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A COMPARISON OF RESTRUCTURED STEAKS MADE FROM PRE-RIGOR AND POST-RIGOR BEEF

A Thesis

Presented for the

Master of Science

Degree

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Mark Dickens Gwin

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ABSTRACT

There is a question of how to best utilize muscle tissue from older (C, D, and E) maturity cattle or from lower priced cuts. This study was undertaken to test the viability of utilizing older cow meat to make intermediate value products (restructured strip steaks) by mixing flaked cow beef with fat from USDA choice grade carcasses. Objectives were to determine: (1) the effect of various ratios of pre-rigor and post-rigor beef on bind, textural and physical properties of restructured steaks, and (2) the effect of various flake size combinations on the bind, textural and physical properties of restructured steaks.

The results showed that the post-rigor treatments showed less distortion, less cooking loss, and had a more attractive appearance. However, the pre-rigor muscle tissue flaked to 0.750 inch flake size proved to be the treatment most resembling an intact muscle product. The pre-rigor 0.750 inch flake size treatment had superior shear, bind, hardness, cohesiveness and chewiness scores.

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CHAPTER I

INTRODUCTION

There has always been some question of how to utilize lower-priced cuts or lower-priced beef carcasses to maximize value and profit. Restructured beef products offer a viable option as these products have an intermediate value between ground beef and intact muscle products (Breidenstein, 1982). Restructuring allows the utilization of lower economic value cuts or carcasses and through manufacturing techniques upgrade these raw materials into desirable meat products of a uniform size, shape and texture (Cordray and Huffman, 1983).

The demand for restructured meat products in the Hotel, Restaurant and Institutional (HRI) trade has risen over the past 3 to 5 years, and is expected to rise for the next 10 years (Cordray and Huffman, 1983). This is very significant as the HRI trade accounts for 40% of the meals eaten daily. It is definitely advantageous to HRI trade to offer meat products of a uniform size, shape and texture (Coon, 1982).

Because the popularity of such restructured meat products is on the upswing, industry has developed methods to manufacture these products. These methods involve product size reduction, blending, and forming the meat particles into a product which resembles an intact muscle (Coon, 1982). There are several advantages to this method of processing including: (1) portion control (size, shape and weight), (2) a bonless product (no waste), (3) control of fat content, (4)

formulation to compositional standards, (5) control of texture, (6) product differentiation, (7) utilization of less valuable carcasses or trimmings, (8) intermediate value (priced between ground beef and intact steaks), and (9) frozen product stability (Mandigo, 1974; Breidenstein, 1982, Coon, 1982).

Another area of potential economic benefit to the meat industry that merits further research is that of pre-rigor or hot-boned meat processing. This process involves the removal of the edible tissues from the carcass soon after slaughter and prior to chilling (West, 1983). Advantages for this method of processing include: (1) decreased amount of cooler space (a 600-lb beef carcass requires approximately 120,400 cubic inches of space whereas the edible portion of this carcass can be cooled in 26,000 cubic inches--a 78% saving in space), (2) superior binding quality and functional characteristics, (3) reduced energy consumption (a 600-lb carcass requires 31,500 BTU's to reduce the temperature from 102°F to 32°F but the 420 pounds of edible portion requires only 22,380 BTU's which represents a 30% savings, (4) lowered labor requirements, (5) less inplant holding time, and (6) higher yields (Henrickson, 1975; Williams, 1978; Reagan, 1983; West 1983).

There are potential disadvantages in the utilization of pre-rigor muscle. These include: (1) tenderness problems due to cold shortening or thaw rigor and (2) handling and trimming problems due to the flaccid properties of the hot meat (Locker and Hagyard, 1963; Marsh and Leet, 1966; Bendall, 1972; Williams 1978; West, 1983).

The objectives of this study were to: (1) determine the effect of various ratios of pre-rigor and post-rigor beef on bind, textural and physical properties of restructured steaks, and (2) evaluate the effect of various flake size combinations on the bind, textural and physical properties of restructured steaks.

CHAPTER II

REVIEW OF LITERATURE

I. RESTRUCTURED MEATS

The concept of restructured beef is to produce a steak which resembles intact muscle in textural properties, is uniform, has desirable color, and is completely edible. Restructuring utilizing flaking technology has expanded meat product utilization to produce low-cost steaks and chops from cuts normally processed into roasts or sausage (Booren et al., 1981a). These restructured products have an intermediate value between intact muscle cuts and ground beef (Breidenstein, 1982).

Comminution Method

The first step in the production of a restructured product is to reduce meat particle size. This is accomplished by chopping, flaking, grinding or sectioning (Coon, 1982). This results in an increase in meat surface area and consequently 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, 1972).

Comminution of meats by flaking involves the use of a high speed centrifugal impeller which forces the meat against stationary

precision honed shearing heads like the Urschel Comitrol (Urschel Laboratories, Inc., Valparaiso, Indiana) (Huffman et al., 1981). The result is uniform size flakes. The size and shape of these flakes may be adjusted by size of head, speed of impeller and temperature of raw material. Flaking enhances textural properties, retention of juices, binding characteristic and cohesive properties. Flaking also results in less cooking losses and improved sensory characteristics as compared to grinding (Fenters and Ziemba, 1971; Huffman et al., 1981).

Hamm (1960) found that the more intensive the comminution, the higher the water-holding capacity (WHC). Grinding or flaking loosens the muscle structure and allows more space to be available for water, resulting in an increased meat hydration. However, if the particle size is too fine (as with grinding) the product resembles ground beef (Anonymous, 1976), and this is not the intended texture for restructured products. However, Chesney et al. (1978) found no difference in WHC, cooking loss or shear values between flaked and ground pork.

Particle Size

Le Maire (1978) found that particle size is an important factor affecting the texture of restructured meat products. The finer the particle size, the larger the surface area. The net result of an increase in meat surface area is an increase in the availability of myofibrillar proteins for binding and a release of muscle fiber contents. There is a directly proportional relationship between the

increase in tissue rupture and the increased release of salt soluble proteins. As both of these increase, there is a decrease in cooking losses and an increase in binding strengths due to the increased availability of myofibrillar proteins (Acton, 1972).

Popenhagen and Mandigo (1978) compared 3.0, 6.9, and 12.7 mm. flake sizes of restructured pork. The smallest flaking size resulted in a less tender, less juicy, and less acceptable product with lower cooking losses than pork processed with larger flake sizes. The larger flake size resulted in a product with inferior cohesive properties. Popenhagen and Mandigo (1978) also pointed out that a higher quality product could be produced by blending a small flake with a larger flake size each flaked at a different temperature in a 50:50 ratio. Likewise, Chesney et al. (1978) compared 3 different flake sizes and 3 grinding sizes of restructured pork. There were no differences for WHC or shear force (Warner-Bratzler) tests but cooking loss decreased as particle size decreased. Panel scores favored the cohesiveness of the smaller particle size. However, Durland et al. (1982) found that restructured beef steaks formulated from a fine flake size produced a more tender product that had lower shear force scores. Durland et al. (1982) also stated that the fine flake size had a more acceptable appearance with less visible fat.

However, if the particle size is too fine, the product resembles ground beef. On the other hand, if the particle size is too large, there are objectionable chewy pieces in the final product (Anonymous, 1976). Anonymous (1976) suggested that the .75 in flaking head was

the best size. Popenhagen and Mandigo (1978) also stated that restructured pork products made from large particles are not as cohesive as those made from smaller flakes.

Meat Temperature

The temperature of the meat at all stages of production of restructured steaks is of extreme importance to the final product. Flaking, blending, and steak formation (patty former) are all affected. The initial temperature of the meat also affects final product color and stability (Coon, 1982).

Farrington (1975) stated that the type of product desired should dictate the processing temperature, since the exact temperature to insure optimal cohesion varies from product to product. This study indicated that a flaking temperature of 28-30°F was best for restructured lamb products.

Popenhagen and Mandigo (1978) studied the properties of restructured pork as affected by 2 different flaking temperatures: -5.6°C and 2.2°C. The flaking temperature affected the textural properties of restructured pork. The pork flaked at 2.2°C resulted in a product with less cooking loss, superior cohesive properties, more juiciness and greater overall acceptability, but lower raw product acceptability scores than pork flaked at -5.6°C. However, this study stated that a higher quality product could be produced by blending a smaller flake with a larger flake, each of a different temperature, in a 50:50 ratio.

