about 35-40% shortening (Marsh and Leet, 1966a,b). High temperature conditioning causes a more rapid pH drop in carcasses (Cassens and Newbold, 1967). The low pH in conjunction with the high carcass temperature enhances the disruption of the lysosomal membrane and the concurrent release of acid hydrolases into the muscle tissue as shown by a rise in percent free enzyme activity of the high temperature samples (Moeller *et al.*, 1976).

Powell (1978) found that drip loss of beef stored at a temperature where cold shortening occurs increased compared with that of beef kept at

10-15°C. Cold shortening occurs before the onset of rigor mortis (Honikel *et al.*, 1981a) and like physiological contraction, is due to the coupling of mechanical and chemical events within the myofibrils (Davey and Gilbert, 1974). However, Davey and Gilbert (1974) found an increase in cooking loss as a result of cold shortening.

Honikel and Hamm (1978) reported that lowering the temperature from about 37°C (immediately after slaughter) to 6-8°C results in a continuous decrease in the rates of ATP turnover and glycolysis; a further decrease of tissue temperature down to the freezing point (about -1°C) causes an acceleration of postmortem metabolism. The increased rates of metabolic processes coincide with "cold shortening" which results in a toughening of the cooked meat (Marsh and Leet, 1966b). Dalrymple and Hamm (1975) state that the postmortem metabolism of glycogen to lactate (glycolysis) plays a leading role in the conversion of muscle to meat and in meat quality.

Cassens and Newbold (1967) found that rigor mortis onset is hastened with the fall of pre-rigor muscle temperature from 5°C to 1°C. As expected, glycolytic rates and adenosine triphosphate hydrolysis were also found to be speeded up (Newbold and Scopes, 1967). These two studies show that cold shortening is coupled to ATP hydrolysis, the most likely explanation being that this is potentiated by Ca^{++} (Davey and Gilbert, 1974). Davey and Gilbert (1974) further reported that the build up of Ca^{++} sufficient to cause cold shortening results from an upset in the complicated ionic balance across the muscle cell membranes. The lack of muscle shortening pre-rigor at temperatures of 20°C and 30°C can be explained by the fact that the activity of the calcium pump within the sarcoplasmic

reticulum membranes, which is relatively high at these temperatures (Whiting, 1980), keeps the Ca^{++} concentration around the myofilaments low enough to maintain the blocking effect of the tropomyosin-troponin system on the myosin-actin interaction and consequently prevents muscular contraction. The pre-rigor tissue shortened considerably more than that in which rigor was established, but its cooking loss was less; it was also significantly more tender, particularly if cooked within about 3 hours of slaughter (Cia and Marsh, 1976).

II. TEXTURAL PROPERTIES

Textural properties of restructured meat products are of extreme importance especially for consumer acceptance. Textural properties of intact muscle are not closely duplicated by restructured meat products. One of the major concerns of researchers has been to produce a restructured product which closely resembles textural properties of intact muscle steaks.

Bind

The ability of meat pieces and chunks to effectively bind together to resemble an intact muscle has been studied extensively. Sato and Nakayama (1970) established that the binding quality of meat is the most important index for measuring the quality of the product. The bind between chunks of meat has been described as a heat mediated reaction (Schnell *et al.*, 1970; Vadehra and Baker, 1970; Wollen, 1971; Schmidt, 1978), since meat in the raw form does not show binding to any extent. Schnell *et al.* (1970), Acton (1972b), and Schmidt (1978) found that the binding is a complex

phenomenon involving water binding cellular destruction, the release of intracellular materials, and physical and chemical changes in the salt soluble proteins produced by heating. Binding is a complex reaction involving simultaneous changes of more than one factor in many meat characteristics (Vadehra and Baker, 1970; Acton, 1972b). Hansen *et al.* (1966), Hamm (1970a), Kotter and Fischer (1975) and Theno *et al.* (1978b) concluded that the binding between chunks of meat is a phenomenon involving structural rearrangement of the solubilized meat proteins. The protein coagulates and the muscle pieces are held together by a loose protein matrix of the realigned myofibrillar proteins, connective tissue, fat, water (Hansen, 1960; Kotter and Fischer, 1975; Siegel *et al.*, 1978a), and pieces of broken muscle fibers (Hansen, 1960). Factors affecting the ability of meat to emulsify fat in a saline system include the extent to which meat is comminuted, the proportion of saline phase, the rates of addition of fat (Swift *et al.*, 1961), mixing (Swift *et al.*, 1961; Pepper and Schmidt, 1975; Booren *et al.*, 1979) and temperature (Swift *et al.*, 1961; Bard, 1965). It appears that when muscle fibers and extracted proteins form an intermingled continuum between adjacent meat surfaces, maximum binding occurs (Trout and Schmidt, 1984). The work of Huffman (1980) showed that thin slices of muscle (which can produce a muscle fiber continuum) when added to restructured meat products, combined with extracted meat proteins to form a strong cohesive bond.

Muscle proteins can be divided into three general categories: 1) sarcoplasmic or those which can be extracted with very low ionic strength solutions; 2) connective tissue or those not salt soluble and 3) myofibrillar or those which are salt soluble (Coon, 1979). Coon (1979) further stated

that the primary myofibrillar proteins were myosin (50 to 55%), actin (15 to 20%), tropomyosin, the troponins and the actinins. When the muscle dies, potassium ions (by diffusion) and adenosine triphosphate (ATP) (by enzymatic breakdown) are removed from myosin (Wierbicki *et al.*, 1954). Actin then combines with myosin to form actomyosin which is intensive and confers on the muscle the rigid condition of rigor mortis. The myofibrillar proteins, particularly myosin, have been found to be the best binding agents in a product like sectioned and formed beef steaks (Schnell *et al.*, 1970; Vadehra and Baker, 1970; Acton, 1972b; Macfarlane *et al.*, 1977; Ford *et al.*, 1978; Siegel *et al.*, 1978a), sausage products (Hansen, 1960; Fukazawa *et al.*, 1961b), and cured porcine muscle (Theno *et al.*, 1978a). The salt-soluble proteins become highly concentrated between the chunks of meat in the restructured product (Schnell *et al.*, 1970; Vadehra and Baker, 1970; Siegel *et al.*, 1978a,b). However, the effectiveness and efficiency of the meat proteins vary with type and concentration of protein (Swift *et al.*, 1961).

Macfarlane *et al.* (1977) compared the ability of myosin, actomyosin and sarcoplasmic proteins to bind pieces of meat together. When myosin was added between pieces of meat that had not been previously subjected to mechanical agitation, it was able to bond the meat pieces to each other at salt concentrations of 0.2 to 1.4 M. They further showed that actomyosin was found to match myosin in that respect only at high concentrations of 1.2 to 1.4 M. The addition of sarcoplasmic proteins to the myosin binder, enhanced binding at no added salt, did not affect it at 0.2 M salt and decreased it at high salt concentrations. Therefore, sarcoplasmic proteins, themselves, exhibited no binding ability (Macfarlane *et al.*, 1977). By

increasing the amount of salt-soluble proteins the processor can increase cook yields (Reynolds *et al.*, 1978), have less product failure due to more stable emulsions, and have a more desirable product due to enhanced binding characteristics in sectioned and formed products (Siegel *et al.*, 1978b). The efficiency of extraction depends on pH, ionic strength, rigor condition, cations, agitation as well as temperature (Solomon and Schmidt, 1980). By increasing the extent of comminution, the amount of protein extracted increased but it did not necessarily lead to an increased tensile strength or cook yield (Acton, 1972a; Trout and Schmidt, 1984). Furthermore, Trautman (1964) stated that salt-soluble proteins were greatly influenced by time postmortem. He suggested that: 1) the proteins had a significant role in fat separation, and 2) the effectiveness of the proteins was influenced by time postmortem.

Salt plays a vital role in the formation of a "glue" in the form of a protein exudate between meat pieces. Increasing salt minimized the effect that lowering pH had on the solubility of the proteins and, hence, favorably affected emulsifying capacity (Swift and Sulzbacher, 1963) and increased the binding quality of processed meats (Theno *et al.*, 1978a). Salt not only aided meat particle binding, but also reduced loss during heating (Wierbicki *et al.*, 1957). Moore *et al.* (1976) showed binding strength increased as salt increased from 1% to 3%. Restructured chops provided evidence of improved binding with the addition of salt over control chops or chops containing tripolyphosphates (TPP) (Huffman and Cordray, 1979). The addition of 1% salt produced quite a noticeable increase in the amount of exudate produced as seen when compared to no salt (Theno *et al.*, 1978b). Bard (1965) and Gillett *et al.*, (1977) reported the maximum extraction of

myofibrillar proteins occurred at 10% salt. However, 1% salt alone was not enough to solubilize the myofibrillar proteins as the ham rolls did not exhibit acceptable characteristics (Theno *et al.*, 1978b).

Maesso *et al.*, (1970a) reported that salt and hexametaphosphate (HMP) enhanced the extraction of salt-soluble protein and resulted in a significant increase in binding of meat pieces into a unit system. Trout and Schmidt (1984) reported that an increase in salt and phosphate levels produced increases ($P < 0.001$) in tensile strength. Chops with no additives had significantly lower bind as compared to the salt plus TPP chops (Huffman and Cordray, 1979). Ham rolls prepared using no salt or phosphates failed to provide adequate binding even after 24 hr of massage while the addition of salt and phosphates dramatically increased binding and product quality (Theno *et al.*, 1978b). This agrees with Moore *et al.* (1976). Theno *et al.* (1978b) further stated that sectioned and formed hams were found to possess good binding characteristics with a high degree of alignment with a salt and phosphate level greater than or equal to 2% and 0.5% respectively. Salt and phosphate can contribute to the disruption of muscle fibers caused by massaging, solubilization of the myofibrillar proteins and the production of an exudate rich in solubilized proteins rather than just broken meat pieces (Theno *et al.*, 1978c).

The addition of phosphate alone greatly increased binding strength (Swift and Ellis, 1957; Fukazawa *et al.*, 1961a,b; Fronning, 1966). Schnell *et al.* (1970) confirmed this by demonstrating that the addition of salt increased the cook yield in poultry loaves and also that salt and phosphates increased binding in the loaf slices. The addition of 0.5% phosphate even in the absence of salt aids in solubilizing the myofibrillar proteins (Fukazawa *et*

al., 1961a,b). Chang *et al.* (1961) reported that when concentrations approached 0.5% sodium tripolyphosphate (STPP), flavor and appearance evaluations increased. At concentrations higher than 0.5% STPP, flavor and appearance scores deteriorated. In all cases STPP was reported to successfully serve as an antioxidant and improve the odor of frozen meat. Fukazawa *et al.* (1961b) stated that the addition of pyrophosphate (PP) resulted in the greatest amount of extracted protein which was greater than TPP or HMP. Trout and Schmidt (1984) stated the effectiveness of the phosphates were: PP > STPP > sodium tetrapolyphosphate > HMP on bind of restructured beef rolls. Schwartz and Mandigo (1976) stated that among 20 combination levels of salt and STPP, 0.75% salt and 0.125% STPP were the most desirable for producing restructured pork. However, Trout and Schmidt (1984) tend to support the hypothesis that the main role of phosphate is to increase ionic strength and pH.

The myofibrillar proteins, especially myosin, have been shown to be excellent binders. The use of salt, phosphate and mechanical agitation enhance binding by increased extraction of myosin (Schmidt, 1978). Myosin was superior to actomyosin in binding strength at ionic strengths up to 1.0 M [(P=0.05-0.001) Macfarlane *et al.*, 1977]. This research further showed that sarcoplasmic protein significantly (P=0.05) enhanced the binding strength of myosin at low ionic strengths (no added NaCl). It decreased the binding strength at higher salt concentrations possibly because of a salt induced denaturation or precipitation of sarcoplasmic proteins (Macfarlane *et al.*, 1977). Solomon and Schmidt (1980) reported significantly greater amounts of crude myosin were obtained due to vacuum treatment (P<.05) and with increased mixing time (P<.01) but the total

amount of protein extracted was not affected. Polyphosphates break the bonds found between actin and myosin (the actomyosin complex formed at rigor) allowing interfilament spaces to form (Theno *et al.*, 1978c). At the same time they alter the ionic strength of the sarcoplasm thus increasing electrostatic repulsions between filaments and further increasing the amount of space available for water binding.

Pre-rigor muscle extraction produced greater ($P<.01$) amounts of crude myosin than post-rigor muscle with extractability of crude myosin from the former increased by 65.62% over post-rigor (Solomon and Schmidt, 1980). They further showed that mixing time had a linear effect on the amount of crude myosin produced from post-rigor meat ($P<.01$). There was an average increase of 2.29g protein of crude myosin for each hour of mixing. Trout and Schmidt (1984) reported that increasing the extraction of myosin and/or other salt soluble proteins was effective in increasing tensile strength only to a point, beyond this it had no beneficial effect.

Goodno and Swenson (1975) hypothesized that during thermal processing the myosin molecule unravels and exposes unprotonated histidine residues. The residues absorb protons from the solvent with a resultant increase in pH. The differences in thermally induced pH increases are due to the different buffering abilities of the phosphates (Ellinger, 1972). Swift and Sulzbacher (1963) showed that at all pH levels (4.0 to 7.85), and with increasing concentrations of salt the emulsifying capacity of these proteins increased. The effect of salt in the pH range of from 5.0 to 6.0 can logically be explained by assuming that an increased concentration of salt lowered the pH to a point at which the salt-soluble proteins lost solubility; consequently,

an increased content of salt enhanced emulsifying capacity by maintaining more thoroughly dispersed proteins (Swift and Sulzbacher, 1963). They further stated that an increasing concentration of salt increased emulsifying capacity at pH values ranging from approximately 5.4 to 6.0, but had no significant effect at low or high pH values (5 or 7 to 8). Maesso *et al.* (1970b) showed that adjustment of meat pH from 5.0 up to 8.0 increases tissue binding. Hegarty *et al.* (1964) reported the greatest emulsifying capacity to least as follows: actin in the absence of salt, myosin, actomyosin, sarcoplasmic proteins and actin in 0.3 M salt.

Salt-soluble rather than the water soluble proteins are more effective for increased meat binding (Hansen, 1960; Fukazawa *et al.*, 1961a; Swift *et al.*, 1961; Trautman, 1964, Schnell *et al.*, 1970; Acton and McCaskill, 1972) and cook yields (Acton and McCaskill, 1972). However, Swift and Sulzbacher (1963) showed that water-soluble proteins exert their maximum activity at a lower pH than is normally obtained in meat and respond favorably to higher concentrations of NaCl than those desired for flavoring purposes.

The development of binding strength among meat particles is clearly temperature dependent (Acton, 1972b). Binding strength increased ($P < .05$) as the internal temperature increased in the range of 35-82°C with maximum binding strength being attained at 82°C. Further heating to an internal temperature of 94°C caused a reduction ($P < .05$) in the binding strength when compared to that observed at 82°C (Acton; 1972b). Booren *et al.* (1979) reported the myofibrillar proteins in the exudate were higher for all treatments than previously reported for sectioned and formed steaks. This is explained by the lower processing temperature of -2°C which is

closer to the optimum temperature for myofibrillar protein extraction (Bard, 1965). Bard (1965) reported that a greater amount of salt-soluble protein was extracted at -5°C from beef or pork. However, Gillett *et al.* (1977) showed that the maximum extraction of water-soluble plus salt-soluble proteins occurred at 7.2°C . Acton (1972b) found that there was no significant change in the quantity of salt-soluble proteins extracted between $4-35^{\circ}\text{C}$ from chicken meat loaves. Denaturation decreased the extractability of myofibrillar proteins and denaturation started at 30°C and mainly occurred from $40-60^{\circ}\text{C}$ (Hamm, 1977b). Acton (1972b) showed no appreciable binding below 35°C and binding strength decreased above 82°C .

Coagulation of contractile proteins with little change in connective tissue is suggested by the higher firmness and cohesiveness values at the 60°C samples (Bouton *et al.*, 1981). Continued heating resulted in collagen solubilization which led to decreased cohesiveness scores although this effect was overcome by the increased coagulation of contractile proteins at the 80°C end point (Paul *et al.*, 1973).

Beef rolls made from hot-boned or cold-boned beef with salt-phosphate treatment displayed higher binding strengths and cook yields than corresponding salt treated rolls (Pepper and Schmidt, 1975). The rolls prepared from hot-boned beef gave higher cook yields (Pepper and Schmidt, 1975; Kardouche *et al.*, 1978) but lower binding strengths in both salt-phosphate and salt treatments than did the rolls prepared from cold-boned beef (Pepper and Schmidt, 1975). Trautman (1964) reported that the post-rigor extract fat emulsion separated immediately and proceeded very rapidly to completion at 30 minutes while the pre-rigor extract fat emulsion

did not separate for several minutes after blending and proceeded less rapidly to completion (approximately 90 minutes). The difference in separation time between the pre-rigor and post-rigor salt soluble protein-fat emulsions indicated that the pre-rigor proteins are several times as effective in fat emulsification as the post-rigor proteins (Trautman, 1964).

Tenderness

For several years, tenderness of restructured meat items has been of great concern for researchers. Texture is synonymous with tenderness which is made up of two structural components - muscle fibers and connective tissue (Cover *et al.*, 1962; Brady and Hunecke, 1985). Because of these 2 components, the measurements of meat tenderness is difficult (Cover *et al.* 1962). Tenderness is the predominant meat quality determinant and has been thoroughly considered by many (Moeller *et al.*, 1977; Cross *et al.*, 1978). However, juiciness has been reported to be related positively to tenderness in some instances but negatively in others (Cover *et al.*, 1962). The rate of tenderization has been shown to be dependent on temperatures of holding or ripening. But beef taken immediately at slaughter and before rigor mortis had set in was more tender than beef in rigor mortis (Wierbicki *et al.*, 1954).

Warner-Bratzler shear values and penetration hardness, cohesiveness and chewiness values are all considered objective indicators of tenderness of meat samples but may not represent the same components of texture. Costello (1985) stated that Warner-Bratzler shear values did not significantly correlate with sensory scores for softness and chewiness. However, penetration hardness and chewiness did significantly correlate

with scores for softness, suggesting that penetration testing may be more appropriate for studying the textural characteristics of restructured meat than is Warner-Bratzler shear testing (Costello, 1985). Warner-Bratzler shear values were highest ($P < .01$) in the pre-rigor restructured pork product at 32.2°C and decreased with decreased processing temperature which was indicative of binding ability (Chesney *et al.*, 1978). Wierbicki *et al.* (1954) stated that connective tissue does not appear to contribute to increases in tenderness on postmortem ageing inasmuch as total alkali insoluble protein does not change. The shearing resistance of cooked meat has been shown to be due to the presence of both connective tissue and actomyosin (Marsh and Leet, 1966b).

Tenderness measured by the Lee Kramer Shear cell increased with increased mixing times [vacuum vs no vacuum; 0, 6, 8, 12, 16 and 18 minutes (Booren *et al.*, 1981a,b)]. Similar increases in tenderness have also been reported due to tumbling and massaging (Schmidt, 1978). Huffman and Cordray (1979) showed that Instron values for the Lee Kramer compression test were higher ($P < .05$) for pork loin chops than for restructured pork chops which agrees with sensory panel evaluation. They further stated that restructured pork chops with added salt had lower compression values than those without added salt while the addition of TPP had little effect. However in 1981, Huffman *et al.* reported that flaked and formed hamburger patties containing salt, TPP, or both required more shear force than the control (no salt or TPP) due to the increase in binding and cohesiveness. Neer and Mandigo (1974a) stated that as salt and TPP were increased simultaneously, texture and general acceptability improved

and Carpenter *et al.* (1961) reported that phosphates increased tenderization of both beef and pork.

Penetration hardness increased as end point temperature was increased while compression (hardness) increased significantly between 60° and 70°C but showed a slight but non-significant decrease between 70° and 80°C (Brady and Hunecke, 1985). Penetration and compression tests appear to be better indicators of connective tissue changes than shear type test (Bouton *et al.*, 1975).

Marsh and Carse (1974) reported that ultimate actomyosin configuration is a major determinant of meat tenderness, since the complex pattern of tenderness variation with length change can be explained entirely in terms of the varying degree of overlap of actin and myosin filaments. Toughening is related directly to the interaction between actin and myosin (Marsh and Leet, 1966b; Marsh and Carse, 1974; Dutson and Lawrie, 1974) during rigor onset. Marsh and Carse (1974) further showed that meat tenderness is strongly influenced by a sliding filament mechanism, and that actomyosin is a major contributor to toughness.

pH has also been shown to play a major role in tenderness of meat. Bouton *et al.* (1957) showed that beef muscle was least tender when the ultimate pH was about 6.0 and increased in tenderness as the ultimate pH increased above or decreased below this value. In contrast, the tenderness of rabbit (Miles and Lawrie, 1970), sheep (Bouton *et al.*, 1971) and fish (Kelly *et al.*, 1966) has been shown to be greater with higher ultimate pH. In chicken muscle, it has been shown that toughness is increased by treatments which increase the rate of pH (and ATP) fall (Khan and Nakamura, 1970). pH has not been shown to change with salt (Neer and Mandigo, 1977), which

conflicts with earlier work done by Wierbicki *et al.* (1957). However, as the amount of STPP increased pH was shown to increase ($P < .01$) linearly (Neer and Mandigo, 1977).

pH of beef has a significant effect on the amount of salt-soluble protein which can be extracted. As pH increased, the amount of protein extracted also increased. The amount of salt-soluble protein was 50% greater in pre-rigor beef than in beef 48 hr postmortem (Saffle and Galbreath, 1964). (The pH was adjusted to 6.0 so the increase in extractable protein was not due to pH). This is due to the fact that any rise in the pH would be away from the isoelectric point of the meat proteins, and thus would result in an increase in the amount of proteins which could be extracted (Saffle and Galbreath, 1964).

Cohesiveness

Ford *et al.* (1978) stated that for sectioned and formed products, protein functionality means increased cohesion between meat chunks. Only a certain amount of extracted myofibrillar protein is needed to produce a cohesive bond between the meat pieces and any additional extracted protein had no beneficial effect (Trout and Schmidt, 1984). Swift and Ellis (1957) showed that cohesiveness of bologna containing added phosphates was significantly greater than that of bologna cured only with ordinary curing agents. The addition of three combinations of phosphates markedly increased the relative binding of sausage components, as indicated by the effect of the additives in increasing the tensile strength or cohesion of meat (Swift and Ellis, 1957). They also reported that markedly increased tensile

strength values were obtained on increasing concentration of salt from 0 to approximately 3%.

Cook Yield

Swift and Ellis (1957) stated that tetrasodium pyrophosphate, sodium acid pyrophosphate or sodium hexametaphosphate had no significant effect on moisture losses, or shrinkage, when sausages were smoked and cooked to a maximum internal temperature of 65.6°C. In contrast, bologna containing added phosphates shrunk significantly less than bologna treated only with normal curing agents, when heated to a higher maximum internal temperature of 71.1°C (Swift and Ellis, 1957). They also stated that phosphates can help decrease the time required in smoking and cooking. However, Neer and Mandigo (1974a, 1977), over all levels of STPP used (0.0 to 0.50%), showed that smokehouse yields increased ($P < .01$) linearly, that 0.25% STPP resulted in maximum cooking yields, products became darker, and organoleptic evaluations improved. This is in agreement with work done by Maesso *et al.* (1970a) and Moore *et al.* (1976).

Salt increased the retention of moisture (Swift and Ellis, 1957; Acton, 1972a; Schwartz and Mandigo, 1976; Huffman *et al.*, 1981) and was responsible for the development of heat during comminution (Swift and Ellis, 1957). Neer and Mandigo (1977) reported that smokehouse and cooking yields increased linearly ($P < .01$) to 2.25% salt then decreased at the 3.0% level. However, Moore *et al.* (1976) showed that cook yields increased from 79% with 1% salt to 93% with 3% salt.

Shults and Wierbicki (1973) showed that concentrations of 0.25-0.5% STPP with salt were most advantageous for reducing smokehouse and

cooking loss. When combinations of both salt and STPP were tested, the response was additive and greater than either salt or STPP used alone (Schnell *et al.*, 1970; Shults and Wierbicki, 1973; Neer and Mandigo, 1974a; Pepper and Schmidt, 1975). Pepper and Schmidt (1975) further stated that for both salt and salt-phosphate treated beef rolls, the highest cook yield occurred at an internal temperature of 68°C. Chops containing salt plus TPP had less cooking loss than other treatment groups (Huffman and Cordray, 1979) which agrees with results obtained by (Schnell *et al.*, 1970; Shults and Wierbicki, 1973; Neer and Mandigo 1977).

Trout and Schmidt (1984) reported that type and concentration of phosphate used and the concentration of salt used had the greatest influence on cook yield and tensile strength and could explain 87 to 96% of the variation that occurred. They showed that pyrophosphate was more effective than TPP ($P < .05$) on cook yield and tensile strength, and the effectiveness of both phosphates increased with increasing phosphate concentrations ($P < .001$). The effectiveness of the different phosphates progressively reduced with increasing number average phosphate chain length and was mainly a result of the reduction in ionic strength and pH (Trout and Schmidt, 1984). Increasing the salt or phosphate concentrations increased the effectiveness of all phosphate types until a maximum value was reached.

Schnell *et al.* (1970) and Acton (1972a) showed that cooking loss decreased and binding strength increased in chicken loaves as tissue rupture increased. Acton and McCaskill (1972) stated that salt-soluble proteins in poultry meat were responsible for the increase in cook yield and binding strength as opposed to the water-soluble proteins (Acton, 1972b) and

cooking loss increased by 120% between 82 to 94°C. In general, cooking loss significantly decreased while binding strength significantly increased when grinding was utilized for tissue break down (Acton, 1972a). Cross *et al.* (1980a) reported that as percent fat increased in raw beef patties, fat loss during cooking also increased. However, total cooking loss was not significantly affected by fat level ($P<.05$).

Processing, hot vs cold, also affects cook yields in restructured meat systems. Cross *et al.* (1979a) reported that total cooking loss was significantly less in hot processed patties when compared to chilled patties (33.85 vs 41.06%, respectively). They further stated that percent moisture in cooked patties was significantly higher from hot than from chilled meat and can be explained by the differences in cooking loss. This water loss was reflected in lower juiciness and tenderness ratings for patties from chilled meat and could contribute to more waste on the plate. Huffman and Cordray (1979) reported that cooking loss was decreased by the addition of salt alone (for pre-rigor chops) and salt and TPP in combination for both pre- and post-rigor chops. They also reported that cooking loss for pre-rigor pork with salt and TPP combined was significantly lower (14.8%) than all other treatment groups. This has been further supported by Schnell *et al.* (1970), Shults and Wierbicki (1973), and Neer and Mandigo (1977). And, Hansen and Mandigo (1972) reported less cooking loss for blends containing greater quantities of pre-rigor pork.

Water Holding Capacity

The addition of salt to processed meat products increases WHC and also helps to significantly reduce cooking losses (Hellendoorn, 1962; Schnell

et al., 1970; Shults and Wierbicki, 1973; Neer and Mandigo, 1974a; Pepper and Schmidt, 1975; Macfarlane *et al.*, 1977; Neer and Mandigo, 1977). Wierbicki *et al.* (1954, 1957) showed that as the concentration of salt in meat was increased WHC values and the amount of drip loss decreased. The addition of polyphosphates to meat products has also been shown to increase WHC and facilitate protein extraction (Fukazawa *et al.*, 1961b; Hamm, 1970b; Neer and Mandigo, 1974a; Pepper and Schmidt, 1975; Macfarlane *et al.*, 1977). Rahelic *et al.* (1966) reported that in addition to increasing WHC, phosphates retained the cured color of pork by inhibiting the development of rancidity. Mahon and Schneider (1968) showed that STPP was the best phosphate for red meat. However, the contribution of the specific phosphate effect on WHC, either the protein binding effect or the actomyosin dissociating effect also depends on the type of phosphate used (Trout and Schmidt, 1984).

When STPP and salt were used together, the WHC increased beyond that seen with either of the two ingredients separately (Neer and Mandigo, 1974a). However, Schwartz and Mandigo (1976) reported that WHC was not changed by addition of salt or STPP. This is in disagreement with work by Wierbicki *et al.* (1957) and in disagreement with Sulzbacher *et al.* (1960) for salt and Sherman (1961) for salt and phosphate. Hamm (1970b) has summarized the effect of phosphates on the increase in WHC (and presumably other functional properties such as binding strength) as being due to : (a) an increase in pH, (b) an increase in ionic strength, (c) the ability of phosphates to bind to meat proteins, and (d) the ability of phosphates to dissociate actomyosin into actin and myosin. All of the phosphates used in meat products increase both pH and ionic strength [factors that are known to

increase functionality, (Schmidt and Trout, 1982)] with the extent of increase depending on the type and concentration of phosphate used. Concerning temperature effects in the range of 0 to 30°C, all phenomena concerning the influence of postmortem changes (pH fall, rigor development) on WHC of meat are independent of temperature; cold shortening has no effect (Honikel *et al.*, 1981b).

TBA

Wistreich (1972) and Neer and Mandigo (1977) reported that low levels of salt (0.0%-2.25%) initiated oxidative rancidity thus yielding unacceptable products. The highest salt level (3.0%) decreased rancidity as indicated by higher iodine numbers and lower 2-thiobarbituric acid (TBA) values. Schwartz and Mandigo (1976) reported that added salt increased TBA values, improved cook color, aroma, flavor and eating texture and decreased raw color. Watts (1961) showed increased TBA values when salt was added to pork. However, Chang and Watts (1950) showed that less than 5% salt in a recipe actually inhibited rancidity. Concentrations above 15% accelerated the development of rancid products.

Booren *et al.* (1981a) stated that TBA values were higher in steaks with 0.5% salt after 90 days of storage. They further reported that TBA values (averaged over all treatments) increased due to salt addition which is consistent with previous work done with restructured flaked products (Schwartz and Mandigo, 1976).

Chang *et al.* (1961), Rahelic *et al.* (1966) and Neer and Mandigo (1977) showed significant retardation in oxidative rancidity due to STPP. The antioxidant effect of STPP was explained by Landes (1972) that

phosphates act as synergistic antioxidants in aqueous fat systems after the hemoglobin has been heat coagulated. Furthermore, Schwartz and Mandigo (1976) reported that as STPP increased TBA values also increased. The TBA value of the product without STPP was less ($P < .01$) than those for products which contained STPP. TBA values among products containing STPP were not different. In regard to temperature, Drerup *et al.* (1981) reported that the susceptibility to autoxidation at 0°C as measured by TBA values was reduced in pre-rigor ground and salted product compared with sausage which was pre-rigor ground-post-rigor salted or ground and salted post-rigor.