Three different temperatures (32.2, 2.2 and -5.6°C) for flaking and grinding pork were evaluated by Chesney et al. (1978). The Warner-Bratzler shear value for these products was highest for the pre-rigor (32.2°C) meat, and decreased with decreasing temperatures. However, panelists found the chilled (2.2°C) meat to be more cohesive. Plus, as the temperature decreased from 32.2°C, cooking losses increased and the 32.2°C meat had higher raw product acceptability scores (better color).

Costello et al. (1981) studied three different flaking temperatures and their effect on restructured beef steaks. This study found that steaks made of meat flaked at 2.2°C had less visible fat, a finer textural appearance and were more appealing in overall appearance than steaks made from meat flaked at -2.2 and -5°C.

Mandigo (1975) utilized two different temperatures for flaked and formed pork. This study said that the fat should be flaked through a fine head at 0 to 2°C to avoid large fat deposits. However, the lean should be coarse flaked at temperatures of -5.6 to -4.4°C.

Mixing Time

Mixing has two purposes in restructured meat products: (1) to extract proteins through mechanical action and (2) to provide a uniform distribution of fat, salt, and any other additives (Coon, 1982).

Maesso et al. (1970) stated that the mixing action increased the surface area and ruptured the muscle cells, thereby releasing the intracellular components of the cell and exposing a greater amount of

protein and non-protein moieties. The exudate that is released upon massaging (especially in the presence of salt and/or phosphate) is principally a solubilized protein suspension containing myofibrillar proteins, fat, water, and pieces of muscle fibers (Theno et al., 1978a). Theno et al. (1978a) also found that 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. This was found by taking samples of the tacky exudate on meat surfaces removed at interval during 24 hours of massaging.

Schmidt (1977) determined that mixers are impractical for agitation of larger chunks of meat due to the fact that the paddles shred and tear the meat and cause significant fiber disruption. This inhibited the effectiveness of the mixing action. This study also found that in order to get optimal binding, it was necessary to solubilize proteins and mechanical energy alone did not suffice. Salt and/or phosphates were added to more effectively solubilize these proteins. Theno et al. (1978b) also found this to be true in a study involving cured ham muscles massaged for differing time periods in the presence of increasing amounts of salt with or without phosphate. This study reported that binding between chunks of meat was a phenomenon involving structural rearrangement of the solubilized meat proteins and that the effects of massaging were more pronounced in the presence of salt and phosphates. The massaging process imparted frictional energy to muscle chunks to extract salt soluble or

myofibrillar proteins rather than impact or shearing energy as in tumblers or mixers. Durland et al. (1982) found that flaked and formed beef steaks made from meat mixed 0 to 5 minutes were more coarse in texture than beef mixing 10 or 15 minutes. Also, mixing for 15 minutes resulted in lower panel tenderness and juiciness scores. Durland et al. (1982) concluded that flaked, restructured beef did not need to be mixed for long periods of time (<10 minutes) as flaking through the comitrol effectively exposed protein surfaces for binding. Also, Booren et al. (1981a) stated that tenderness was highest after 8 minutes mixing time and after this time, case hardening affected tenderness ratings. Plus, Pepper and Schmidt (1975) worked with beef rolls and found that increased mixing times resulted in higher cooking yield but had little effect on binding strength. In work with restructured pork, Mandigo (1975) concluded that 8-10 minutes was optimum mixing time. However, Booren et al. (1981b) experimented with vacuum mixing beef and found that an increase in mixing time results in superior tenderness as measured by Lee-Kramer shear. Vacuum mixing produces a less desirable surface color in finished steaks as measured by a trained panel and a spectrophotometer. Therefore, Booren et al. (1981b) concluded that there is no need for vacuum mixers for restructured products. Additionally, Booren et al. (1981c) and Wiebe and Schmidt (1982) found an increase in bind (measured objectively) due to vacuum mixing, but no effect on cook yield. They concluded that the benefits were too subtle to warrant its use. Therefore, gentle massaging or tumbling in the presence of

salt and/or phosphates for less than 10 minutes resulted in a product with superior bind.

Belohlavy and Mandigo (1974), working with beef, pork and lamb, found WHC decreased to its lowest level as mixing time increased up to 14 minutes but increased after 14 minutes mixing time. The researchers stated that the initial breakdown of cell walls released free water; however, more mixing extracted more proteins that bound additional water. They also said that further mixing may also loosen the muscle structure thereby increasing the intermolecular space available for water.

Salt Level

There has been considerable controversy in recent years surrounding salt and the sodium content of foods. This is primarily due to the question of the role of dietary sodium in aggravated hypertension (Abernathy, 1982). Andres (1982) stated that 20% of the U.S. population has some degree of hypertension and 10 to 30% of these people could benefit from a decrease in the average American intake of almost 5000 mg of salt per day (Paquette, 1982). Of this 5000 mg, 1200 mg occurs naturally in food and water, 1200 mg are added by the cook or at the table, and 2400 mg are added during commercial processing of the food. However, the minimum daily requirement of sodium is thought to be approximately 200 mg per day with 1100-1300 mg per day being safe (Andres, 1982). According to this data, the concern over excess sodium is justified.

However, a direct link between sodium intake and hypertension has not been established. There are many factors affecting hypertension, including genetic makeup, obesity, nutrition, and stress (Andres, 1982). This is significant as the meat industry relies heavily on salt because salt increases shelf life and product stability by reducing water activity and inhibiting microbial growth. Salt solubilizes myofibrillar proteins which are very important in bind and textural characteristics of meat products. Salt also increases the WHC and the yield of meat products. Additionally, salt provides flavor enhancement properties that contribute to the final product flavor and acceptability (Anonymous, 1981; Andres, 1982; Paquette, 1982). It has been estimated that processed meats account for approximately 10% of daily sodium intake (Anonymous, 1981). Abernathy (1982) stated that 14% of the salt consumed by young adults came from meat, fish and poultry.

Pepper and Schmidt (1975) found that salt increased bind in restructured beef rolls. Schmidt (1977) worked with massaging and tumbling and found that in order to get optimal binding it was necessary to solubilize proteins and mechanical energy alone did not do this, but salt and phosphate did. Schnell et al. (1970) stated that, in general, as salt concentration increased, myofibrillar protein extractability increased and binding properties were enhanced. Theno et al. (1978a,b,c) said that salt addition increased bind in sectioned and formed ham and Neer and Mandigo (1977) found the same effect in flaked cured pork. Samples with no added salt showed fiber

disruption, but those with added salt showed fiber disruption and solubilized proteins (Theno, 1978a). Theno et al. (1978b) massaged cured ham muscles for different lengths of time and found the effects of massaging more pronounced in the presence of salt and phosphate. Wierbicki et al. (1957) and Theno et al. (1978b) also stated that the addition of salt to processed meat products increased the water holding capacity (WHC). Pepper and Schmidt (1975), Schwartz and Mandigo (1976), Neer and Mandigo (1977) and Theno et al. (1978b) also found that the addition of salt greatly reduced cooking losses. Wierbicki et al. (1957) also found that when salt was added to meat prior to freezing there was less drip loss upon thawing.

Trautman (1964) stated that increased salt soluble protein extraction created a more stable emulsion as salt soluble proteins are the major emulsifying components. Water soluble proteins and salt insoluble residue have little emulsifying power (Swift et al., 1961; Trautman, 1964). Swift et al. (1961) and Swift and Sulzbacher (1963) reported that the action of salt appeared to enhance the tendency of the water soluble or sarcoplasmic proteins to stabilize emulsions.

The electrostatic interaction between salt ions and protein ions explains the effect of salt in meat hydration (Hamm, 1960). More negatively charged groups occur in meat proteins when the pH is above the isoelectric point of muscle (pH>5.0). The salt ions (Na^+) screen the plus charges of the proteins and the net charge of the protein is increased as the electrostatic repulsion between the proteins

is increased by the binding ions. There is a subsequent increase in the WHC because of the resultant widening of the muscle structure (Hamm, 1960).