Fat Percent

Steaks that contained 25% fat had approximately 33% total cooking losses which was significantly greater than the total cooking losses of steaks with 15 or 20% fat (Costello *et al.*, 1985). Cross *et al.* (1980a) reported that total cooking losses in ground beef patties were not affected by fat level. However, as the fat level increased, fat losses increased while water losses decreased. Costello *et al.* (1985) further reported that as the fat level increased (15, 20 and 25%) in the steaks tenderness, moisture release and greasiness also increased while off-flavors of the steaks decreased. Miller *et al.* (1968) and Chesney *et al.* (1978) found a decrease in WHC as fat level increased due to the increase in the moisture:protein ratio.

Penetration hardness and chewiness values decreased as the amount of fat increased (Costello *et al.*, 1985). The steaks with the higher fat levels were easier to penetrate with a flat probe and had a lower chewiness value

than did steaks that contained the lower amounts of fat. Steaks that contained 25% fat were more cohesive than were steaks with 15% fat.

Less force was required to shear steaks that contained 20 and 25% fat than was required for steaks that contained 15% fat (Costello *et al.*, 1985). Huffman and Powell (1970) reported that ground beef patties with 35% fat required less force to shear than did patties that contained 15 or 25% fat. Cross and Stanfield (1976) discussed similar results with beef patties that contained 20 and 30% fat and which were evaluated by panelists who cut the patties with a knife.

Generally, increasing fat levels (16, 20, 24 and 28% fat) in formulations resulted in higher tenderness and juiciness scores and ratings indicative of lower connective tissue amount. Neither collagen content nor total cooking loss was significantly affected by fat level (Cross *et al.*, 1980a).

Berry *et al.* (1979) reported that ground beef formulated to 28% fat was scored as having more off-odor than the 16% fat product. The use of kidney and brisket fat resulted in higher aerobic bacterial counts at the initiation of the shelf life study. However, the rate of bacterial increase over a 3 day display period was less for product containing these two fat sources. However, Cross *et al.* (1980a) stated that tenderness, juiciness, connective tissue, flavor intensity, mouth coating and total cooking loss were not significantly affected by fat source. Saffle and Galbreath (1964) showed that fat had no effect on the percent protein which could be extracted for determining the percent of meat protein which was salt soluble.

CHAPTER 3

MATERIALS AND METHODS

I. SAMPLE PREPARATION

Raw Materials and Preparation of Samples

Approximately 50 pounds of U.S. Utility cow top rounds (semimembranosus) were acquired from Lay Packing Company, Knoxville, Tennessee. The carcasses from which these muscles were excised were chilled prior to boning and represented the post-rigor or conventionally processed beef. All external fat was removed. All of the post-rigor top rounds were flaked by an Urschel Comitrol (Model 3600) utilizing the 0.750 inch (19 mm) head. At this time the pH was measured utilizing a Fisher Accumet pH meter (Model 600).

Forty pounds of the flaked post-rigor meat was placed in a Lyco vacuum tumbler (Model 40) drum. One percent salt and 0.5% sodium tripolyphosphate (STPP) was added. The meat was vacuum tumbled 2 hours at 15 rpm (Ghavimi *et al.*, 1985) in a 2.2°C cooler. Ghavimi *et al.* (1985) recommended a speed of 15 rpm for maximum protein extraction and bindability. Additionally, they reported that superior results were achieved with use of a smaller size diameter tumbler. After tumbling, the pH was read and the meat was held until the following day for formulating.

Four beef plates were also acquired at this time. These were boned and ground through a 2.54 cm (1.0 inch) plate and mixed in a Leland ribbon

mixer (Model #L-100 DA) for 10 minutes. The fat was placed in trays, layered approximately 2.54 cm (1 inch) thick and stored in a blast freezer (-28°C) until tempered. The tempered fat was ground through a 3/8 inch plate and chopped in a Fatosa bowl chopper for approximately 30 to 45 seconds to yield a finely chopped fat source. The fat was stored in a blast freezer (-28°C) until needed for formulating.

Approximately 50 pounds of pre-rigor or hot processed top round muscle (semimembranosus) from U.S. Utility cow carcasses was acquired from Lay Packing Company on the following day. The muscles were excised approximately 45 minutes to 1 hour postmortem. All external fat was removed and the meat was flaked by an Urschel Comitrol (Model 3600) utilizing the 0.750 inch (19mm) head. The pH of the meat was measured at this time.

Forty pounds of flaked, pre-rigor meat was placed in a vacuum tumbler along with salt and STPP (1.0% and 0.5%, respectively) and tumbled for 2 hours at 15 rpm (Ghavimi *et al*, 1985) after which the pH of the forty pound batch was measured. Fat percentages for the beef plate (fat source) and post- and pre-rigor meat were determined by the Modified Babcock method (Ockerman, 1969).

The meat (both pre- and post-rigor) percentages (Table 1), fat, salt and STPP were mixed in a Hobart mixer (Model A-200; speed #1) for 2 1/2 minutes. The pounds of fat and lean for each treatment were calculated through the use of a Pearson Square (Terrell, 1971). Following mixing, the pH was measured for treatments 1, 5, 6 and 10 (Table 1). Each treatment was then hand stuffed into an E-Z smoke casing (Viskase Corporation, Chicago, IL) and placed between ham presses for cooking. The beef rolls

Table 1. Description of Experimental Treatments.

	Fat Content									
	10%					20%				
Treatment # ¹	1	2	3	4	5	6	7	8	9	10
% Post-rigor	100	75	50	25	0	100	75	50	25	0
% Pre-rigor	0	25	50	75	100	0	25	50	75	100

¹All treatments contained 1.0% salt, 0.5% STPP and were all 0.750 inch flake sizes.

were cooked by dry heat in a smokehouse to an internal temperature of 62.8°C (150°C-1hr; 170°C-1hr; 200°C-remainder of time until internal temperature was reached). Once cooked the beef rolls were allowed to chill in a 2.2°C cooler and then vacuum packaged in barrier heat shrink bags utilizing a Cryovac double chamber vacuum packaging machine [(Model 8210), Cryovac Division, W.R. Grace & Co. Duncan, SC] until evaluated.

II. ANALYSIS OF SAMPLES

pH

Meat samples were taken from each of the forty pound pre- and post-rigor batches before the addition of salt and STPP and after the meat had been vacuum tumbled. Also, meat samples were taken from treatments 1, 5, 6 and 10 just before stuffing and after cooking (chilled product). All meat samples were ground 3 times (Hobart grinder: Model 4722) through a 0.32 cm (1/8 inch) plate. A 10 g sample was combined with 40 ml of distilled water and thoroughly mixed before reading. The pH meter (Fisher

Accumeter; Model 600) was standardized to a pH of 6.0 (Ricco Chemical Company, Arlington, TX) at a temperature of 25°C. Each sample was done in triplicate.

Proximate Composition

Moisture and fat analyses were run on both raw and cooked products according to AOAC (1984) procedure. Raw meat samples were taken for each treatment before stuffing, ground three times through a 0.32 cm (1/8 inch) plate, put in Whirl- PakTM bags and stored in a blast freezer (-28°C) until analyzed. Cooked, chilled samples were taken for each treatment and handled in the same manner as the raw samples.

Moisture content of each treatment was determined in triplicate by the vacuum oven drying procedure. Two gram samples were enclosed in sample envelopes made from Whatman No. 1 filter paper and dried according to method specifications (AOAC, 1984). These same samples were used for fat analysis through the use of the Soxhlet method.

Cook Yields

Weights were taken on each prepared beef roll before cooking and on the chilled, cooked product. Smokehouse yields were determined by the following equation:

$$SHY = \frac{CCWt}{UCWt} * 100$$

where SHY = smokehouse yield
CCWt = cooked, chilled weight
UCWt = uncooked weight

Expressible Moisture Index

The water holding capacity for the samples was determined by using modifications of the methods reported by Wierbicki and Deatherage (1958) and Miller and Harrison (1965). Raw meat samples were taken of each treatment before stuffing, placed in Whirl-PakTM bags and stored in a blast freezer (-28°C) until analyzed. Cooked samples were taken from the chilled, cooked treatments and stored the same as the raw samples. All samples (raw and cooked) were allowed to thaw over night in a cooler (2.2°C). A 400 to 600 mg sample of each treatment (raw and cooked) was placed in the center of a Whatman No. 1 filter paper (15.0 cm diameter) which had previously been dried at approximately 107°C overnight. Filter papers were stacked between two pieces of 15.2 cm by 15.2 cm plexiglass plates and subjected to 5,000 psi pressure for 5 minutes using the Carver Laboratory Press (Model C). Samples were analyzed in duplicate and 6 samples were pressed at a time.

After pressing, the bottom plexiglass plate was carefully removed and the circles of the meat and expressed moisture areas that appeared on the filter paper were traced to preserve their integrity. The filter paper was then xeroxed and the areas of the two circles were cut out and weighed on an analytical balance (Mettler AE 160). The weight of the pressed meat sample was subtracted from the weight of the expressed moisture plus pressed sample to calculate the weight of the expressed moisture. The result is given as the ratio of the weight of the pressed meat sample to the weight of the expressed moisture, which is the expressible moisture index (EMI).

Oxidation (TBA)

The modified distillate method (Rhee, 1978) was used for determination of lipid oxidation. A ten gram sample of meat, 5 ml of 0.5% propylgallate (PG), 5 ml of 0.5% ethylenediamine tetra-acetic acid (EDTA) and 40 ml of deionized water were blended for 2 minutes in a Virtis homogenizer (Virtis, 16 235 1) at a speed setting of 30 in a stainless steel container. Then 2.5 ml of 4N hydrochloric acid (HCl) was added to the homogenate. This diluted homogenate was quantitatively transferred to an 800 ml Kjeldahl flask using 47.5 ml of deionized water for rinsing the homogenizing flask. Boiling beads and 1 ml of antifoaming agent (Arthur H. Thomas Co. Philadelphia, PA) were added to the Kjeldahl flask. Fifty ml of the distillate was collected within 15 minutes after the onset of boiling and stored under nitrogen until analyzed for malonaldehyde (MA) content.

For preparation of the standard curve for MA determination, 5 ml of 1×10^{-4} M tetraethoxypropane (TEP) were mixed with 2.5 ml of 4N HCl and 92.5 ml of deionized water in a Kjeldahl flask, and 50 ml of distillate was collected from this solution in 15 minutes after the onset of boiling. The distillate, which was assumed to be 1×10^{-5} M MA, was used to prepare the solutions of different concentrations of the colored malonaldehyde-2-thiobarbituric acid complex used to construct the standard curve. Solutions containing 1×10^{-5} , 2×10^{-5} , 3×10^{-5} , 4×10^{-5} and 5×10^{-5} moles MA/10 ml solution were prepared by pipetting 1, 2, 3, 4 and 5 ml of the distillate from TEP, respectively, into separate test tubes. Enough deionized water was added to each test tube to bring the total volume to 5 ml. To each tube was then added 5 ml of 0.02M TBA solution, and the tubes were heated 30 to 35 minutes in a water bath for MA-TBA complex formation. The absorbance

(ABS) of each concentration of MA was determined at 532 nm. The equation of the standard curve as ABS versus MA concentration was determined by linear regression.

Five ml distillate of each treatment was analyzed in the same manner as the distillate of TEP except only 5 ml of 0.02M TBA solution was added to the test tube. The ABS of the sample was converted to mole of MA by the linear regression equation and then converted to mg MA/kg meat which is the TBA number. TBA analyses were done in duplicate on the raw sample, cooked and chilled product and after 30 days of storage (2.2°C cooler) for all treatments.

III. TEXTURAL TRAITS

Tenderness Measurement

The Instron Universal Testing machine with the Lee Kramer shear attachment was used to test the tenderness of the beef rolls. The Lee Kramer shear analysis of 4 samples for each beef roll was performed to test the kilograms of force required to shear 4-slices of meat (6.5 cm * 6.5 cm). A template (6.5 cm * 6.5 cm) was used to cut a sample out of the geometric center of a slice of meat for each treatment. Each slice of meat was .25 cm (.1 inch) thick. A 500 kg compression load cell was used with a total force across the chart being 100 kg.

Bind

The Instron Universal Testing Machine was also used to test the bind of the meat by (1) bind test using a 9.5 cm bridge, and (2) measurement of

tensile strength. A modification of Pepper and Schmidt (1975) and Coon (1982) was used where a .25 cm (.1 inch) thick slice of meat was cut to dimensions of 7 cm * 11 cm and placed across a 9.5 cm span. The force necessary to break a slice of meat bridging this span by driving a straight edge shear plate through its midpoint was recorded. The binding strength of the roll was expressed as maximum pressure per cm² of the cross-sectional area. The Instron was equipped with a 50 kg tensile load cell where total force across the chart was set at 10 kg.

Bind as determined by tensile strength on the Instron Universal Testing Machine was further tested by using a modification of a procedure described by Penfield *et al.* (1976). A template (Fig. 1) was used to cut samples from the center of .25 cm (.1 inch) thick slice of meat. All strips (6 per treatment) were 14 cm in length. A 500 g compression load cell was used with a deflection equal to 200 g.

Data was collected for 6 satisfactorily ruptured strips from each treatment. A rupture was considered satisfactory when the strip ruptured between but not at the clamps.

IV. STATISTICAL ANALYSIS

All data were analyzed through the General Linear Models procedure (SAS) with fat, combination of pre- and post-rigor meat, treatment and replication as independent variables. A Student-Newman-Keuls Mean Separation was utilized to test the range of all means. Orthogonal contrasts were also used to test differences between treatments (T). These contrasts are shown in Table 2. An explanation of the contrasts is as follows:

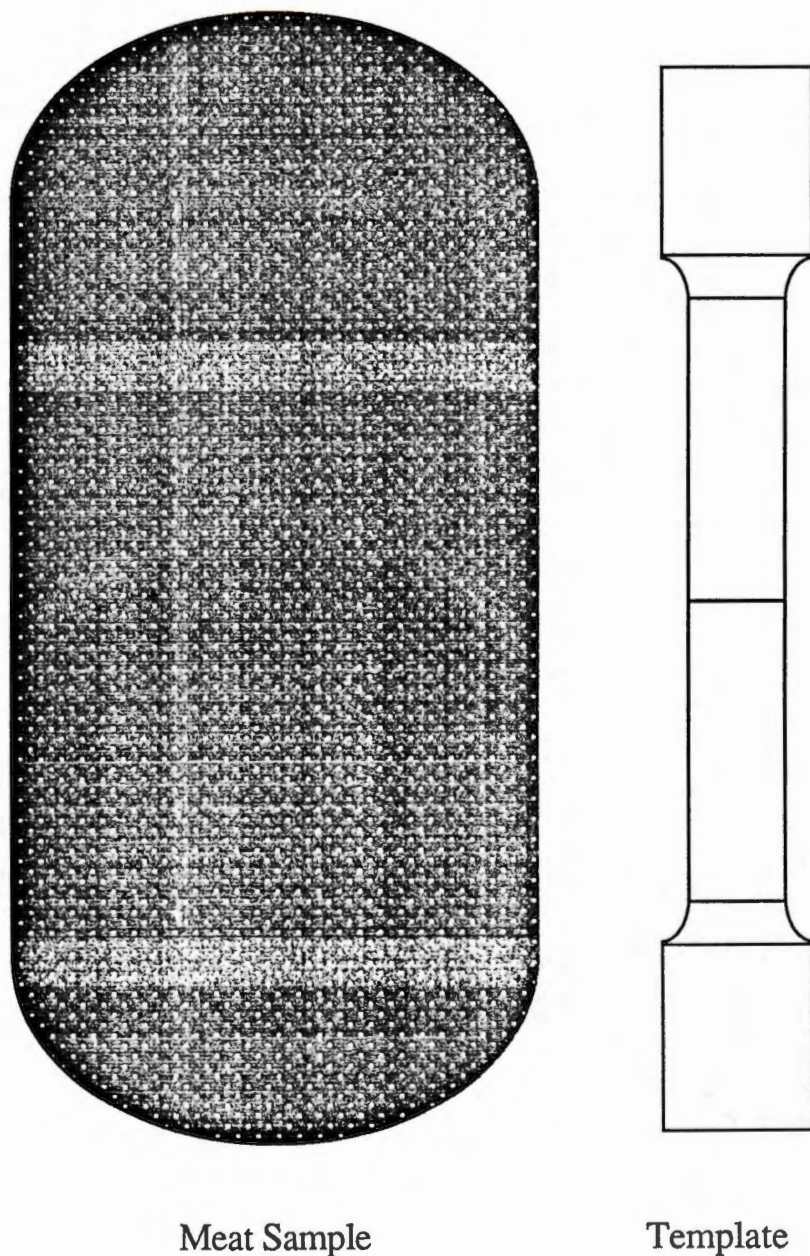


Fig 1. Tensile Strength Template.

Table 2. Orthogonal Contrast Between Treatments for Restructured Beef Rolls.

Contrast	Treatment ¹									
	1	2	3	4	5	6	7	8	9	10
1	1	0	0	0	0	-1	0	0	0	0
2	0	1	0	0	0	0	-1	0	0	0
3	0	0	1	0	0	0	0	-1	0	0
4	0	0	0	1	0	0	0	0	-1	0
5	0	0	0	0	1	0	0	0	0	-1
6	1	0	0	0	-1	0	0	0	0	0
7	0	0	0	0	0	1	0	0	0	-1
8	1	-1	0	0	0	0	0	0	0	0
9	1	0	-1	0	0	0	0	0	0	0
10	1	0	0	-1	0	0	0	0	0	0
11	0	0	0	0	0	1	-1	0	0	0
12	0	0	0	0	0	1	0	-1	0	0
13	0	0	0	0	0	1	0	0	-1	0
14	1	0	0	0	-1	1	0	0	0	-1
15	0	1	0	-1	0	0	1	0	-1	0
16	0	0	1	0	-1	0	0	0	0	0
17	0	0	0	0	0	0	0	1	0	-1

¹Treatment 1 = 100% post-rigor meat—10% fat,
 Treatment 2 = 75% post-rigor—25% pre-rigor meat—10% fat,
 Treatment 3 = 50% post-rigor—50% pre-rigor meat—10% fat,
 Treatment 4 = 25% post-rigor—75% pre-rigor meat—10% fat,
 Treatment 5 = 100% pre-rigor meat—10% fat,
 Treatment 6 = 100% post-rigor—20% fat,
 Treatment 7 = 75% post-rigor—25% pre-rigor meat—20% fat,
 Treatment 8 = 50% post-rigor—50% pre-rigor meat—20% fat,
 Treatment 9 = 25% post-rigor—75% pre-rigor meat—20% fat,
 Treatment 10 = 100% pre-rigor meat—20% fat.

1. Contrast 1--mean of 100% post-rigor, 10% fat (T1) contrasted against the mean of 100% post-rigor, 20% fat (T6).
2. Contrast 2--mean of 75% post-rigor/25% pre-rigor, 10% fat (T2) contrasted against the mean of 75% post-rigor/25% pre-rigor, 20% fat (7).
3. Contrast 3--mean of 50% post-rigor/50% pre-rigor, 10% fat (T3) contrasted against the mean of 50% post-rigor/50% pre-rigor, 20% fat (T-8).
4. Contrast 4-- mean of 25% post-rigor/75% pre-rigor, 10% fat (T4) contrasted against the mean of 25% post-rigor/75% pre-rigor, 20% fat (T9).
5. Contrast 5-- mean of 100% pre-rigor, 10% fat (T5) contrasted against the mean of 100% pre-rigor, 20% fat (T10).
6. Contrast 6--mean of 100% post-rigor, 10% fat (T1) contrasted against the mean of 100% pre-rigor, 10% fat (T5).
7. Contrast 7--mean of 100% post-rigor, 20% fat (6) contrasted against the mean of 100% pre-rigor, 20% fat (T10).
8. Contrast 8--mean of 100% post-rigor, 10% fat (T1) contrasted against the mean of 75% post-rigor/25% pre-rigor, 10% (T2).
9. Contrast 9--mean of 100% post-rigor, 10% fat (T1) contrasted against the mean of 50% post-rigor/50% pre-rigor, 10% fat (T3).
10. Contrast 10--mean of 100% post-rigor, 10% fat (T1) contrasted against the mean of 25% post-rigor/75% pre-rigor, 10% fat (T4).
11. Contrast 11--mean of 100% post-rigor, 20% fat (T6) contrasted against the mean of 75% post-rigor/25% pre-rigor, 20% fat (T7).
12. Contrast 12--mean of 100% post-rigor, 20% fat (T6) contrasted against the mean of 50% post-rigor/50% pre-rigor, 20% fat (T8).
13. Contrast 13--mean of 100% post-rigor, 20% fat (T6) contrasted against the mean of 25% post-rigor/75% pre-rigor, 20% fat (T9).

14. Contrast 14--mean of 100% post-rigor, 10 and 20% fat (T1 and T6) contrasted against the mean of 100% pre-rigor, 10 and 20% fat (T5 and T10).

15. Contrast 15--mean of 75% post-rigor/25% pre-rigor, 10 and 20% fat (T2 and T7) contrasted against the mean of 25% post-rigor/75% pre-rigor, 10 and 20% fat (T4 and T9).

16. Contrast 16--mean of 50% post-rigor/50% pre-rigor, 10% fat (T3) contrasted against the mean of 100% pre-rigor, 10% fat (T5).

17. Contrast 17--mean of 50% post-rigor/50% pre-rigor, 20% fat (T8) contrasted against the mean of 100% pre-rigor, 20% fat (T10).

CHAPTER 4

RESULTS AND DISCUSSION

There were five variables of the cooked restructured beef rolls that had significant differences between the two replications of this study (Table 3). The pH of the raw meat (pH1) was higher ($P<.02$) for replication 2 which can be attributed to processing pre-rigor meat sooner following exsanguination therefore, pH of the pre-rigor meat was higher than in replication 1. This same trend ($P<.0001$) can be seen for pH2 and pH3 with differences ($P<.0001$ and $P<.04$, respectively) in replications.

Replication 1 beef rolls had higher raw fat percentages (Table 3), higher cooking yields, relatively lower raw moisture percentages, and had higher bind strengths. Also, replication 1 presumably had greater extraction of myosin and/or other salt soluble proteins, thus increasing the bind strength. The development of bind strength among meat particles is clearly temperature dependent (Acton, 1972b), indicating possibly that end point temperatures of the cooked beef rolls were different between replications.

The differences between replications in cooking yield were statistically different (Table 3). Replication 1 had greater ($P<.0003$) cooking yields than did replication 2. Even though replication 1 had higher raw fat percentages and lower raw moisture percentages it lost more moisture than did replication 2. It is logical to expect higher cooking loss from replication 2 (Cross *et al.*, 1980b; Gwin, 1986) due to the fact that more fat was

Table 3. Means for Selected Variables of Restructured Beef Rolls by Replication.

Variable	Replication	
	1	2
pH1 ¹	5.69	5.85
pH2 ²	5.62	5.73
pH3 ³	5.82	5.89
pH4 ⁴ ns	6.03	6.00
Fat (raw) ^{ns}	15.21	13.85
Fat (cooked) ^{ns}	16.00	12.46
Moisture (raw) ^{ns}	65.90	66.79
Moisture (cooked) ^{ns}	62.27	63.91
Bind ⁵	1.57	0.83
Cooking Yield ⁶	91.21	84.16

¹pH1 means after flaking but before the addition of salt, STPP and tumbling were significantly different at $P < .02$.

²pH2 means after vacuum tumbling with salt and sodium tripolyphosphate were significantly different at $P < .0001$.

³pH3 means of the formulated (after addition of fat) 8 lb. batch of meat before stuffing significantly different at $P < .04$.

⁴pH4 means on the cooked, chilled product.

⁵Tensile strength (bind) means were significantly different at $P < .0004$.

⁶Means were significantly different at $P < .0003$.

^{ns}Means were not significantly different.

formulated into the replication 2 treatments, and a good mix was not attained, therefore more fat being cooked out of the beef rolls.

Hamm (1977) and Honikel and Hamm (1978) suggest that addition of salt to ground muscle before rigor development inhibits glycolysis and production of lactic acid. Also, Judge and Aberle (1980) reported that pre-rigor grinding limited the extent of pH decline which is accelerated by pre-rigor grinding, the extent of pH decline may have been limited by prolonged aerobic metabolism supported by the oxygen incorporated during grinding.

Table 4 shows a significant difference between pH (pH1) of the 100% post-rigor (pH=5.54) and pre-rigor (pH=6.00) combinations (combination 1 vs 5, respectively). There was also a difference in pH (pH4) of the cooked, chilled product as the pH of the 100% post-rigor beef was higher ($P<.05$) than the 100% pre-rigor beef. This can be attributed to STPP raising the pH of the post-rigor beef.

Table 5 shows there were significant differences ($P<.05$) between treatments for pH1, pH3 and pH4. As would be expected, pH1 values were lower for the post-rigor treatments (T1 and T6, 5.54) than for the pre-rigor (T5 and T10, 6.00). After the flaked meat was vacuum tumbled with salt and STPP the mean pH2 values for the four treatments were the same but when compared to pH1 values the post-rigor treatments (T1 and T6) showed an increase in pH and the pre-rigor treatments (T5 and T10) had a decrease in pH. STPP has a pH value of 10.0 so it is logical to expect the meat pH to increase as it did in T1 and T6 after addition of STPP. However, the lower pH2 values of meat in T6 and T10 indicates the STPP did not react with pre-rigor meat the same as with post-rigor meat. This difference may have been caused by a very rapid rate of glycolysis during vacuum tumbling which

Table 4. Means¹ of Restructured Beef Roll Variables for Different Combinations of Flaked Pre- and Post-Rigor Beef.

Variable	Combination ²				
	1	2	3	4	5
pH1 ³	5.54a				6.00b
pH4 ⁴	6.14a				5.89b
Moisture (Raw)	67.19a	64.80b	65.73ab	67.20a	66.82a
Tensile	0.12ab	0.16a	0.09b	0.08b	0.07b
Cooking Yield	89.67ab	91.94a	87.12ab	85.32b	84.39b

¹Means represent combined values of two replications and two fat levels (10 and 20%).

²Combination 1 = 100% post-rigor beef, 10 and 20% fat,
Combination 2 = 75% post-rigor/25% pre-rigor beef, 10 and 20% fat,
Combination 3 = 50% post-rigor/50% pre-rigor beef, 10 and 20% fat,
Combination 4 = 25% post-rigor/75% pre-rigor beef, 10 and 20% fat,
Combination 5 = 100% pre-rigor beef, 10 and 20% fat.

³pH1 was taken on 100% post- and 100% pre-rigor beef after flaking, but before the addition of salt, STPP and vacuum tumbling.

⁴pH4 was taken on the cooked, chilled beef rolls made of 100% post- or 100% pre-rigor beef.

abMeans in the same row with different superscripts are significantly different at $P < .05$.

Table 5. Means¹ of pH Values for Selected Treatments.

Treatment ⁶	pH1 ²	pH2 ³	pH3 ⁴	pH4 ⁵
1	5.54 ^b	5.67 ^a	5.88 ^{ab}	6.13 ^a
5	6.00 ^a	5.68 ^a	5.75 ^c	5.83 ^c
6	5.54 ^b	5.67 ^a	5.96 ^a	6.14 ^a
10	6.00 ^a	5.68 ^a	5.83 ^{bc}	5.96 ^b

¹Means for both replications (n=6).

²pH1 was taken after flaking and before the addition of salt and STPP.

³pH2 was taken after vacuum tumbling with salt and STPP.

⁴pH3 was taken on the formulated (after addition of fat) 8 lb. batch of meat before stuffing.

⁵pH4 was taken on the cooked, chilled product.

⁶Treatments are described on page 50.

^{abc}Means in the same column with different superscripts are significantly different at P < .05.

would have resulted in a large amount of lactic acid production and a lower pH. The lower pH values in pre-rigor meat (T5 and T10) were also found after fat was added to make formulations that contained either 10% (T1 and T5) or 20% fat (T6 and T10). The pH values (pH4) of the cooked and chilled beef rolls showed a general increase compared to the values (pH3) before cooking. Also, the treatments with 100% post-rigor beef (T1 and T6) had higher ($P<.05$) pH4 values than did the treatments with 100% pre-rigor beef (T5 and T10).

Table 6 shows means for fat and moisture content of the raw or uncooked beef rolls. The difference in raw fat percentage was expected because treatments 1 through 5 were formulated to contain 10% fat and treatments 6 through 10 were formulated to 20% fat. However, in the cooked product there was no difference ($P>.05$) in fat percentage among the treatments. For raw moisture there was a difference ($P<.05$) between the 10% fat treatments (1-5) and the 20% fat treatments (6-10). Treatment 4 had the highest raw moisture as well as the highest moisture percent in the cooked product. Even though there was no difference ($P<.05$) in moisture of the cooked product the treatments with higher percentages of pre-rigor meat had the higher moisture (raw and cooked) percentages (T4, 5, 9 and 10). Also, for both fat percentages, the combinations (Table 4) with 75% pre-rigor/ 25% post-rigor and 100% pre-rigor beef had higher raw moisture ($P<.05$) than did the treatment with 75% post-rigor/ 25% pre-rigor beef.

Table 7 shows differences ($P<.05$) in fat (raw and cooked) and moisture (raw and cooked) percentages for treatments of 10% fat and 20% fat. For 10% fat (T 1-5), the fat slightly decreased from the raw to the

Table 6. Means¹ and Standard Deviations of Composition of Restructured Beef Rolls Made From Flaked Pre- and Post-Rigor Beef.

Treatment ²	Fat (%)				Moisture (%)			
	Raw	S.D.	Cooked	S.D.	Raw	S.D.	Cooked	S.D.
1	10.05 ^c	±1.56	11.75 ^a	±1.68	69.81 ^a	±0.57	65.21 ^a	±1.8
2	12.79 ^{bc}	±2.79	10.17 ^a	±3.90	67.86 ^a	±2.09	65.14 ^a	±2.46
3	11.77 ^{bc}	±1.65	11.23 ^a	±1.58	68.20 ^a	±1.11	65.61 ^a	±1.86
4	8.89 ^c	±0.83	8.39 ^a	±0.59	70.27 ^a	±0.69	66.15 ^a	±1.70
5	10.14 ^c	±0.36	8.52 ^a	±2.59	69.51 ^a	±0.45	65.43 ^a	±1.99
6	17.20 ^{ab}	±0.16	20.42 ^a	±7.07	64.57 ^b	±0.33	59.25 ^a	±3.81
7	20.92 ^a	±3.31	18.28 ^a	±8.20	61.74 ^b	±1.77	61.14 ^a	±5.56
8	18.46 ^{ab}	±4.12	20.10 ^a	±5.56	63.26 ^b	±2.26	59.74 ^a	±3.30
9	17.33 ^{ab}	±0.08	17.76 ^a	±5.85	64.13 ^b	±0.07	61.39 ^a	±3.68
10	17.79 ^{ab}	±1.68	15.67 ^a	±8.69	64.13 ^b	±1.18	61.86 ^a	±5.13

¹Means of two replications.