Mandigo et al. (1973), Schwartz and Mandigo (1976), Cross and Stanfield (1976), Neer and Mandigo (1977) and Huffman et al. (1981) agreed that the addition of salt increased all palatability measurements (aroma, flavor, eating texture and juiciness). However, Schwartz and Mandigo (1976) and Booren and Mandigo (1981) found that salt had a detrimental effect on the color of restructured meat products. Salt can contain impurities such as iron, copper and possibly cadmium which can promote oxidation of myoglobin to metmyoglobin (Booren and Mandigo, 1981). Therefore, this study recommended that a minimal amount of salt be added (.5-.75%) to achieve binding of meat pieces. The findings of Huffman et al. (1981) contradict the previous researchers concerning color as they showed that the addition of salt enhanced the color of the patties in their research.

Schwartz and Mandigo (1976) also proved that salt increases oxidative rancidity as measured by malonaldehyde content (measured by the thiobarbituric acid or TBA method) in restructured pork products. This is significant as lipid oxidation has long been recognized as a key factor affecting the quality and acceptability of foods and malonaldehyde (MA) is an important product of oxidative rancidity. MA has been shown to be toxic, mutagenic and perhaps carcinogenic (Addis et al., 1983). Addis et al. (1983) also said that TBA values should be used to measure the general extent of lipid oxidation but not to quantify MA specifically.

Fat Content

Berry et al. (1985) evaluated the effects of fat level on sensory, cooking, and Instron properties of restructured beef steaks and found little difference in textural or cooking properties. The fat levels tested were 10, 14, 18, and 22%. The 18 and 22% fat levels resulted in more mouth coating for panelists, and these fat levels resulted in more distortion and configurational changes during cooking.

Cross and Stanfield (1976) studied consumer preference for two levels of fat (20 and 30%) in restructured beef steaks. The consumer panel rated the higher level of fat over the lower level for juiciness, ease of cutting, tenderness and overall acceptability but not for aroma and flavor.

Cross et al. (1980) prepared ground beef patties with fat contents of 16, 20, 24, and 28%. The 16% patties were much tougher and the patties became more tender with increasing fat levels according to a trained sensory panel and the Instron shear machine. Patties with the higher fat level were juicier than patties containing 16-20%; however, the 28% patty had a very high panel rating for mouth coating.

II. PRE-RIGOR PROCESSING

Advantages

There are numerous advantages to hot processing meat. The benefits of pre-rigor processing include decreased cooler space, less energy consumption, lower labor requirements, and less in-plant holding time as well as increased yields and functional characteristics (Reagan, 1983; West, 1983).

Pre-rigor processing has the potential to reduce or eliminate the chilling period of conventional processing between slaughter and fabricating. In doing this, approximately 30% of the inedible fat trim and bone is removed before chilling. This results in energy savings in both the chilling of the edible portion and rendering of the inedible portion of the carcass (Williams, 1978). Williams (1978) also stated that the average beef carcass requires 3.5 cubic meters of space for cooling, but the saleable meat from the carcass occupies only 5% of this volume. Likewise, Henrickson (1975) reported that a 600 pound beef carcass occupied approximately 120,400 cubic inches, but the edible portion of this size carcass could be cooled in approximately 26,000 cubic inches which was a 78% savings in space. Plus, Henrickson (1975) found that a 600 pound beef carcass required 31,500 BTU's to reduce the temperature from 102°F to 32°F whereas the 420 pounds of edible portion required only 22,380 BTU's or a 30% energy saving. Cordray and Huffman (1983) found that a 600 pound beef carcass required only 24% less energy to chill after excess fat and bone was removed.

Taylor et al. (1981) claimed that evaporative losses due to conventional methods of chilling (1-2°C with moving air) resulted in 2-4% shrink. These researchers stated that the product yield would be increased due to the reduction of such shrinkage losses by pre-rigor processing and vacuum packaging.

Reagan (1983) proposed several other advantages for hot processing of pork which could be applicable to pre-rigor processing

of beef as well. The proposed advantages include: (1) product identify or the ability for meat packers to maintain the identity of their product all the way through the marketing system, (2) improved shelf life, (3) more uniform quality, (4) creative marketing, (5) reduced shrinkage, (6) reduced levels of purge, and (7) increased rendering efficiency. Additionally, West (1983) stated that the microbial quality of hot boned product was superior to that of conventionally processed product.

Disadvantages

Even though the advantages of pre-rigor processing are sizable, there are a number of disadvantages which inhibit large scale use of this process. Systems for chilling the hot processed product must be established. Plus, there was difficulty in packaging and the product was often distorted (Reagan, 1983). Reagan (1983) also stated that beef exhibited a greater degree of cold shortening than pork. Cross et al. (1981) pointed out that no system exists for assigning a yield or quality grade for hot processed meat.

There was difficulty in placing the sticky, flaccid pre-rigor meat into a vacuum package. Moreover, this type of product results in a higher degree of purge loss, a higher percentage of leakers, and unattractive cut distortion (Apple, 1981 and Reagan, 1983). Reagan (1983) tried using larger vacuum package bags in order to more easily place the flaccid, sticky, hot cuts into the bags; however, this resulted in more purge loss. Reagan (1983) also reported that the

hot, sticky meat could be more easily placed in a thermo-form type package; however, moisture or fat buildup around the seals of these packages resulted in a higher percentage of leakers. West (1983) said that the "unattractive cut distortion" previously described was caused by uncontrolled muscle contraction of the hot cuts.

Although West (1983) found the microbial quality of hot boned product to be superior to conventionally processed product, Taylor et al. (1981) contradicted this. Taylor et al. (1981) found that due to the sticky nature of the hot processed meat, bacterial contamination was increased during deboning and packaging. Plus, some of the surfaces on the carcass, which cooled quickly during conventional processing, were covered and cooled more slowly when packaged as hot boned meat and gave more opportunity for bacterial growth (Taylor et al., 1981).

Taylor et al. (1981) discussed that with the more rapid chilling that occurred during hot processing there was a higher likelihood of cold shortening. Locker and Hagyard (1963), Marsh and Leet (1966), and Davey and Gilbert (1976) said that the muscle tissue may go through shortening due to cold or to heat. This was due to the fact that pre-rigor muscle was in a dynamic state, undergoing ATP hydrolysis, glycolysis (subsequent pH change), and ultimately uncontrolled irreversible muscle contraction or rigor mortis. Marsh and Thompson (1958) stated that severe shortening of the muscle fibers resulted when muscle was frozen while in the pre-rigor state, and the more rapid the thaw rate, the more intense the shortening became. Hamm

and Van Hoof (1971) found that muscle fiber shortening could result when pre-rigor muscle was ground, blended, sliced or stimulated in a similar manner. The shortening of the muscle fibers had a detrimental effect upon meat tenderness (Marsh and Thompson, 1958; Locker; 1960; Locker and Hagyard, 1963; Marsh and Leet, 1966; Davey and Gilbert, 1976).

Postmortem Muscle Physiology and Biochemistry

Upon exsanguination the body attempts to maintain homeostasis by pumping blood to supply vital organs. The heart rate increases and peripheral vessels constrict. As oxygen becomes limited, the body converts from aerobic to anaerobic metabolic pathways (glycolysis). This results in a buildup of lactic acid in the muscles and a subsequent lowering of the pH (Forrest et al., 1975).

Hoinkel et al. (1981a) found a decrease in the extensibility of neck muscles at an adenosine triphosphate (ATP) concentration of 1.0 micromole (μmol) per gram at a pH of 5.9. This was an insufficient level of ATP to keep the myofilaments in a relaxed state and was called the onset of rigor mortis. At this ATP level, the calcium pump could not operate and the sarcoplasmic reticulum released calcium which concentrated in the myofibrils and resulted in muscle contraction and rigor mortis. The decreased extensibility and increased muscle fiber shortening associated with the onset of rigor mortis became more severe until the level of ATP fell below 0.1 μmol per gram and the pH was approximately 5.5 (Honikel et al., 1981a). Newbold and Harris

(1972) agreed with this as they found that the 0.1 μmol per gram ATP level rigor mortis was complete (completely irreversible extensibility). At this point, the ultimate pH was reached due to the cessation of lactate production because of the depletion of glycogen or the denaturation of glycolytic enzymes (Newbold and Harris, 1972).