²Treatment 1=100% post-rigor-10% fat,
 Treatment 2=75% post-rigor/25% pre-rigor-10% fat,
 Treatment 3=50% post-rigor/50% pre-rigor-10% fat,
 Treatment 4=25% post-rigor/75% pre-rigor-10% fat,
 Treatment 5=100% pre-rigor-10% fat,
 Treatment 6=100% post-rigor-20% fat,
 Treatment 7=75% post-rigor/25% pre-rigor-20% fat,
 Treatment 8=50% post-rigor/50% pre-rigor-20% fat,
 Treatment 9=25% post-rigor/75% pre-rigor-20% fat,
 Treatment 10=100% pre-rigor-20% fat.

abc Means in the same column with different superscripts are significantly different at P<.05.

Table 7. Means¹ of Restructured Beef Roll Variables That Were Significantly Different Between Fat Percentages.

Variable	Fat Level (%)	
	10%	20%
Fat (raw)	10.73 ^a	18.34 ^b
Fat (cooked)	10.01 ^a	18.44 ^b
Moisture (raw)	69.13 ^a	63.56 ^b
Moisture (cooked)	65.51 ^a	60.27 ^b
Lee Kramer (shear)	0.75 ^a	0.61 ^b
TBA (30 days storage)	0.8724 ^a	0.5849 ^b

¹Means of each fat level (10 and 20%) for both replications.

^{a,b}Means in the same row with different superscripts are significantly different at $P < .05$.

cooked product. For 20% fat treatments there was a slight increase in fat content of the cooked beef roll.

Water holding capacity (raw and cooked), indicated by Expressible Moisture Index (EMI), and cooking yields are shown in Table 8. A larger EMI number represents lower water holding capacity. Even though there were no differences ($P>.05$) in EMI of the raw product, T4, T5, T9 and T10 had the lowest EMI values of the 10% and 20% fat percentages, respectively. According to the method of Miller and Harrison (1965) the low EMI values indicate greater WHC in the beef rolls that had a higher proportion of pre-rigor meat. Cooking yields showed no differences between treatments. Belohlavy and Mandigo (1974) stated that water holding capacity is most affected by mixing time and is reduced with increased mixing time to a low at 14 minutes mixing time. They further stated that the WHC then increased from the 14 to 20 minutes mixing time for beef, lamb and pork with the 20 minutes mixing time resulting in the greatest WHC for all mixing times studied (2, 8, 14 and 20 minutes). This reasoning may account for the low and nonsignificant EMI values for this study since the meat was only mixed for 2 1/2 minutes.

Table 8 also shows no differences ($P>.05$) in cooking yield for the treatments. However, treatments 1, 2 and 7 had the highest cooking yield percentages and were high in post-rigor beef percentages. Treatments 4 and 5 had the lowest cook yields for the 10% fat treatments. Beef rolls (T2 and 7) made from 75% post-rigor/25% pre-rigor beef (Table 4) had the highest cooking yield percentage and were significantly different ($P<.05$) from rolls made from 75% pre-rigor/25% post-rigor or 100% pre-rigor.

Table 8. Means¹ and Standard Deviations of Expressible Moisture Index (EMI) and Cooking Yield of Restructured Beef Rolls Made From Flaked Pre- and Post-Rigor Beef.

Treatment ²	EMI				Cooking Yield	S.D.
	Raw	S.D.	Cooked	S.D.		
1	1.77 ^a	±0.93	0.26 ^a	±0.03	90.74 ^a	±2.23
2	1.00 ^a	±0.16	0.26 ^a	±0.00	92.80 ^a	±0.87
3	0.70 ^a	±0.24	0.28 ^a	±0.04	84.91 ^a	±5.58
4	0.57 ^a	±0.03	0.26 ^a	±0.04	83.37 ^a	±5.64
5	0.66 ^a	±0.20	0.26 ^a	±0.08	83.22 ^a	±8.10
6	1.26 ^a	±1.05	0.28 ^a	±0.11	83.22 ^a	±8.10
7	1.73 ^a	±0.23	0.32 ^a	±0.04	91.80 ^a	±5.56
8	2.31 ^a	±1.03	0.30 ^a	±0.05	89.33 ^a	±4.77
9	0.86 ^a	±0.08	0.31 ^a	±0.02	87.28 ^a	±7.01
10	1.07 ^a	±0.36	0.34 ^a	±0.06	85.56 ^a	±8.20

¹Means of two replications.

²Treatment 1=100% post-rigor-10% fat,
 Treatment 2=75% post-rigor/25% pre-rigor-10% fat,
 Treatment 3=50% post rigor/50% pre-rigor-10% fat,
 Treatment 4=25% post-rigor/75% pre-rigor-10% fat,
 Treatment 5=100% pre-rigor-10% fat,
 Treatment 6=100% post-rigor-20% fat,
 Treatment 7=75% post-rigor/25% pre-rigor-20% fat,
 Treatment 8=50% post-rigor/50% pre-rigor-20% fat,
 Treatment 9=25% post-rigor/75% pre-rigor-20% fat,
 Treatment 10=100% pre-rigor-20% fat.

^aMeans in the same column with the same superscript are not significant at P<.05.

The means of shear values are given in Table 9. Treatment 5 (100% pre-rigor, 10% fat) had the highest shear score and was less tender ($P < .05$) than treatments 2, 3, 6, 7, 8, 9 and 10. Treatments 9 and 10, even though they were not significantly different from the rest of the 20% fat treatments, had the highest shear scores of all the beef rolls with 20% fat. Taylor *et al.* (1981), Hollingsworth *et al.* (1982) and Gwin (1986) also showed similar Lee Kramer Shear Scores associated with the use of pre-rigor meat in the formation of restructured meat products. The differences in these scores were affected by differences in cooking loss percentage. Treatments 4 and 5 had higher shear values and cooking losses than all other 10% fat treatments. Treatments 9 and 10 also had high shear and cooking loss values for the 20% fat treatments. The 10% fat treatments [(T1-5), Table 7] had significantly higher ($P < .05$) shear values than did the 20% fat treatments (T6-10). This is due to the differences in fat percent in the cooked treatments and cooking yields. Treatments 3, 4 and 5 (increasing percentages of pre-rigor beef from T3 to T5) had the lowest tensile strengths and were different ($P < .05$) from the other seven treatments (Table 9). Treatment 2 (75% post-rigor/25% pre-rigor, 10% fat) had the highest tensile score which is indicative of greater bind. Also, treatments 8, 9 and 10 have low tensile scores thus reinforcing the trend that as the percentage of pre-rigor meat increases the tensile strength decreases. Tensile strength values for combinations (Table 4) also show that the 75% post-rigor/25% pre-rigor combination is higher ($P < .05$) than the other 4 combinations of post- and pre-rigor meat. Again, as the percent of pre-rigor meat increased (combination 3, 4 and 5) tensile scores decreased with the 100% pre-rigor combination having the lowest scores.

Table 9. Means and Standard Deviations of Shear and Certain Physical Characteristics of Restructured Beef Rolls Made From Flaked Pre- and Post-Rigor Beef.

Treatment ²	Lee Kramer (kg/cm)	S.D.	Tensile Strength (kg/cm)	S.D.	Bind ³ (kg)	S.D.
1	0.74 ^{ab}	±0.04	0.13 ^{ab}	±0.03	4.84 ^a	±0.07
2	0.67 ^b	±0.02	0.17 ^a	±0.02	5.26 ^a	±0.83
3	0.69 ^b	±0.06	0.06 ^b	±0.03	4.34 ^a	±0.47
4	0.78 ^{ab}	±0.11	0.05 ^b	±0.04	3.44 ^a	±0.59
5	0.86 ^a	±0.04	0.05 ^b	±0.04	3.87 ^a	±0.21
6	0.59 ^b	±0.02	0.12 ^{ab}	±0.11	4.97 ^a	±0.88
7	0.60 ^b	±0.58	0.14 ^{ab}	±0.07	4.93 ^a	±0.99
8	0.61 ^b	±0.05	0.11 ^{ab}	±0.03	5.23 ^a	±0.72
9	0.62 ^b	±0.05	0.12 ^{ab}	±0.02	4.83 ^a	±0.58
10	0.61 ^b	±0.04	0.10 ^{ab}	±0.06	4.90 ^a	±0.99

¹Means of two replications.

²Treatment 1=100% post-rigor-10% fat.

Treatment 2=75% post-rigor/25% pre-rigor-10% fat,

Treatment 3=50% post-rigor/50% pre-rigor-10% fat,

Treatment 4=25% post-rigor/75% pre-rigor-10% fat,

Treatment 5=100% pre-rigor-10% fat,

Treatment 6=100% post-rigor-20% fat,

Treatment 7=75% post-rigor/25% pre-rigor-20% fat,

Treatment 8=50% post-rigor/50% pre-rigor-20% fat,

Treatment 9=25% post-rigor/75% pre-rigor-20% fat,

Treatment 10=100% pre-rigor-20% fat.

³Bind - breaking bridge apparatus of 1 inch slice of meat on the Instron Universal Testing Machine.

^{abc} Means in the same column with different superscripts are significantly different at P<.05.

Bind, as determined by the force required to break a one inch thick slice of meat that spanned a bridge attachment on the Instron Universal Testing Machine, was not different ($P < .05$) among any of the treatments (Table 9). However, treatments 2 and 8 had the highest bind values with treatments 4, 5 (10% fat), 9 and 10 (20% fat) having the lowest bind values and containing the higher amounts of pre-rigor meat. The utilization of pre-rigor meat has been shown to increase bind (Pepper and Schmidt, 1975; Coon, 1982) but this research contradicts those reports as treatments 4 and 5 had the lowest bind values and contained the highest amount of pre-rigor meat (75% pre-rigor/25% post-rigor and 100% pre-rigor, respectively).

Means of oxidation (TBA) for the raw product, cooked product and at 30 days of storage are shown in Table 10. For the raw product, there were no differences among treatments, but treatment 1 (100% post-rigor, 10% fat) did exhibit a slightly higher TBA value than the other treatments. Once cooked, treatments 4 and 5 had the highest TBA values with treatment 2 having the lowest value. For treatments 6 through 10, (20% fat), treatments 9 and 10 had the highest values as well as the highest percent of pre-rigor meat.

At 30 days of storage there was still no significance between the treatments. However, treatments 4 and 5 still had the highest TBA number after 30 days, but were slightly less than in the cooked, 0 day sample. Treatment 9 (75% pre-rigor/25% post-rigor, 20% fat) had the lowest TBA number at 30 days and the number was less than it was at 0 day in the cooked product. Pre-rigor processing has been shown to improve the oxidative stability of muscle foods, including pork and beef (Judge and Aberle, 1980). Even though the results of this study are inconclusive, they seem to contradict

Table 10. Means¹ and Standard Deviations of Oxidation (TBA) of Restructured Beef Rolls Made From Flaked Pre-and Post-Rigor Beef.

Treatment ²	Raw	S.D.	Cooked	S.D.	Cooked + 30 Days	S.D.
1	0.5595 ^a	±0.31	0.6270 ^a	±0.20	0.6766 ^a	±0.25
2	0.4814 ^a	±0.03	0.3782 ^a	±0.20	0.6212 ^a	±0.15
3	0.4645 ^a	±0.12	0.6418 ^a	±0.35	0.9991 ^a	±0.34
4	0.4263 ^a	±0.05	0.9474 ^a	±0.63	0.9115 ^a	±0.25
5	0.4740 ^a	±0.03	1.5426 ^a	±1.22	1.1507 ^a	±0.54
6	0.4178 ^a	±0.01	0.6144 ^a	±0.02	0.6823 ^a	±0.12
7	0.4651 ^a	±0.01	0.5553 ^a	±0.05	0.5839 ^a	±0.29
8	0.4654 ^a	±0.21	0.5480 ^a	±0.06	0.5660 ^a	±0.17
9	0.4359 ^a	±0.11	0.7201 ^a	±0.19	0.5130 ^a	±0.02
10	0.4389 ^a	±0.17	0.7688 ^a	±0.13	0.5791 ^a	±0.17

¹Means of two replications.

²Treatment 1=100% post-rigor-10% fat,

Treatment 2=75% post-rigor/25% pre-rigor-10% fat,

Treatment 3=50% post-rigor/50% pre-rigor-10% fat,

Treatment 4=25% post-rigor/75% pre-rigor-10% fat,

Treatment 5=100% pre-rigor-10% fat,

Treatment 6=100% post-rigor-20% fat,

Treatment 7=75% post-rigor/25% pre-rigor-20% fat,

Treatment 8=50% post-rigor/50% pre-rigor-20% fat,

Treatment 9=25% post-rigor/75% pre-rigor-20% fat,

Treatment 10=100% pre-rigor-20% fat.

^aMeans in the same column with the same superscript are not significant at P<.05.

the previous work of Judge and Aberle (1980). Some of the microorganisms associated with spoilage of refrigerated meat are capable of breaking down meat proteins into various amino acids which can react with malonaldehyde and thus make it unavailable for reaction with TBA (Buttkus and Bose, 1972). This could possibly be the reason that treatments 4, 5, 9 and 10 had slightly less TBA numbers at 30 days of storage. Also, certain genera of Pseudomonas and Achromobacter have been found to be capable of selectively attacking and utilizing carbonyl compounds which may have removed some of the malonaldehyde (Smith and Alford, 1968).

Table 11 shows orthogonal contrast probability levels for pH of restructured beef rolls. No significant probability levels were shown for pH before vacuum tumbling and the addition of salt and STPP (pH1). However, contrasts 1, 3, 4 and 6 had relatively low probability levels which would be expected since each contrast was comparing a post-rigor treatment to a pre-rigor treatment. pH after tumbling with salt and STPP (pH2) had no significance for any of the contrasts and the probability levels were high. There were no significant differences for pH3 (pH before the meat was stuffed) however, contrasts 1, 4 and 6 had relatively lower probability levels. As expected, there should be a difference between pre-rigor and post-rigor beef. Significant differences were found for contrasts 1 and 4 for pH4 (pH taken on the cooked, chilled product). Again, contrast 1 compared T1 (100% post-rigor) to T5 (100% pre-rigor) which would be expected to be significant. The same holds true for contrast 4 which compared T5 to T6 (100% pre-rigor, 10% fat vs 100% post-rigor, 20% fat).

Table 12 shows orthogonal contrast probability levels for composition of restructured beef rolls. Significant probability levels for fat in the raw

Table 11. Orthogonal Contrast Probability Levels for pH of Restructured Beef Rolls Made From Flaked Pre- and Post-Rigor Beef.

Contrast ¹	pH1 ²	pH2 ³	pH3 ⁴	pH4 ⁵
1	0.114	0.910	0.303	0.012
2	1.000	1.000	0.466	0.947
3	0.114	0.910	0.724	0.069
4	0.114	0.910	0.118	0.011
5	1.000	1.000	0.466	0.130
6	0.114	0.910	0.303	0.064

¹Contrast1 = T1 vs T5,
 Contrast2 = T1 vs T6,
 Contrast 3=T1 vs T10,
 Contrast4 = T5 vs T6,
 Contrast5 = T5 vs T10,
 Contrast6 = T6 vs T10.