In the primary stages of post-mortem metabolism creatine phosphate, glycogen, and glycolytic intermediates are depleted to keep the level of ATP relatively constant while the level of lactate increases. This occurs because the cells resynthesize ATP from adenosine diphosphate (ADP) first by dephosphorylation of creatine phosphate, then by glycolysis (anaerobic metabolism of glycogen resulting in the formation of lactate), and then by the myokinase reaction. Finally, when the degradation of ATP becomes greater than its replenishment, the ATP level declines rapidly. As the ATP levels fall, this allows cross-bridges to form between the actin and myosin filaments thus preventing the filaments from sliding over each other (Marsh, 1977b). When the ATP level reaches 0.1 μmol per gram or lower, the actin and myosin filaments are maximally cross-bridged forming actomyosin and complete rigor is reached (Newbold and Harris, 1972 and Marsh, 1977b).

Influence of Collagen on Texture

Two muscle components, collagen and the contractile apparatus determine meat tenderness. Collagen causes an increase in meat toughness due to intermolecular crosslinks, which, with increasing age, become more thermally resistant and less readily broken during

the cooking process (Marsh, 1977a). The actin and myosin filaments overlap during rigor mortis and form a bond called the actomyosin bond (Forrest et al., 1975). This is significant as when the muscles are exposed to extreme hot or cold situations, the tissue can go through heat or cold induced shortening (Locker and Hagyard, 1983; Marsh and Leet, 1966; Davey and Gilbert, 1976). For meat, texture has come to be synonymous with tenderness and consumer research has determined that tenderness is the single most important factor in assessing meat acceptability (Brady and Hunecke, 1985).

Collagen is composed of overlapped, triple-stranded helices known as tropocollagen. The content of collagen is not a factor in tenderness; rather it is the intermolecular crosslinks between the overlapped tropocollagen molecules. As the animal ages, these cross-links undergo structural changes which decrease the solubility and increase the stability of the collagen fibril (Marsh, 1977a; Stryer, 1981).

Enzymatic degradation by proteolytic enzymes called cathepsins also affect tenderness in a positive manner. During postmortem aging of meat, these cathepsins are released from the lysosomes of the cell as the pH drops. The tenderization phenomenon occurs partially because of the breakdown of some of the collagen connective tissues and partially due to denaturation of proteins by these enzymes (Forrest et al., 1975). Davey (1983) stated that if rigor muscle is aged for a number of days before cooking, it is usually appreciably more tender.

Postmortem Temperature

The rate at which chemical reactions occur in muscle tissue immediately following slaughter can be changed distinctly by differences in temperature. In order to minimize protein denaturation and to inhibit microbial growth, it is desirable to reduce muscle temperature after slaughter as quickly as possible. However, undesirable consequences occur if the muscle tissue undergoes extremely rapid reductions in temperature (Forrest et al., 1975).

Marsh (1954) found a direct linear relationship between temperature and the rate of pH decline. Marsh (1954) subjected beef to temperatures from 43° to 7°C and found the lower the temperature, the slower the rate of pH decline. He reasoned that the normal influence of temperature on biochemical reactions affected the rate of postmortem metabolism in this manner. However, Cassens and Newbold (1967) and Jolley et al. (1981) found a non-linear relationship between the lowering of temperatures and the rate of pH decline. Casens and Newbold (1967) agreed with Marsh's (1954) linear relationship in that as the temperature was lowered from 37° to 5°C, beef sternomandibularis muscles took a longer time to reach their ultimate pH levels. However, the pH dropped faster at 1°C than at 5°C. Plus, Cassens and Newbold (1967) found that the ultimate pH level at 1° or 5°C was significantly higher than at 15°, 25°, or 37°C. Bendall (1972) said that the glycolytic rate and ATP turnover are at their minimum at 5°C and at 1°C the rate is as rapid as at 15°C. Jolley et al. (1981) affirmed these findings as this study exposed beef sternomandibularis

muscles to temperatures ranging from -1° to 30°C within 45 minutes of stunning and reported that the pH declined more quickly at temperatures above 10°C and below 5°C. This study suggested that the rapid drop in pH at temperatures below 5°C was due to the effect of cold shortening.

There is a shortening effect in muscle tissue due to both hot and cold conditions after slaughter (Locker and Hagyard, 1963; Marsh and Leet, 1966; Davey and Gilbert, 1976). The more severely contracted a muscle is, the less tender it becomes (Locker, 1960). Locker and Hagyard (1963) found that the sarcomere length of beef muscle tissue shortens more at 2°C than at 37°C. This study also showed that shortening began immediately at lower temperatures and was most rapid at 0°C. If the temperature was raised to 2°C, there was a decline in the rate of shortening but the ultimate degree of shortening changed little (Locker and Hagyard, 1963). Marsh and Leet (1966) reported a non-linear relationship between muscle tenderness and the effects of muscle fiber shortening thereby contradicting Locker (1960). The maximum shear force values were found to be at approximately 40% shortening. Then, as the tissues were subjected to even more severe temperature conditions causing a higher degree of shortening than 40%, the force required to shear the sample decreased. This relationship is effective whether the sample is hot, cold, or thaw shortened (Marsh and Leet, 1966). Marsh and Carse (1974) and Marsh et al. (1974) explained that in this highly contracted state, the myosin filament penetrates the Z-line thereby causing structural

damage to the myofilaments. Muscle fibers undergo cold shortening at low temperatures due to changes in the lipoprotein system of the cell membrane (Hamm, 1982). Marsh et al. (1974) reported that some localized supercontraction (up to 80%) occurred when parts of the muscle were shortened 50%. This resulted in structural damage in the form of myofibril rupture that resulted in the increase in tenderness and fluid losses in these extremely shortened muscle fibers. Honikel and Hamm (1978) affirmed the fact that ATP breakdown and lactate formation decreased as the temperature was lowered from 24° to 6°C and that as the temperature was lowered below 6°C, the rate of ATP depletion and lactate formation increased to a maximum at -1°C due to cold shortening. When temperatures were lowered to below approximately 15°C, the ATP-driven calcium pump of the sarcoplasmic reticulum became increasingly inactive with decreasing temperature thereby causing the release of calcium ions and the activation of myosin adenosine triphosphatase (ATPase). This consequently resulted in the onset of rigor mortis (Davey and Gilbert, 1974; Honikel and Hamm, 1978). Davey and Gilbert (1974) reported 30-40 fold increase in the concentration of calcium ions in the myofibrils as the temperature of pre-rigor muscle decreased from 15° to 0°C.

Severe shortening occurred when muscle was frozen while in the pre-rigor state, then thawed. The shortening became more extreme as the thaw rate was increased. This phenomenon occurred due to freeze damage and/or temperature inhibition of the calcium pump and a consequent influx of calcium ions into the myofibrillar region upon

thawing (Marsh and Thompson, 1958). Fennema (1971) explained this as he found that during the freezing process (-10 to -15°C), ice crystals formed thereby increasing the concentration of solute substances which accelerate the rate of metabolic reactions. Behnke et al. (1973) agreed with this as they froze beef sternomandibularis muscles and then tempered them back to temperatures between 10° and -10°C. The back tempering temperatures of -1° and -3°C resulted in the fastest rate of ATP depletion and -3°C resulted in the highest lactate accumulation. Concentration of solutes in the unfrozen phase during freezing was blamed for this phenomenon at these temperatures.

However, ATP was utilized in frozen muscle tissue, and if held in freezing conditions long enough or by back tempering before thawing, thaw contracture was avoided (Behnke and Fennema, 1973; Davey and Gilbert, 1976). Davey and Gilbert (1974) found that lambs frozen in a pre-rigor state did not experience thaw rigor if they were held at -12°C for 1 month. Behnke and Fennema (1973) reported that back tempering beef sternomandibularis muscles that were rapidly frozen and then held at -3°C for 24 hours before thawing revealed a decrease in shear values over this time frame. This was attributed to adequate ATP depletion and lactate accumulation at this high sub-freezing temperature to prevent sarcomere shortening upon thawing.

Likewise, myofibrillar shortening with a rapid decrease in pH and in ATP level resulted from high postmortem temperatures. This heat contracture began at approximately 43°C, peaked at around 45°C and declined to zero at 50°C at which point the contractile proteins

were denatured (Drainsfield and Rhodes, 1975; Bowling et al., 1978). These high temperatures denature the proteins of the sarcoplasmic reticulum resulting in the release of calcium ions into the myofibrillar spaces causing ATP utilization, pH decline, and muscle contraction (Cia and Marsh, 1976).