²pH1 was taken after flaking and before the addition of salt and STPP.

³pH2 was taken after vacuum tumbling with salt and STPP.

⁴pH3 was taken on the formulated 8 lb. batch of meat before stuffing.

⁵pH4 was taken on the cooked, chilled product.

Table 12. Orthogonal Contrast Probability Levels for Composition of Restructured Beef Rolls.

Contrast ¹	Fat Raw	Fat Cooked	Moisture Raw	Moisture Cooked
1	0.007	0.136	0.002	0.111
2	0.003	0.160	0.001	0.267
3	0.010	0.128	0.003	0.116
4	0.003	0.110	0.001	0.192
5	0.005	0.211	0.002	0.319
6	0.969	0.559	0.819	0.949
7	0.784	0.395	0.735	0.460
8	0.223	0.774	0.159	0.985
9	0.434	0.924	0.236	0.909
10	0.593	0.543	0.730	0.788
11	0.108	0.697	0.051	0.589
12	0.564	0.953	0.330	0.887
13	0.952	0.630	0.738	0.544
14	0.824	0.316	0.689	0.568
15	0.031	0.767	0.024	0.800
16	0.457	0.623	0.329	0.960
17	0.759	0.427	0.515	0.547

¹Contrast 1 - T1 vs T6,
 Contrast 2 - T2 vs T7,
 Contrast 3 - T3 vs T8
 Contrast 4 - T4 vs T9,
 Contrast 5 - T5 vs T10,
 Contrast 6 - T1 vs T5,
 Contrast 7 - T6 vs T10,
 Contrast 8 - T1 vs T2,
 Contrast 9 - T1 vs T3,
 Contrast 10 - T1 vs T4,

Contrast 11 - T6 vs T7,
 Contrast 12 - T6 vs T8,
 Contrast 13 - T6 vs T9,
 Contrast 14 - T1 and T6
 vs T5 and T10,
 Contrast 15 - T2 and T7
 vs T4 and T9,
 Contrast 16 - T3 vs T5,
 Contrast 17 - T8 vs T10.

product are shown for contrast 1, 2, 3, 4, 5 and 15. This was expected for contrast 1 through 5 since those contrasts were comparing the same treatments but at different formulated fat levels (10 and 20% fat). However, contrast 15 which compared 75% post-rigor/25% pre-rigor (10 and 20% fat) to 25% post-rigor/75% pre-rigor (10 and 20% fat) can be attributed to possible errors in figuring fat percent of the raw pre- and post-rigor beef. None of the contrasts showed significant differences for fat in the cooked beef rolls but contrasts 1 through 5 had the lowest probability levels. This would be expected since they were contrasting the same treatments against different fat levels.

For raw moisture content contrasts 1 through 5, 11 and 15 showed significant differences. Contrasts 1 through 5 showed that beef rolls made of 10% fat contained more moisture than beef rolls made of 20% fat. For contrast 11, 100% post-rigor (20% fat) contained more moisture than 75% post-rigor/25% pre-rigor (20% fat). However, for contrast 15, beef rolls with 25% post-rigor/75% pre-rigor (10 and 20% fat) contained more moisture than beef rolls with 75% post-rigor/25% pre-rigor (10 and 20% fat). Even though there was no significance for moisture in the cooked products, contrast 1 through 5 had the lowest probability levels. The beef rolls with 10% fat which had higher raw moisture levels also had the highest cooked moisture levels.

Table 13 shows orthogonal contrast probability levels for expressible moisture index (EMI) and cooking yield. For EMI of the raw product, contrast 3 was significant. For contrast 3, the beef roll with 50% post-rigor/50% pre-rigor (10% fat) had a higher EMI than did the same beef roll at 20% fat. For contrasts 6, 9, and 10, treatments with the high percent of

Table 13. Orthogonal Contrast Probability Levels of Expressible Moisture Index (EMI) and Cooking Yield of Restructured Beef Rolls.

Contrast ¹	EMI Raw	EMI Cooked	Cooking Yield
1	0.398	0.723	0.712
2	0.235	0.299	0.767
3	0.020	0.723	0.450
4	0.626	0.383	0.504
5	0.499	0.152	0.687
6	0.085	0.929	0.212
7	0.749	0.299	0.602
8	0.212	1.000	0.722
9	0.095	0.790	0.325
10	0.064	0.929	0.220
11	0.435	0.482	0.669
12	0.099	0.790	0.899
13	0.504	0.658	0.820
14	0.144	0.494	0.215
15	0.143	0.802	0.128
16	0.946	0.723	0.771
17	0.057	0.431	0.519

¹Contrast 1 - T1 vs T6,
 Contrast 2 - T2 vs T7,
 Contrast 3 - T3 vs T8
 Contrast 4 - T4 vs T9,
 Contrast 5 - T5 vs T10,
 Contrast 6 - T1 vs T5,
 Contrast 7 - T6 vs T10,
 Contrast 8 - T1 vs T2,
 Contrast 9 - T1 vs T3,
 Contrast 10 - T1 vs T4,

Contrast 11 - T6 vs T7,
 Contrast 12 - T6 vs T8,
 Contrast 13 - T6 vs T9,
 Contrast 14 - T1 and T6
 vs T5 and T10,
 Contrast 15 - T2 and T7
 vs T4 and T9,
 Contrast 16 - T3 vs T5,
 Contrast 17 - T8 vs T10.

pre-rigor beef had low EMI values over beef rolls with 100% post-rigor meat. The contrasts used did not show a significant difference in EMI of the cooked beef rolls but contrast 5 showed there was a difference in fat percents (10 vs 20%) for the 100% pre-rigor treatments.

The probability levels for the orthogonal contrasts comparing the cooking yield values were very high (Table 13).

Table 14 shows the orthogonal contrast probability levels of shear and certain physical characteristics of restructured beef rolls. The lowest probability ($P < .05$) levels of Lee Kramer shear values were contrast 1, 4, 5 and 16. Contrasts 1, 4 and 5 show that beef rolls made of 20% fat were more tender than rolls made from 10% fat. However, beef rolls made from 100% pre-rigor beef (10% fat) were less tender than rolls made from 50% post-rigor/50% pre-rigor beef (10% fat) as shown in contrast 16.

The only contrast which had a low probability level for tensile strength was contrast 15 (Table 14). This contrast compared a mixture of 75% post-rigor/25% pre-rigor (10 and 20% fat) to 25% post-rigor/75% pre-rigor (10 and 20% fat). Tensile strength for the former beef rolls was greater than for the latter rolls.

Even though there was no significant difference for bind (Table 14), contrasts 4, 10 and 15 had the lowest values. Beef rolls with the higher percent of post-rigor meat (contrasts 10 and 15) had less bind than rolls with a higher percent of pre-rigor meat. Also, contrast 4 shows that 75% pre-rigor/25% post-rigor (10% fat) had less bind than the same beef roll at 20% fat.

Table 15 shows contrast probability levels of oxidation (TBA) of restructured beef rolls. There were no significant differences for the

Table 14. Orthogonal Contrast Probability Levels of Shear and Certain Physical Characteristics of Restructured Beef Rolls.

Contrast ¹	Lee Kramer Shear	Tensile Strength	Bind
1	0.024	0.833	0.857
2	0.194	0.500	0.648
3	0.183	0.290	0.230
4	0.021	0.311	0.075
5	0.001	0.368	0.170
6	0.055	0.158	0.194
7	0.735	0.721	0.922
8	0.258	0.402	0.562
9	0.356	0.196	0.487
10	0.525	0.166	0.074
11	0.940	0.703	0.956
12	0.792	0.961	0.718
13	0.574	0.839	0.846
14	0.106	0.210	0.316
15	0.126	0.062	0.081
16	0.011	0.890	0.517
17	0.940	0.758	0.648

¹Contrast 1 - T1 vs T6,
 Contrast 2 - T2 vs T7,
 Contrast 3 - T3 vs T8
 Contrast 4 - T4 vs T9,
 Contrast 5 - T5 vs T10,
 Contrast 6 - T1 vs T5,
 Contrast 7 - T6 vs T10,
 Contrast 8 - T1 vs T2,
 Contrast 9 - T1 vs T3,
 Contrast 10 - T1 vs T4,

Contrast 11 - T6 vs T7,
 Contrast 12 - T6 vs T8,
 Contrast 13 - T6 vs T9,
 Contrast 14 - T1 and T6
 vs T5 and T10,
 Contrast 15 - T2 and T7
 vs T4 and T9,
 Contrast 16 - T3 vs T5,
 Contrast 17 - T8 vs T10.

Table 15. Orthogonal Contrast Probability Levels of Oxidation (TBA) of Restructured Beef Rolls.

Contrast ¹	Raw	Cooked	Cooked + 30 Days
1	0.342	0.979	0.983
2	0.911	0.710	0.891
3	0.995	0.844	0.134
4	0.929	0.634	0.161
5	0.810	0.126	0.057
6	0.561	0.076	0.104
7	0.885	0.746	0.705
8	0.595	0.603	0.839
9	0.519	0.975	0.252
10	0.370	0.505	0.391
11	0.746	0.901	0.719
12	0.745	0.889	0.671
13	0.884	0.824	0.538
14	0.755	0.133	0.346
15	0.695	0.289	0.567
16	0.948	0.080	0.581
17	0.856	0.644	0.962

¹Contrast 1 - T1 vs T6,
 Contrast 2 - T2 vs T7,
 Contrast 3 - T3 vs T8,
 Contrast 4 - T4 vs T9,
 Contrast 5 - T5 vs T10,
 Contrast 6 - T1 vs T5,
 Contrast 7 - T6 vs T10,
 Contrast 8 - T1 vs T2,
 Contrast 9 - T1 vs T3,
 Contrast 10 - T1 vs T4,

Contrast 11 - T6 vs T7,
 Contrast 12 - T6 vs T8,
 Contrast 13 - T6 vs T9,
 Contrast 14 - T1 and T6
 vs T5 and T10,
 Contrast 15 - T2 and T7
 vs T4 and T9,
 Contrast 16 - T3 vs T5,
 Contrast 17 - T8 vs T10.

contrast used for TBA values in the raw product. Contrast 1 had a relatively low probability level showing a difference between rolls made from 100% post-rigor beef at 10 and 20% fat levels. Also, contrast 10 had a relatively low probability showing the beef roll with more pre-rigor beef had a lower oxidation level which can possibly be attributed to pH and total percent of pre-rigor beef vs post-rigor beef.

For oxidation in the cooked, chilled product there was no significance among the contrasts (Table 15). However, contrasts 6 and 16 had relatively low probabilities which show that rolls with a higher percent of post-rigor meat had less oxidation than rolls with 100% pre-rigor beef. This is the opposite of what was observed for oxidation in the raw product. Also, the contrast used did not show a significant difference in oxidation at 30 days. However, the probability level of contrast 5 showed there was a difference in 100% pre-rigor rolls at 10 and 20% fat.

CHAPTER 5

CONCLUSION

The objectives of this study were to determine the effects of pre- and post-rigor beef and combinations of the two on selected processing characteristics, textural traits and shelflife of cooked beef rolls. However, some of the results of this study differ from previous research but some of the results agree with previous studies.

Treatments 1 and 6 (100% post-rigor, 10 and 20% fat) gained the highest percent of fat (16.9% and 18.72%, respectively) from the raw to the cooked products. This would be expected since they also had the highest moisture losses with 6.59% and 8.24%, respectively.

For water holding capacity, treatments 4 and 5 (25% post-rigor/75% pre-rigor and 100% pre-rigor, respectively) had the lowest EMI values thus representing the highest water holding capacity for all treatments. Both of these treatments had relatively high raw and cooked moisture contents, representing a higher ratio of free vs bound water in the meat. Treatment 7 had the lowest (0.97%) moisture percent loss from the raw to the cooked product and had high EMI values (low water holding capacity) and a high cooking yield percent (91.80%).

Treatments 4 and 5 (25% post-rigor/75%pre-rigor and 100% pre-rigor, respectively) exhibited the greatest shear values and displayed the lowest tensile strength and bind as well as having low cooking yields. Beef

rolls containing 20% fat had lower shear values with rolls increasing in tenderness as the percent post-rigor meat increased. Beef rolls with greater amounts of post-rigor meat had greater bind and tensile strength which can be attributed to the fact that the raw post-rigor meat was vacuum tumbled with salt and STPP the night before formulating. This gave the salt longer time to extract the salt soluble proteins thus giving rise to the higher bind values.

Treatments 4 and 9 (25% post-rigor/75% pre-rigor, 10 and 20% fat) and treatments 5 and 10 (100% pre-rigor, 10 and 20% fat) had the highest oxidation in the 0 day cooked, chilled product which could possibly be due to slightly higher pH values for the pre-rigor meat. After 30 days of storage the treatments that contained 10% fat had greater oxidation as the percent of pre-rigor meat increased.

In conclusion, with better restraints on processing techniques, longer mixing and/or tumbling times, better incorporation of salt for extraction of proteins, an acceptable restructured beef roll could be made utilizing combinations of post- and pre-rigor beef. This study showed treatment 2 (75% post-rigor/25% pre-rigor, 10% fat) displaying the highest bind, tensile strength and cooking yield. However, treatment 2 had an average WHC (raw) and lost 4.01% moisture from the raw to the cooked product. Even though treatment 2 had relatively high TBA values on the raw product, after cooking the value went down considerably (the lowest for all 10 treatments) and increased slightly to 30 days of storage which would be indicative of a good trend to possess for acceptable shelflife.

REFERENCES

- AOAC. 1984. "Official Methods For Analysis." 14th ed. Association of Official Analytical Chemist. Washington, D.C.
- Acton, J.C. 1972a. The effect of meat particle size on extractable protein, cooking loss and binding strength on chicken loaves. J. Food Sci. 37:240.
- Acton, J.C. 1972b. Effect of heat processing on extractability of salt-soluble protein, tissue binding strength and cooking loss in poultry meat loaves. J. Food Sci. 37:244.
- Acton, J.E. and McCaskill, L.H. 1972. Effect of partial protein removal from muscle cubes on properties of poultry meat loaves. J. Milk and Food Tech. 35(10):271.
- Anonymous. 1971. New developments in ham and meat tumbling. Food Processing. 40 (472):57.
- Anonymous. 1973. Facts, flakes and fabricated meats. Bull. 703. Urschel Laboratories Incorporated, Valparaiso, Ind.
- Anonymous. 1974. Low cost, high protein reformed and formulated meat with consumer appeal. Food Processing 35:26.
- Anonymous. 1977 The massaging - tumbling revolution. Meat Industry. April., p. 36.
- Anonymous. 1978. Advantages of vacuum chopping in sausage manufacturing. Meat Industry. 24(10):65.
- Apple, John C. 1981. Concepts for packaging pre-rigor meat. Proceedings of the 34th Reciprocal Meats Conference 31:85.
- Aref, M.M. and Tape, N.W. 1966. A new method for processing turkey rolls. Can. Food Ind. 37:15.