Honikel et al. (1981b) stated that rigor shortening occurred when the muscle was exposed to temperatures that did not cause cold or heat shortening. Rigor shortening occurred only after ATP depletion disengaged the calcium pump causing its release. This was significant as heat or cold shortening was an immediate response and rigor shortening happened at a pH of approximately 5.9 at rigor onset (Honikel et al., 1981b).

Locker and Hagyard (1963), Marsh and Leet (1966), Cassens and Newbold (1967), and Bowling et al. (1978) found the lowest degree of muscle fiber shortening at temperatures between 14° and 19°C. Additionally, Locker and Daines (1976) reported that cold shortening (33%) beef sternomandibularis muscles which were held at 37°C during the final phases of rigor had mean shear values equal to unshortened tissue cooled at 15°C. They said that the final stage of rigor onset was more important to tenderness than the initial stages.

Salt

Honikel and Hamm (1978) observed that when 2% salt was added to minced sternomandibularis muscles within 30 minutes postmortem, the rates of ATP depletion and lactate formation decreased linearly

as the temperature decreased to freezing. This differed from unsalted muscle tissue as ATP was depleted and lactate accumulated more slowly as the temperature was lowered from 24°C to 6°C. Then below 6°C, the ATP depletion rate and lactate accumulation rate increased until the temperature reached freezing. This effect was explained by Van Hoof and Hamm (1973) as they said that the sodium ions of the salt were exchanged with the calcium ions from the sarcoplasmic reticulum. Therefore, Van Hoof and Hamm (1973) reasoned that calcium release from the sarcoplasmic reticulum into the myofibrillar spaces was caused by the addition of salt. The released calcium increased the myosin adenosine triphosphatase (ATPase) activity thereby accelerating ATP breakdown. Therefore, a linear relationship between temperature decline and the rate of ATP depletion results as a decline in temperature cannot cause an additional release of calcium (Van Hoof and Hamm, 1973).

Hamm (1977) found that when 2% salt was added to ground pre-rigor beef, there was an increase in the breakdown of ATP and ADP to inosine monophosphate (IMP). However, this addition of salt did not affect the rate of glycogen breakdown during the first few hours post-mortem but it did increase the level of lactate buildup. Fischer et al. (1980) affirmed this finding as they found that salt retards glycolysis but accelerates the decrease in ATP concentration over a range of freezing temperatures. Drerup et al. (1981) reported that glycolysis and the production of lactate were inhibited in ground pork when salted prior to rigor development.

Hamm (1977) found a decrease in the water holding capacity (WHC) of muscle tissue due to the breakdown of ATP postmortem which resulted in the development of rigor mortis. Upon addition of salt to pre-rigor ground meat, the WHC did not decrease because the onset of rigor in the fiber fragments was prevented by strong electrostatic repulsion between adjacent protein molecules caused by the combination of the effect of ATP, high pH, and high ionic strength which prevented cross-linking of myofibrillar proteins.

Salt soluble proteins are extremely important in the binding of restructured meat products. Trautman (1964) stated that a more stable emulsion was produced by increased salt soluble protein extraction. The major emulsifying components are salt soluble proteins with water soluble proteins and salt insoluble residue having low emulsifying power. Acton and Saffle (1969) affirmed this as this study found that pre-rigor muscle has a much greater emulsifying capacity than post rigor tissue. Acton and Saffle (1969) also reported that pre-rigor beef yielded 48% more extractable salt soluble proteins than post-rigor meat when 50 grams of meat was blended in 200 ml of 3% salt solution. Trautman (1964) found that 42% of the total extracted protein from pre-rigor meat was salt soluble as opposed to 39% for post-rigor meat. Saffle and Galbreath (1964) stated that pre-rigor beef yielded 50% more extractable salt soluble proteins than post rigor meat when blended in a 3% salt solution. Johnson and Henrickson (1970) reported that pre-rigor pork subjected to the same treatments as just described yielded 69.9% more salt soluble proteins than post-rigor pork.

Saffle and Galbreath (1964) reported a close relationship between protein extractability and pH level. If the pH rises above the isoelectric point, there is a consequent increase in soluble protein extraction. This stands to reason as Hamm (1977), Honikel and Hamm (1978) and Drerup et al. (1981) found that addition of salt to pre-rigor ground muscle resulted in inhibition of glycolysis and decreased lactate production.

Flaking and Grinding

Mechanical stimulation such as grinding accelerates the breakdown of ATP and ADP resulting in quicker increases in IMP levels. This results in a more rapid pH drop and glycogen depletion (Hamm and Van Hoof, 1971 and Dalrymple and Hamm, 1975). Dutson (1983) affirmed this as he reported a rapid rate of glycolysis in muscle in which the membrane had been disrupted (i.e., cutting, grinding, or powdering). Physical stimulation damages the sarcoplasmic reticulum releasing calcium ions into the myofibrillar spaces thereby activating myosin ATPase and causing contraction resulting in increased glycolytic activity (Hamm and Van Hoof, 1971).

Product Appearance

Restructured products must have fresh color, a fine distribution of fat particles, and texture resembling that of intact muscle. The measurement of color and other appearance criteria utilizing sensory panels are subject to influence by personal preference, lighting, and deficiencies in the eye itself. Human evaluation, although biased,

relates the total impression of the product, while objective measurements evaluate small areas and can be influenced by a difference in a small area (Coon, 1982). Kropf (1984) reported that objective measurements reinforce visual or subjective observations.

The two major pigments contributing to the color of meat are hemoglobin and myoglobin. Myoglobin constitutes 80 to 90% of the total pigment with hemoglobin making up the majority of the remaining color (Forrest et al., 1975; Booren and Mandigo, 1981). Huffman (1980) stated that hemoglobin constitutes 12 to 30% of the total muscle pigment. These two pigments have similar spectral properties; however, as myoglobin is present in larger quantities, it is used as an index of fresh meat color (Huffman, 1980). The myoglobin proteins differ in color depending on the chemical state of the heme molecules within the myoglobin. If the heme is in the reduced state, the myoglobin is purplish red in color and is called reduced myoglobin; if the heme is oxygenated, the myoglobin is bright cherry-red in color and is called oxymyoglobin; if the heme is oxidized, the myoglobin is brown in color and is called metmyoglobin. The chemical state of the heme group of myoglobin is influenced by many factors such as microbial contamination, light, oxygen tension, oxidizing chemicals, and temperature (Forrest et al., 1975; Huffman, 1980; Booren and Mandigo, 1981).

Booren and Mandigo (1981) noted that the addition of salt can cause color deterioration. This is because salt can contain impurities like iron, copper, and sometimes cadmium which cause

oxidation of myoglobin to metmyoglobin. However, Huffman et al. (1981) found that the addition of salt enhanced the color of hamburger patties. Huffman (1980) stated that the darker color initially noted in meat when salt is added could be due to the higher WHC and/or water binding capacity of the meat upon addition of salt. Salt increases the WHC and swelling of meat tissue on the alkaline side of the isoelectric point. This results in a more compact structure and darker appearance due to a drop in scattered incident light. This is similar to the effect observed in dark cutting beef. Although Huffman and Cordray (1979) found decreased color scores with increased salt, they stated that pre-rigor porcine muscle was less susceptible to color deterioration due to the addition of salt than post-rigor muscle. Judge and Aberle (1980) affirmed this as they reported that oxidation of myoglobin to metmyoglobin did not occur as readily in pre-rigor pork. Additionally, Judge and Aberle (1980) said that pre-rigor ground pork was much less susceptible to lipid oxidation than post-rigor meat when formulated to a 2% salt level, especially when stored in aerobic conditions. This additional stability was explained by the high pH of pre-rigor muscle, thus limiting the pro-oxidant effect of salt.

Booren et al. (1981b) reported that the surface color of sectioned and formed beef steaks as measured by a spectrophotometer and by a trained panel was less desirable after vacuum mixing beef for longer than 12 minutes resulted in lowered color scores for sectioned and formed steaks.