- Bard, J.C. 1965. Some factors influencing extractability of salt soluble proteins. Presented at the Annual Meat Industry Research Conference. Chicago, Ill.
- Barrett, A.J. 1972. Lysosomal enzymes. In "Lysosomes." p. 46. North Holland Publishing Co., Ltd. London.
- Belohlavy, R. 1975. The effects of mechanical mixing time and salt on the chemical and physical properties of flaked, formed and sectioned meat products. M.S. Thesis, Univ. of Nebraska, Lincoln, NE.
- Belohlavy, R. and Mandigo, R.W. 1974. The influence of mixing time on chemical and physical properties of flaked, formed and sectioned meat. J. Anim. Science. 39:166.
- Berry, B.W., Wells, L.H., Cross, H.R., Emswiler, B.S. and Muse, H.D. 1979. Shelflife and bacterial characteristics of ground beef as influenced by fat level and source. J. Food Protec. 46:390.
- Booren, A., Jones, K.W., Mandigo, R.W. and Olson, D.G. 1979. Processing factors influencing binding of meat pieces into restructured, fresh beef steaks. Abstr. Proc. 71st Annual Meeting of the Am. Soc. of Anim. Sci., Tucson, AZ.
- Booren, A.M., Jones, K.W., Mandigo, R.W. and Olson, D.G. 1981a. Effects of blade tenderization, vacuum mixing, salt addition and mixing time on binding of meat pieces into sectioned and formed beef steaks. J. Food Sci. 46:1678.
- Booren, A.M., Mandigo, R.W., Olson, D.G. and Jones, K.W. 1981b. Effect of muscle type and mixing time on sectioned and formed beef steaks. J. Food Sci. 46:1665.
- Booren, A.M., Mandigo, R.W., Olson, D.G. and Jones, K.W. 1981c. Vacuum mixing influence on characteristics of sectioned and formed beef steaks. J. Food Sci. 46:1673.
- Bouton, P.E., Harris, P.V. and Shorthose, W.R. 1971. Effect of ultimate pH upon the water holding capacity and tenderness of mutton. J. Food Sci. 36:435.

- Bouton, P.E., Ford, A.L., Harris, P.V. and Ratcliff, D. 1975. Objective-subjective assessment of meat tenderness. *J. Texture Studies* 6:315.
- Bouton, P.E., Howard, A. and Lawrie, R.A. 1957. Studies on beef quality. Part 6. Effects on weight losses and eating quality of further preslaughter treatments. CSIRO Australian DW. Food Preserv. Tech. Paper. 26:137.
- Bouton, P.E., Harris, P.V. and Ratcliff, D. 1981. Effect of cooking temperature and time on the shear properties of meat. *J. Food Sci.* 46:1082.
- Brady, P.L. and Hunecke, M.E. 1985. Correlations of sensory and instrumental evaluations of roast beef texture. *J. Food Sci.* 50:300.
- Buttkus, H. and Bose, R.J. 1972. Amine-malonaldehyde condensation products and their relative color contribution in the thiobarbituric acid test. *J. Am. Oil Chem.* 49:440.
- Carpenter, J.A., Saffle, R.L. and Kamstra, L.P. 1961. Tenderization of beef by a pre-rigor infusion of a chelating agent. *Food Technol.* 15(4):197.
- Cassens, R.G. and Newbold, R.P. 1967. Temperature dependence of pH changes in ox muscle post-mortem. *J. Food Sci.* 32:13.
- Chang, I. and Watts, B.M. 1950. Some effects of salt and moisture on rancidity in fats. *Food Res.* 15:313.
- Chang, I., Younathan, M.T. and Watts, B.M. 1961. Lipid oxidation in precooked beef preserved by refrigeration, freezing and irradiation. *Food Technol.* 15:168.
- Chesney, M.S. 1973. Properties of pork muscle as influenced by comminution method, size and temperature. M.S. Thesis. University of Nebraska Lincoln, NE.
- Chesney, M.S. and Mandigo, R.W. 1974. Chemical, physical and organoleptic properties of formed and sectioned pork muscle as influenced by size, temperature and comminution method. *J. Food Sci.* 39:531.

- Chesney, M.S., Mandigo, R.W. and Campbell, J.F. 1978. Properties of restructured pork product as influenced by meat particle size, temperature and comminution method. *J. Food Sci.* 43:1535.
- Cia, G. and Marsh B.B. 1976. Properties of beef cooked before rigor onset. *J. Food Sci.* 41:1259.
- Coon, F.P. 1982. The utilization of pre-rigor muscle in sectioned and formed meat products. M.S. Thesis, Univ. of Nebraska, Lincoln.
- Costello, C.A., Penfield, M.P. and Riemann, M.J. 1985. Quality of restructured steaks: effects of days on feed, fat level, and cooking method. *J. Food Sci.* 50:685.
- Cover, S., Ritchey, S.J. and Hostetler, R.L. 1962. Tenderness of beef. 1. The connective tissue component of tenderness. *J. Food Sci.* 27:469.
- Cross, H.R. 1977. Effects of amount, distribution and texture of marbling on cooking properties of beef longissimus. *J. Food Sci.* 42:182.
- Cross, H.R., and Stanfield, M.S. 1976. A research note - Consumer evaluation of restructured beef steaks. *J. Food Sci.* 41:1257.
- Cross, H.R., Stanfield, M.S. and Franks, Jr., W.J. 1978. Objective measurements of texture in ground beef patties. *J. Food Sci.* 43:1510.
- Cross, H.R., Berry, B.W. and Muse, D. 1979a. Sensory and cooking properties of ground beef prepared from hot and chilled beef carcasses. *J. Food Sci.* 44:1432.
- Cross, H.R., Tennent, I. and Muse, D.A. 1979b. Storage properties of primal cuts of hot and cold boned beef. *J. Food Quality.* 4:289.
- Cross, H.R., Berry, B.W. and Wells, L.H. 1980a. Effects of fat level and source on the chemical, sensory and cooking properties of ground beef patties. *J. Food Sci.* 45:791.
- Cross, H.R., Berry, B.W. and Wells, L.H. 1980b. Effects of fat level and source on the chemical method and pressure on restructures beef steaks. *J. Food Protec.* 44:425.

- Cross, H.R. and Tennen, I. 1980. Accelerated processing systems for U.S.D.A. choice and good beef carcasses. *J. Food Sci.* 45:765.
- Dalrymple, R.H. and Hamm, R. 1975. Post mortem glycolysis in pre-rigor ground bovine and rabbit muscle. *J. Food Sci.* 40:850.
- Dalton, L.M. 1979. The effects of mechanical mixing and salt on the chemical, physical and organoleptic properties of sectioned and formed fresh pork chops.. M.S. Thesis. University of Nebraska Lincoln, NE.
- Davey, C.L. and Gilbert K.V. 1974. The mechanism of cold-induced shortening in beef muscle. *J. Food Tech.* 9:51.
- Drerup, D.L., Judge, M.D. and Aberle, E.D. 1981. Sensory properties and lipid oxidation in pre-rigor processed fresh pork sausage. *J. Food Sci.* 46:1659.
- Dutson, T.R. and Lawrie, R.A. 1974. Release of lysosomal enzymes during post mortem conditioning and their relationship to tenderness. *J. Food Tech.* 9:43.
- Dutson, T.R., Smith, G.C., Hostetler, R.L. and Carpenter, Z.L. 1975. Post-mortem carcass temperature and beef tenderness. *J. Anim. Sci.* 41:289 (Abstr.).
- Ellinger, R.H. 1972. Phosphates as food ingredients. CRC Press, Cleveland, OH.
- Farrington, A.E. 1975. Flaked, formed and frozen lamb products. Proceedings of the 28th Reciprocal Meats Conference 28:140.
- Ferren, R. 1972. Flake-cutting. A guide to determine the formulation for the type of meat and poultry products you want. Bull. 691. Urschel Laboratories Incorporated. Valparaiso, Ind.
- Fields, P.A., Carpenter, Z.L. and Smith, G.C. 1975. Effects of elevated temperature conditioning on youthful and mature carcasses. *J. Anim. Sci.* 39:174.

- Ford, A.L., Jones, P.M., Macfarlane, J.J., Schmidt, G.R. and Turner, R.H. 1978. Binding of meat pieces: objective and subjective assessment of restructured steakettes containing added myosin and/or sarcoplasmic protein. *J. Food Sci.* 43:815.
- Froning, G.W. 1966. Effect of various additives on the binding properties of chicken meat. *Poultry Sci.* 45:185.
- Fukazawa, T., Hashimoto, Y. and Yasui, T. 1961a. Effect of some proteins on the binding quality of an experimental sausage. *J. Food Sci.* 26:541.
- Fukazawa, T., Hashimoto, Y. and Yasui, T. 1961b. The relationship between the components of myofibrillar protein and the effect of various phosphates that influence the binding quality of sausage. *J. Food Sci.* 26:550.
- Ghavimi, B. Althen, T.G. and Rogers, R.W. 1985. Influence of continuous vs intermittent tumbling for various lengths of time on the characteristics of restructured cured beef. *Animal Science Fact Sheet, ASC:85-12, MAFES, Mississippi State University.*
- Gillett, T.A., Meiburg, D.E., Brown, C.L. and Simon, S. 1977. Parameters affecting meat protein extraction and interpretation of model system data for meat emulsion formation. *J. Food Sci.* 42:1606.
- Goodno, C.C. and Swenson, C.A. 1975. Thermal transitions of myosin and its helical fragments. 2. Solvent induced variations in conformational stability. *Biochemistry* 14(5):873.
- Gwin, M.D. 1986. A comparison of restructured steaks made from pre-rigor and post-rigor beef. M.S. Thesis. University of Tennessee, Knoxville.
- Hamm, R. 1960. Biochemistry of meat hydration. *Adv. Food Research* 10:355.
- Hamm, R. 1970a. Influence of salting beef immediately after slaughter on the water-holding capacity of meat and sausage mixtures. *British Food Manufact. Ind. Research Assoc. Technic, Circular No.447.*

- Hamm, R. 1970b. Interactions between phosphates and meat proteins. In "Symposium Phosphates in Food Processing." Ed. Deman, J.M. and Melnychyn, P., Chapt. 5 p. 65. AVI Publishing Co.
- Hamm, R. 1977a. Post-mortem breakdown of ATP and glycogen in ground muscle. *Meat Sci.* 1:15.
- Hamm, R. 1977b. Changes of muscle proteins during the heating of meat. In "Physical, Chemical, and Biological Changes in Food Caused by Thermal Processing," Ed. Hoyem, T. and Kvale, O., p. 101. The Norwegian Food Research Institute, As. Norway, Applied Science Publishers Limited, London.
- Hamm, R. 1978. The use of freeze-dried pre-rigor beef in sausages. Proceed Meat Industry Research Conference, AMSA, American Meat Institute Foundation. p. 32.
- Hamm, R. and Deatherage, F.E. 1960. Changes in hydration, solubility and charges of muscle proteins during heating of meat. *Food Res.* 25:587.
- Hansen, L. J. 1960. Emulsion formation in finely comminuted sausage *Food Tech.* 14:565.
- Hansen, L.J., Hills, C. and Schwall, D.V. 1966. Method of preparing a poultry product. U.S. Patent 3, 285, 752.
- Hansen, K.R. and Mandigo, R.W. 1972. The effect of pre-chill pork on flaked formed and sectioned pork products. *J. Anim. Sci.* 35:1096 (Abstr.).
- Hegarty, G.R., Bratzler, L.J., Pearson, A.M. 1964. Studies on the emulsifying properties of some intracellular beef muscle proteins. *J. Food Sci.* 29:663.
- Hellendoorn, E.W. 1962. Water-binding capacity of meat as affected by phosphates. *Food Tech.* 16(9):119.
- Henrickson, R.L. 1975. Hot-boning . Proc. of the Meat Ind. Res. Conf., p. 25. Amer. Meat Inst. Foundation.
- Hess, E., Ruosch, W. and Breer, C. 1980. Extending the shelf life of prepackaged fresh meat. *Fleischwirtsch.* 60(8).

- Hollingsworth, C.A., Mandigo, R.W. and Calkins, C.R. 1982. Rapid chilling and pre-rigor muscle influences on the bind, texture and ultrastructure of restructured beef steaks. *J. Anim. Sci.* 57:222 (Abstr.).
- Honikel, K.O. and Hamm, R. 1978. Influence of cooling and freezing of minced pre-rigor muscle on the breakdown of ATP and glycogen. *Meat Sci.* 2:181.
- Honikel, K.O., Fischer, C. Hamid, A. and Hamm, R. 1981a. Influence of post-mortem changes in bovine muscle on the H₂O holding capacity of beef. Post-mortem storage of muscle at 20°C. *J. Food Sci.* 46:1.
- Honikel, K.O., Hamid, A., Fischer, C. and Hamm, R. 1981b. Influence of post-mortem changes in bovine muscle in the H₂O holding capacity of beef post-mortem storage of muscle at various temperatures between 0 and 30°C. *J. Food Sci.* 46:36.
- Hostetler, R.L., Carpenter, Z.L., Smith, G.C. and Dutson, T.R. 1975. Comparison of post-mortem treatments for improving tenderness of beef. *J. Food Sci.* 40:223.
- Huffman, D.L. 1980. Process for production of a restructured fresh meat product. U.S. Patent. 4, 210, 677.
- Huffman, D.L. and Cordray, J.C. 1979. Restructured fresh meat cuts from chilled and hot processed pork. *J. Food Sci.* 44:1564.
- Huffman, D.L., Cross, H.R., Campbell, K.J. and Cordray, J.C.. 1981. Effect of salt and tripolyphosphate on acceptability of flaked and formed hamburger patties. *J. Food Sci.* 46:34.
- Huffman, D.L. and Powell, W.E. 1970. Fat content and soya level effect on tenderness of ground beef patties. *Food Tech.* 24:100.
- Judge, M.D. and Aberle, E.D. 1980. Effect of pre-rigor processing on the oxidative rancidity of ground light and dark pork muscles. *J. Food Sci.* 45:1736.

- Kardouche, M.B., Pratt, D.E. and Stadelman, W.J. 1978. Effect of soy protein isolate on turkey rolls made from pre- and post-rigor muscle. *J. Food Sci.* 43:882.
- Kelly, K., Jones, N.R., Lowe, R.M. and Olley, J. 1966. Texture and pH in fish muscle related to 'cell fragility' measurements. *J. Food Tech.* 1:9.
- Khan, A.W. and Nakamura, R. 1970. Effects of pre- and post-mortem glycolysis on poultry tenderness. *J. Food Sci.* 35:266.
- Kotter, L. and Fischer, A. 1975. The influence of phosphates or polyphosphates on the stability of foams and emulsions in meat technology. *Die Fleischwirtschaft Nv.* 3:365.
- Krause, R.J., Ockerman, H.W., Krol, B., Moerman, P.C. and Plimpton, Jr., R.F. 1978a. Influence of tumbling, tumbling time, trim and sodium tripolyphosphate on quality and yield of cured hams. *J. Food Sci.* 43:853.
- Krause, R.J., Plimpton, Jr., Ockerman, H.W. and Cahill, V.R. 1978b. Influence of tumbling and sodium tripolyphosphate on salt and nitrite distribution in porcine muscle. *J. Food Sci.* 43:190.
- Laakkonen, E., Wellington, G.H. and Sherborn, J.W. 1970. Low-temperature, longtime heating of bovine muscle. 1. Changes in tenderness, water-binding capacity, pH and amount of water-soluble components. *J. Food Sci.* 35:175.
- Landes, D.R. 1972. The effects of polyphosphates on several organoleptic, physical and chemical properties of stored precooked frozen chickens. *Poultry Sci.* 51:641.
- Locker, R.H. 1960. Degree of muscular contraction as a factor in tenderness of beef. *J. Food Sci.* 25:304.
- Lawrie, R.A. *Meat Science*. 3rd. Edition. Pergamon Press Ltd. Oxford. 1979.
- Locker, R.H. and Hagyard, C.J. 1963. A cold shortening effect in beef muscles. *J. Food Sci. Agric.* 14:787.