Walker (1980) stated that the factors affecting the color changes on meat surfaces include: (1) partial pressure of oxygen in the environment; (2) bacterial growth; (3) artificial atmospheres; (4) temperature; (5) tissue lipid oxidation; and (6) drying of the meat surface. Walker (1980) also explained the two types of oxidative changes that cause the oxidation of myoglobin to metmyoglobin with its brown, grey, and green discoloration of the meat. These are: (1) oxidation of ferrous iron in the heme compound to the ferric condition; and (2) a direct attack by oxygen on the porphyrin ring.

Proteins

The proteins in muscle can be broadly divided into three general categories: (1) sarcoplasmic or those which are soluble in water or diluted salt solutions; (2) myofibrillar or those which are soluble in concentrated salt solutions; and (3) connective tissue proteins which are insoluble in concentrated salt solutions (at low temperatures) (Lawrie, 1979). Proteins constitute the major portion of the animal body on a water-free basis (Bodwell and McClain, 1971).

The sarcoplasmic proteins represent 5.5-6% of the total muscle of the animal (Forrest et al., 1975; Lawrie, 1979). They represent a complex mixture of about 50 components, many of which are enzymes of the glycolytic cycle (Lawrie, 1979). These proteins are found in the sarcoplasmic fluid surrounding and permeating the myofibrils (Bodwell and McClain, 1971).

Swift et al. (1961) reported that sarcoplasmic proteins tend to stabilize emulsions in the presence of salt. However, Macfarlane

et al. (1977) stated that sarcoplasmic proteins enhance the binding strength of myosin in a synergistic manner at low ionic strength (no added salt). Swift and Sulzbacher (1963) found that the optimum water-soluble protein emulsifying capacity occurs at a pH of 5.2.

The proteins that give structural rigidity to muscle and function in the transduction of chemical energy into the mechanical energy of contraction collectively constitute the myofibrillar or salt soluble proteins (Bodwell and McClain, 1971). Myofibrillar proteins represent approximately 9.5-11.5% of the total muscle content (Forrest et al., 1975; Lawrie, 1979). These salt-soluble proteins are made up principally of myosin (5%), actin (2%), tropomyosin and troponin (each at 0.8%) (Forrest et al., 1975).

Theno et al. (1978a) stated that the extraction of myofibrillar proteins is essential for the binding of pieces of muscle tissue. This study found that the process of massaging disrupts the muscle structure through frictional energy thereby producing a larger surface area that allows greater extraction of salt-soluble proteins. Schmidt (1977) reported that in order to achieve optimal binding, the salt-soluble proteins must be solubilized and mechanical energy (massaging or tumbling) alone is not sufficient; salt and/or phosphates must be added. Schnell et al. (1970) found that myofibrillar protein extractability increases thereby increasing binding ability as salt or ionic concentration is increased.

Swift et al. (1961) said that salt-soluble proteins are essential for the production of meat emulsions as these proteins are

more effective in stabilizing emulsions than water-soluble proteins. Fukazawa et al. (1961) found that actin and tropomyosin and the sarcoplasmic proteins do not significantly influence the binding quality of sausage; however, myosin is of extreme importance for binding.

Collagen is the major fibrous element of the connective tissues and the most abundant single protein in the body, representing 20 to 25% of the total protein. These proteins are the major supportive element of the animal body (Bodwell and McClain, 1971; Kramlich et al., 1973; Stryer, 1981). Marsh (1977a) and Stryer (1981) reported that intermolecular cross-links between tropocollagen increase in stability as the animal ages. Although connective tissue proteins have little effect on bind, they contribute to the texture of the product (Coon, 1982).

CHAPTER III

MATERIALS AND METHODS

I. SAMPLE PREPARATION AND ANALYSIS

Approximately 50-60 pounds of cow (C, D, and E maturity) top rounds (semimembranosus) were acquired from Lay's Packing Company. The carcasses from which these muscles were excised were chilled prior to boning and represented the cold or conventionally processed beef. All external fat was removed. Three choice beef plates were also acquired at this time. These were boned and ground through a 0.75 inch plate and then a 0.125 inch plate to provide the fat for the restructured product. The fat was frozen in a blast freezer (-26°C) and reground through a 0.125 inch plate to form pellets.

Approximatley 60-70 pounds of pre-rigor or hot processed top round muscle (Semimembranosus) from C, D and E maturity cow carcasses were acquired from Lay's Packing Company on the following day. The muscles were excised approximately one hour postmortem. The pH and temperature of each muscle was read at this time utilizing a Markson pH and Temperature Meter (Model 6102). The external fat was removed. One-half of both the pre-rigor and post-rigor top rounds was flaked by an Urschel Comitrol (Model 3600) utilizing the 0.750 inch head and the other half was flaked with the 0.510 inch comitrol head. These four batches--the hot-processed 0.750 flake, the cold-processed 0.750 flake, the hot-processed 0.510 flake, and the cold-processed

0.510 flake were held separately until their fat percentages were ascertained by the Modified Babcock method (AOAC, 1975). The pH and temperature of each batch was measured at this time.

Each treatment (Table 1) was mixed in a Leland Mixer 3 minutes while sufficient fat was added to bring the fat percentage to 15%. Each treatment was mixed an additional 3 minutes after the fat was added. The pounds of fat and lean for each treatment were calculated through the use of a Pearson Square (Ross, 1928). Means were utilized when mixtures of two of the flake sizes or process treatments were mixed. The meat was mixed only 6 total minutes to prevent shredding, tearing, and disruption of the individual flakes (Schmidt, 1977).

Following mixing, the pH and temperature were again measured. The meat was then formed into 226.8 g steaks (2.54 cm. thick) by a Koppens Model VM400 food forming machine equipped with a form plate for strip steaks. The steaks were placed in a blast freezer (-26°C) until they were crust frozen, then were vacuum packaged (five steaks/ package) in barrier heat shrink bags utilizing a Cryovac Double Chamber Vacuum Packaging machine (Model 8210). The packages were then placed in a blast freezer (-26°C) for storage until analyzed.

Four steaks per treatment per analysis were thawed completely in a 2°C cooler for 16-18 hours prior to cooking (Costello et al., 1985). The raw weight of each thawed steak was recorded. The length was measured along the center line and the width was measured at 33% and 66% of the original length (Berry et al., 1985). A thermometer was inserted into the geometric center of each steak (Contreras et al.,

TABLE 1. Description of Experimental Treatments

Treatment[1]	Process	Flake Size[2] (in.)
1	Pre-rigor	0.75
2	Post-rigor	0.75
3	Pre-rigor	0.51
4	Post-rigor	0.51
5	Pre-rigor	1/2 0.75 : 1/2 0.51
6	Post-rigor	1/2 .075 : 1/2 0.51
7	1/2 Pre- : 1/2 post-rigor	0.51
8	1/2 Pre- : 1/2 post-rigor	0.75
9	1/2 Pre- : 1/2 post-rigor	1/2 0.75 : 1/2 0.51
10	1/2 Post- : 1/2 pre-rigor	1/2 0.75 : 1/2 0.51

[1]All treatments contained 0.5% NaCl and 15% fat.

[2]Urschell Comitrol cutting head sizes: 0.75 inch (19 mm) or 0.51 inch (12 mm).

1981). The steaks were cooked to an internal temperature of 70°C by the modified oven broiling method in a Despatch Oven set at 176.7°C (350°F). The cooked product was allowed to cool 5 to 10 minutes and was weighed to determine cooking loss according to the method of Kastner et al., 1973. The thickness of each cooked steak was measured in three locations along the center line (Berry et al., 1985).

The steaks were allowed to cool to room temperature (3-4 hours). The analyses, run on four steaks per treatment utilizing an Instron Universal Testing Machine, included: (1) L.E.E. Kramer shear test (Booren et al., 1981a and Coon, 1982); (2) bind test using a 66 mm bridge (Coon 1981b, 1982), and (3) penetrometer to measure hardness, cohesiveness, and chewiness parameters (Bouton et al., 1971, Costello et al., 1985). A 500 kg load cell was used for each analysis with crosshead chart speed of 10 centimeters per minute.

The L.E.E. Kramer shear analysis of the steaks was performed to test the kilograms of force required to shear a 3.5 x 6.0 cm. block of each steak cut from a uniform area of the steak. This block was weighed and sheared to give the results in kilograms of force required to shear each gram of sample (kg force/g sample) (Booren et al., 1981a,b). Total force across the chart was set at 200 kg.

This analysis of four steaks per treatment was run to determine breaking strength (bind) of the steaks from each treatment. Each steak was placed across the 66 mm span and was broken twice, once at the large end and once at the small end by driving a straight edge shear plate through the steak. Total force across the chart was set at 50 kg.

A 0.63 cm. diameter flat ended plunger was driven vertically 80% of the way through three uniform points per steak for four steaks per treatment. The plunger was driven into the meat twice at each location and the work and force for each penetration curve completed and recorded. Hardness described the force required to make the first penetration and cohesiveness was the ratio of the work (area) done during the second penetration to that performed on the first. A secondary parameter called chewiness was defined as the product of cohesiveness and hardness (Bouton et al., 1971). A total force across the chart was set at 50 kg.

Moisture, fat, and protein analyses were run on both raw and cooked product according to AOAC (1975) procedures. Samples were prepared by triple grinding through a one-eighth inch plate. Moisture contents of each treatment were determined in triplicate by the vacuum oven drying procedure. Two gram samples were enclosed in sample envelopes made from Whattman No. 1 filter paper and dried according to method specifications. These same samples were used for fat analysis through the use of the Soxhlet Method. Protein content was determined by the Kjeldhal method.

Both subjective and objective methods were employed in the analysis of four steaks in the frozen packaged state. Kropf (1984) suggested that a subjective appraisal be utilized to back up objective appraisals. A modified version of the subjective scale employed by Gokalp et al. (1979) was utilized and is shown in Table 2. A panel of six evaluators rated the steaks according to color and discoloration of the product.

TABLE 2. Subjective Color and Discoloration Scales

Color	Discoloration
1. Brown	1. Total surface discoloration
2. Purple	2. 80% surface discoloration
3. Very dark red	3. 60% surface discoloration
4. Dark red	4. 50% surface discoloration
5. Dark cherry red	5. 40% surface discoloration
6. Bright cherry red	6. 30% surface discoloration
7. Light cherry red	7. 20% surface discoloration
8. Pinkish-red	8. 10% surface discoloration
9. Very light pinkish-red	9. No surface discoloration

The Hunter Tristimulus Colorimeter (Model D25-2) was utilized to give an objective measure of appearance. Four steaks were used as a representative sample of each treatment. Each package was carefully kept frost-free during the analysis. The Hunter colorimeter was standardized with a pink color standard (L:69.1, a:22.0, b:11.9) and a black color standard. Measurements taken included the "L" range denoting lightness or darkness, the "a" value denoting redness and the "b" value denoting yellowness.

II. STATISTICAL ANALYSIS

All data were analyzed through the General Linear Models procedure (SAS) with treatment and replication as independent variables.

Replication x treatment was specified as the error term. A Student-Newman-Keuls Mean Separation test 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 3. An explanation of the contrasts is as follows:

1. Contrast 1--mean of pre-rigor, 0.75 in. flake (T1) and pre-rigor, 0.51 in. flake (T3) contrasted against the mean of post-rigor, 0.75 in. flake (T2) and post-rigor, 0.51 in. flake (T4).

2. Contrast 2--mean of pre-rigor, 0.75 in. flake (T1) and post-rigor, 0.75 in. flake (T2) contrasted against the mean of pre-rigor, 0.51 in. flake (T3) and post-rigor, 0.51 in. flake (T4).

3. Contrast 3--mean of a mixture of 50% pre-rigor, 0.75 in. flake and 50% pre-rigor, 0.51 in. flake (T9) contrasted against the mean of a mixture of 50% post-rigor, 0.75 in. flake and 50% post-rigor, 0.51 in. flake (T6).

4. Contrast 4--mean of a mixture of 50% pre-rigor, 0.51 in. flake and 50% post-rigor, 0.51 in. flake (T7) contrasted against the mean of a mixture of 50% pre-rigor, 0.75 in. flake and 50% post-rigor, 0.75 in. flake (T8).

5. Contrast 5--mean of post-rigor, 0.75 in. flake (T2) and mean of post-rigor, 0.51 in. flake (T4) contrasted against the mean of a mixture of 50% post-rigor, 0.75 in. and 50% post-rigor, 0.51 in. flake (T6).

6. Contrast 6--mean of pre-rigor, 0.75 in. flake (T1) and mean of pre-rigor, 0.51 in. flake (T3) contrasted against the mean of a

TABLE 3. Orthogonal Contrasts Between Treatments for Restructured Strip Steak Analysis

Treatments	Contrasts										
	1	2	3	4	5	6	7	8	9	10	11
1. Pre-rigor 0.75 in. flake	1	1	0	0	0	-1	0	0	-1	1	0
2. Post-rigor 0.75 in. flake	-1	1	0	0	-1	0	0	0	-1	0	1
3. Pre-rigor, 0.51 in. flake	1	-1	0	0	0	-1	0	-1	0	-1	0
4. Post-rigor, 0.51 in. flake	-1	-1	0	0	-1	0	0	-1	0	0	-1
5. Pre-rigor, 1/2 0.75 in. and 1/2 0.51 in. flake	0	0	1	0	0	2	0	0	0	0	0
6. Post-rigor, 1/2 0.75 in. and 1/2 0.51 in. flake	0	0	-1	0	2	0	0	0	0	0	0
7. 1/2 Pre- and 1/2 post-rigor, 0.51 in. flake	0	0	0	1	0	0	1	2	0	0	0
8. 1/2 Pre- and 1/2 post-rigor, 0.75 in. flake	0	0	0	-1	0	0	1	0	2	0	0
9. 1/2 Pre-rigor, 0.51 in. flake and 1/2 Post-rigor, 0.75 in. flake	0	0	0	0	0	0	-1	0	0	0	0
10. 1/2 Post-rigor, 0.51 in. flake and 1/2 Pre-rigor, 0.75 in. flake	0	0	0	0	0	0	-1	0	0	0	0

mixture of 50% pre-rigor, 0.75 in. flake and 50% pre-rigor, 0.51 in flake (T5).

7. Contrast 7--mean of 50% pre-rigor, 0.51 in. flake, 50% post-rigor, 0.51 in. flake (T7) and 50% pre-rigor, 0.75 in. flake and 50% post-rigor, 0.75 in. flake (T8) contrasted against the mean of 50% pre-rigor, 0.51 in. flake, 50% post-rigor, 0.75 in. flake (T10) and 50% pre-rigor, 0.75 in. flake and 50% post-rigor, 0.51 in. flake (T9).

8. Contrast 8--mean of pre-rigor, 0.51 in. flake (T3) and the mean of post-rigor, 0.51 in. flake (T4) contrasted against the mean of a mixture of 50% pre-rigor, 0.51 in. flake and 50% post-rigor, 0.51 in. flake (T7).

9. Contrast 9--mean of pre-rigor, 0.75 in. flake (T1) and the mean of post-rigor, 0.75 in. flake (T2) contrasted against the mean of a mixture of 50% pre-rigor, 0.75 in. flake and 50% post-rigor, 0.75 in. flake (T8).

10. Contrast 10--mean of pre-rigor, 0.75 in. flake (T1) contrasted against the mean of pre-rigor, 0.51 in. (T2) flake.

11. Contrast 11--mean of post-rigor, 0.75 in. flake (T2) contrasted against the mean of post-rigor, 0.51 in. flake (T4).

CHAPTER IV

RESULTS AND DISCUSSION

There were significant differences between the two replications of this study which are shown in Tables 4 and 5. The pH, after flaking the semimembranosus muscle but prior to blending with salt and fat, was higher for replication 1 (Table 4). This difference was due to the combined effect of dissimilar techniques employed by the individuals performing this task and to possible differences in the setting of the Markson pH Meter (Model 6102). The discrepancy between the temperature values of the two replicates after flaking and blending with salt and fat was due to the addition of more frozen plate fat to replication 2. The higher pH and temperature values of replication 1 enhanced the myosin extraction thereby increasing the bind of replication 1 (Reagan, 1983; West, 1983) as shown in Table 5.

The differences between replications in percent moisture of raw and cooked steaks and percent protein of cooked steaks, although small, were statistically significant (Table 4). However, there is little realistic difference between these values.