- MacFarlane, J.J., Schmidt, G.R. and Turner, R.H. 1977. Binding of meat pieces: A comparison of myosin, actomyosin and sarcoplasmic proteins as binding agents. *J. Food Sci.* 42:1603.
- Maesso, E.R., Baker, R.C., Bourne, M.C. and Vadehra, D.V. 1970a. Effect of some physical and chemical treatments on the binding quality of poultry loaves. *J. Food Sci.* 35:440.
- Maesso, E.R., Baker, R.C. and Vadehra, D.V. 1970b. The effect of vacuum, pressure, pH and different meat types on the binding ability of poultry meat. *Poultry Sci.* 49:697.
- Mahon, J.H. and Schneider, C. 1968. Phosphate meat additives. Canadian Patent 788, 939.
- Mandigo, R.W. 1974 Restructured meat products. Proceedings of the 27th Reciprocal Meats Conference 27:403.
- Mandigo, R.W. 1975. Restructured meat in: Proc. 11th Annual Meat Industry Research Conference. American Meat Institute, Washington, D.C. 3:43.
- Mandigo, R.W., Hanson, K.R. and Chesney, M.S. 1972. Effect of salt content and flaking temperature on flaked, formed and sectioned meat products. *J. Anim. Sci.* 35:198 (Abstr.).
- Marsh, B.B. and Leet, N.G. 1966a. Resistance to shearing of heat-denatured muscle in relation to shortening. *Nature, London* 211:635.
- Marsh, B.B. and Leet, N.G. 1966b. Studies in meat tenderness. 3. The effects of cold shortening on tenderness. *J. Food Sci.* 31:450.
- Marsh, B.B., Woodhams, P.R. and Leet, N.G. 1968. Studies in meat tenderness. 5. The effects on tenderness of carcass cooling and freezing before the completion of rigor mortis. *J. Food Sci.* 33:12.
- Marsh, B.B. and Carse, W.A. 1974. Meat tenderness and the sliding-filament hypothesis. *J. Food Tech.* 9:129.
- Marsh, B.B., Leet, N.G. and Dickson, M.R. 1974. The ultrastructure and tenderness of highly cold-shortened muscle. *J. Food Tech.* 9:141.

- McCrae, S.E., Seccombe, C.G., Marsh, B.B. and Carse, W.A. 1971. Studies in meat tenderness. 9. The tenderness of various lamb muscles in relation to their skeletal restraint and delay before freezing. *J. Food Sci.* 36:566.
- Miles, C.A. and Lawrie, R.A. 1970. Relation between pH and tenderness in cooked muscle. *J. Food Technol.* 5:325.
- Miller, E.M. and Harrison, D.L. 1965. Effect of marination in sodium hexametaphosphate solution on the palatability of loin steaks. *Food Tech.* 19:94.
- Miller, W.O., Saffle, R.L. and Zirkle, S.B. 1968. Factors which influence the water-holding capacity of various types of meat. *Food Tech.* 22:1139.
- Moeller, P.W., Fields, P.A., Dutson, T.R., Landmann, W.A. and Carpenter, Z.L. 1976. Effect of high temperature conditioning on subcellular distribution and levels of lysosomal enzymes. *J. Food Sci.* 41:216.
- Moeller, P.W., Fields, P.A., Dutson, T.R., Landmann, W.A. and Carpenter, Z.L. 1977. High temperature effects on lysosomal enzyme. Distribution and fragmentation of bovine muscle. *J. Food Sci.* 42(2):510.
- Moore, S.L., Theno, D.M., Anderson, C.R. and Schmidt, G.R. 1976. Effect of salt, phosphate and nonmeat protein on binding strengths and cook yields of beef rolls. *J. Food Sci.* 41:424.
- Neer, K.L. and Mandigo, R.W. 1974a. Effect of tripolyphosphate and salt on flaked, cured pork. *J. Anim. Sci.* 39:173.
- Neer, K.L. and Mandigo, R.W. 1974b. Effect of frozen storage on flaked cured pork. *J. Anim. Sci.* 39:973.
- Neer, K.L. and Mandigo, R.W. 1977. Effects of salt, Na tripolyphosphate and frozen storage time on properties of a flaked, cured pork product. *J. Food Sci.* 42(3) 738.
- Newbold, R.P. and Harris, P.V. 1972. The effect of pre-rigor changes on meat tenderness. A Review. *J. Food Sci.* 37:337.

- Newbold, R.P. and Scopes, R.K. 1967. Postmortem glycolysis in ox skeletal muscle. Effect of temperature on the concentration of glycolytic intermediates and cofactors. *Biochem. J.* 105:127.
- Ockerman, H.W. 1969. Quality control of post-mortem muscle tissue. 3rd ed. Ohio State University.
- Ockerman, H.W., Plimpton, Jr., R.F., Cahill, V.R. and Parrett, N.A. 1978. Influence of short term tumbling, salt and phosphate on cured canned pork. *J. Food Sci.* 43:878.
- Parrish, F.C. 1974. Relationship of marbling to meat tenderness. *Proc. Meat Ind. Res. Conf.* 117.
- Parrish, F.C., Jr., Rust, R.E., Popenhagen, G.R. and Miner, B.E. 1969. Effect of post-mortem aging time and temperature on beef muscle attributes. *J. Anim. Sci.* 29:398.
- Paul, P.C., McCrae, S.E. and Hofferber, L.M. 1973. Heat-induced changes in extractability of beef muscle collagen. *J. Food Sci.* 38:66.
- Penfield, M.P., Barker, C.L. and Meyer, B.H. 1976. Tensile properties of beef semitendinosus muscle as affected by heating rate and end point temperature. *J. Text. Studies.* 7:77-85.
- Pepper, F.H. and Schmidt, G.R. 1975. Effect of blending time, salt, phosphate and hot boned beef on binding strength and cook yield of beef rolls. *J. Food Sci.* 40:227.
- Perdue, R.R., Kuehne, R.O. and Brown, W.L. 1975. Vacuum packaging to extend the shelf-life of fresh beef. Presented at the 35th Annual Meeting of Institute of Food Technologists, Chicago, IL.
- Pietraszek, G. 1972. Broader markets sought through fabricated pork. *Nat'l. Provisioner* 166:16.
- Popenhagen, G.R., Mandigo, R.W., Hansen, K.R., Chesney, M.S. and Mahoney, L.C. 1973. The effect of temperature, flake size and blending on flaked formed and sectioned pork products. *J. Anim. Sci.* 37:269.

- Popenhagen, G.R. and Mandigo, R.W. 1974. Influence of flake size, flake temperature and blend combinations on the chemical, physical and organoleptic properties of fabricated pork. *J. Food Sci.* 37(1):227.
- Popenhagen, G.R. and Mandigo, R.W. 1978. Properties of restructured pork as affected by flake size, flake temperature and blend combinations. *J. Food Sci.* 43:1641.
- Powell, V.H. 1978. Weep in vacuum packaged meat. Proceed 24th Europ, Meeting Meat Research Workers, Kulmbach, paper D.1.
- Rahelic, S., Rede, R. and Jovicic, V. 1966. Effect of polyphosphates on some physicochemical properties of cured pork. *Tech. Mesa.* 7(9):253.
- Rahelic, S., Pribis, V. and Vicevic, Z. 1974. Influence of mechanical treatment of cured muscles on some characteristics of pasteurized canned pork. *Proceedings of the 20th European Meeting of Meat Research Workers.* HS, p133.
- Randall, C.J. and Larmond, E. 1977. Effect of method of comminution (flake-cutting and grinding) on the acceptability and quality of hamburger patties. *J. Food Sci.* 42(3):728.
- Reynolds, J.B., Anderson, D.B., Schmidt, G.R., Theno, D.M. and Siegel, D.G. 1978. Effects of ultrasonic treatment on binding strength in cured ham rolls. *J. Food Sci.* 43:866.
- Rhee, K.S. 1978. Minimization further lipid peroxidation in the distillation 2-thiobarbituric acid test of fish and meat. *J. Food Sci.* 43:1776.
- Saffle, R.L. and Galbreath, J.W. 1964. Quantitative determination of salt-soluble protein on various types of meat. *Food Tech* (1943)119.
- Sato, Y. and Nakayama, T. 1970. Relationships between binding quality of meat and myofibrillar proteins. I. Discussion of the binding quality of minced meats based on their rheological properties before and after heating. *J. Texture Studies* 1:309.
- Schmidt, G.R. 1977. Why massage or tumble? *Meat Ind.* 11:40.

- Schmidt, G.R. 1978. Sectioned and formed meat. Proceedings of the 31st Reciprocal Meats Conference 31:18.
- Schmidt, G.R. and Trout, G.R. 1982. The chemistry of meat binding, In "Proceedings International Symposium Meat Science and Technology," (Ed.) Franklin, K.R. and Cross, H.R., p.265. National Livestock and Meat Board. Chicago, IL.
- Schnell, P.G., Vadehra, P.V. and Baker, R.C. 1970. Mechanism of binding chunks of meat. 1. Effect of physical and chemical treatments. Can. Inst. Food Tech. J. 3(2):44.
- Schwartz, W.C. and Mandigo, R.W. 1976. Effect of salt, sodium tripolyphosphate and storage on restructured pork. J. Food Sci. 41:1266.
- Seideman, S.C., Vanderzant, C. Smith, G.C., Hanna, M.O. and Carpenter, Z.L. 1976. Effect of degree of vacuum and length of storage on the microflora of vacuum packaged beef wholesale cuts. J. Food Sci. 41:738.
- Sherman, P. 1961. The water binding capacity of fresh pork. 1. The influence of sodium chloride, pyrophosphate and polyphosphate on water absorption. Food Tech 15:79.
- Shults, G.W. and Wierbicki, E. 1973. Effect of sodium chloride and condensed phosphates on the water-holding capacity, pH and swelling of chicken muscle. J. Food Sci. 38:991.
- Siebert, H. 1978. A look at the plusses of vacuum cutting. Food in Canada 38(3):26.
- Siegel, D.G., Theno, D.M. and Schmidt, G.R. 1978a. Meat massaging: The effects of salt, phosphate and massaging on the presence of specific skeletal muscle proteins in the exudate of sectioned and formed ham. J. Food Sci. 43:327.
- Siegel, D.G., Theno, D.M., Schmidt, G.R. and Norton, H.W. 1978b. Meat massaging: The effects of salt, phosphate and massaging on cooking loss, binding strength and exudate composition in sectioned and formed ham. J. Food Sci. 43:431.

- Smith, J.L. and Alford, J.A. 1968. Action of micro-organisms on the peroxides and carbonyls of rancid fat. *J. Food Sci.* 33:93.
- Smith, G.C., Arango, T.C. and Carpenter, Z.L. 1971. Effects of physical and mechanical treatments on the tenderness of the beef longissimus. *J. Food Sci.* 36:445.
- Solomon, L.W. and Schmidt, G.R. 1980. Effect of vacuum and mixing time on the extractability and functionality of pre and post-rigor beef. *J. Food Sci.* 45:283.
- Sulzbacher, W.L., Gibbs, R.J., Swift, C.E. and Fryar, A.J. 1960. Protein investigations at the USDA Beltsville Meat Laboratory. *Proc. 12th Res. Conf. Amer. Meat Inst., Chicago.* p.61.
- Swift, C.E. and Ellis, R. 1957. Action of phosphates in sausage products II. pilot plant studies of the effects of some phosphates on binding and color. *J. Food Tech.* Aug:450.
- Swift, C.E., Lockett, C. and Tryar, A.J. 1961. Comminuted meat emulsions. The capacity of meats for emulsifying fat. *Food Tech.* 15:468.
- Swift, C.E. and Sulzbacher, W.L. 1963. Factors affecting meat proteins as emulsion stabilizers. *Food Tech.* 225:107.
- Taylor, A.A., Shaw, B.G. and MacDougall, D.B. 1981. Hot deboning of beef with and without electrical stimulation. *Meat Sci.* 5:109.
- Terrell, R.N. 1971. Rapid and official analytical methods for the meat industry. Griffith Laboratories. Chicago.
- Theno, D.M., Siegel, D.G. and Schmidt, G.R. 1977. Meat massaging. In "Proc. Meat Ind. Research Conf." Am. Meat Sci. Assoc. and Am. Meat Inst. Foundation, Chicago, Mar. 24-25. p.53.
- Theno, D.M., Siegel, D.G. and Schmidt, G.R. 1978a. Meat Massaging: Effects of salt and phosphate on the ultrastructure of cured porcine muscle. *J. Food Sci.* 43:488.

- Theno, D.M., Siegel, D.G. and Schmidt, G.R. 1978b. Meat Massaging: Effects of salt and phosphate on the micro structure of binding junctions in sectioned and formed hams. *J. Food Sci.* 43:493.
- Theno, D.M., Siegel, D.G., Schmidt, G.R. 1978c. Meat Massaging: Effects of salt and phosphate on the micro structural composition of the muscle exudate. *J. Food Sci.* 43:483.
- Trautman, J.C. 1964. Fat emulsifying properties of pre-rigor and post-rigor pork proteins. *J. Food Tech.* 7:121.
- Trout, G.R. and Schmidt, G.R. 1984. Effect of phosphate type and concentration, salt level and method of preparation on binding in restructured beef rolls. *J. Food Sci.* 49:687.
- Vadehra, D.V. and Baker, R.C. 1970. The mechanism of heat initiated binding of poultry meat. *Food Tech.* 24:766.
- Watts, B.M. 1961. Meat products. In "Symposium on Foods: Lipids and Their Oxidation." p. 202. AVI Publishing Co., Westport, Conn.
- Weiss, G.M. 1974. Ham tumbling and massaging. A special report reprinted from *Western Meat Industry*, Oct.
- Whiting, R.C. 1980. Calcium uptake by bovine muscle mitochondria and sarcoplasmic reticulum. *J. Food Sci.* 45:288.
- Wiebe, W.R., Jr. and Schmidt, G.R. 1982a. Effects of mixing and thermal processing on shelf-stable sectioned and formed beef. *J. Food Sci.* 47:409.
- Wiebe, W.R., Jr. and Schmidt, G.R. 1982b. Effects of vacuum mixing and precooking on restructured steaks. *J. Food Sci.* 47:386.
- Wierbicki, E., Cahill, V.R. and Deatherage, F.E. 1957. Effects of added sodium chloride, potassium chloride, calcium chloride, magnesium chloride and citric acid on meat shrinkage at 70°C. and of added NaCl on drip losses after freezing and thawing. *Food Tech.* 11:74.
- Wierbicki, E. and Deatherage, F.E. 1958. Determination of water-holding capacity of fresh meats. *Agric. and Fd. Chem.* 6(5):387.

- Wierbicki, E. and Kunkle, L.E., Cahill, V.R. and Deatherage, F.E. 1954. The relation of tenderness to protein alterations during post mortem ageing. J. Food Tech. 11:506.
- Wistreich, H.E. 1972. The role of salt in meat processing. National Provisioner. 166(26):17.
- Woollen, A. 1971. Growing interest in meat tumbling. Fd. Manufacture 46:(10):35.

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