Replication 1 steaks had lower raw fat percentages, therefore it is logical to expect lower cooking loss from replication 1 steaks (Table 4). Similar results have been reported by Cross et al. (1980). This factor was also largely responsible for the proportionately smaller decreases in the width and thickness of the steaks upon cooking.

TABLE 4. Means[1] of Restructured Steak Variables That Were Significantly Different Between Replications

Variable	Replication 1	Replication 2
pH[2]	6.22	5.93
Temperature[3] (°C)	10.07	2.17
Moisture, raw (%)	68.83	63.14
Moisture, cooked (%)	59.13	58.44
Fat, raw (5)	13.46	14.62
Protein, cooked (%)	24.12	24.86
Hunter "b" value[4]	9.63	8.46
Length, raw (cm)	15.89	15.67
Length, cooked (cm)	14.04	14.26
Width, large end, raw (cm)	6.01	6.37
Width, large end, cooked (cm)	5.79	5.98
Width, small end, raw (cm)	4.53	4.76
Width, small end, cooked (cm)	4.43	4.47
Thickness, large end (cm)	2.67	2.46
Thickness, midline (cm)	2.69	2.49
Thickness, small end (cm)	2.69	2.54
Cooking loss (%)	23.32	26.56

[1]Means in each row are significantly different at $P<.05$.

[2]pH after flaking and before blending.

[3]Temperature after flaking and blending with salt and fat.

[4]Higher numbers indicate greater yellowness (Anonymous, 1980).

TABLE 5. Means[1] of Restructured Steak Textural Traits That Were Significantly Different Between Replications

Textural trait	Replication 1	Replication 2
Shear[2] (kg/g)	3.17	3.49
Bind strength, small end[3] (kg)	0.96	0.68
Bind strength, large end[3] (kg)	1.02	0.66
Hardness, small end[4] (kg)	0.99	0.84

[1]Means in each row are significantly different at $P<.05$.

[2]L.E.E. Kramer shear value (kg)/weight of 3.5 x 6 cm. sheared block (g).

[3]Measure of bind by breaking a steak across a 66 mm bridge.

[4]Peak force to insert a 0.63 cm diameter penetrometer 80% into the center of the small end of a steak.

A higher Hunter "b" value on the Hunter Tristimulus Colorimeter indicates greater yellowness (Anonymous, 1980). Replication 1 exhibited greater yellowness (Table 4) than replication 2 due to the fact that the Cryovac bags utilized for both replicates, although identical, were not shrunk in the first replicate whereas they were in the second. This may have caused a more yellow appearance in replication 1 since color measurements were made through the bag.

Dimensions of the form plate used in the Koppens Food Forming Machine (Model VM 400) were 16.0 cm. long, 6.0 cm. wide at the large end (33% from the large end down the center line) and 4.5 cm. wide at the small end (33% from the small end down the center line). Table 4 reveals that although replication 1 steaks shrunk proportionately less in width than replication 2 upon cooking, they shrunk proportionately more in length. Replicate 1 steaks also remained thicker after cooking than replicate 2. The difference in thickness caused the difference in shear values (Table 5). A 3.5 x 6.0 cm. block of steak was excised from the center of the steaks. The L.E.E. Kramer Shear was inserted and this value was in kilograms of force. Then this value was divided by the weight of the 3.5 x 6.0 cm. block of steak (grams). Therefore, because samples from replication 1 had greater thickness, it weighed more and was possibly less dense thereby causing replication 2 to show higher shear scores (Table 5). The greater thickness combined with a lower fat percentage of replication 1 steaks caused replication 1 to have much higher bind strength for both large and small ends which agrees with conclusions in work reported by Coon (1982).

Steaks from replication 1 exhibited higher hardness values (Table 5) due to greater myosin extraction because of higher pH and temperature at the time of mixing (Reagan, 1983; West, 1983). The lower fat percentage of steaks from replication 1 also helped increase this score.

Table 6 shows higher temperature and pH values for the pre-rigor treatments which were expected. These values became very similar to post-rigor treatments for treatments 6-10 (pre-rigor mixed with post-rigor meat). There were no significant ($P>.05$) differences between treatments in percentages of moisture, fat, or protein for either raw or cooked steaks.

Table 7 shows that there was no difference in treatments for length between raw and cooked steaks. Treatment 1 was significantly ($P<.05$) narrower in width for both raw and cooked product than all other treatments when measured at the large end. Treatment 1 was also significantly ($P<.05$) thicker than all other treatments in all three areas measured. This indicates more distortion occurred in treatment 1 (pre-rigor, 0.750 inch flake) freezing, thawing, and cooking. There were no differences in small end width for raw steaks; however, there were some significant differences ($P<.05$) in the small end width of cooked steaks. Treatments 2, 9, and 10 remained significantly wider ($P<.05$) after cooking than treatment 5. This is explained simply by differences in cooking loss percentages, as treatments 2, 9, and 10 lost significantly less ($P<.05$) upon cooking than treatment 5 (Table 7).

TABLE 6. Mean[1] pH, Temperature and Composition of Restructured Steaks Made From Flaked Pre- and Post-Rigor Cow Beef

Treatments	pH1[2]	pH2[3]	Temp 1 (°C)[4]	Temp 2 (°C)[5]	Moisture (%)		Fat (%)		Protein (%)	
					Raw	Cooked	Raw	Cooked	Raw	Cooked
1. Pre-rigor, 0.75 in. flake	6.31	5.98	24.70[a]	8.50[a]	62.81	58.88	14.29	12.79	19.39	24.39
2. Post-rigor, 0.75 in. flake	5.84	5.95	11.45[b]	4.20[b]	63.95	58.49	14.01	11.99	19.35	25.06
3. Pre-rigor, 0.51 in. flake	6.13	5.88	27.80[a]	7.85[ab]	62.70	58.28	14.82	13.71	18.97	24.56
4. Post-rigor, 0.51 in. flake	6.02	6.14	13.65[b]	6.85[ab]	63.88	60.36	12.94	11.43	19.04	24.09
5. Pre-rigor, 1/2 0.75 in. and 1/2 0.51 in. flake		5.87		7.50[ab]	63.68	58.19	14.08	13.64	19.25	24.95
6. Post-rigor, 1/2 0.75 in. and 1/2 0.51 in. flake		6.00		4.90[ab]	63.98	59.00	13.92	12.87	18.78	24.65
7. 1/2 Pre- and 1/2 post-rigor, 0.51 in. flake		6.01		5.60[ab]	64.18	57.95	12.92	12.54	18.53	23.96
8. 1/2 Pre- and 1/2 post-rigor, 0.75 in. flake		6.03		5.90[ab]	63.42	58.93	14.96	12.44	18.74	24.67
9. 1/2 Pre-rigor, 0.51 in. flake and 1/2 post-rigor, 0.75 in. flake		5.98		4.45[b]	62.86	58.98	14.46	11.98	18.81	24.18
10. 1/2 Post-rigor, 0.51 in. flake and 1/2 pre-rigor, 0.75 in. flake		6.06		4.35[b]	63.44	58.81	13.99	13.37	19.15	24.43

[1]Mean of two replications.

[2]pH after flaking and before blending.

[3]pH after flaking and blending with salt and fat.

[4]Temperature after flaking and before blending.

[5]Temperature after flaking and blending with salt and fat.

[a,b]Means in the same column with different superscripts are significantly different at P<.05.

TABLE 7. Means[1] of Physical Dimensions and Cooking Loss of Restructured Strip Steaks Made From Flaked Pre- and Post-Rigor Cow Beef

Treatments	Length (cm)		Width, large end (cm)		Width, small end (cm)		Thickness (cm)			Cooking loss (%)
	Raw	Cooked	Raw	Cooked	Raw	Cooked	Large end	Midline	Small end	
1. Pre-rigor, 0.75 in. flake	15.68	14.06	6.08^{a}	5.62^{a}	4.69	4.42	2.87^{a}	2.82^{a}	2.92^{a}	25.26^{b}
2. Post-rigor, 0.75 in. flake	15.82	14.23	6.17^{b}	5.92^{b}	4.68	4.51^{a}	2.62^{b}	2.59^{bc}	2.59^{b}	25.17^{bc}
3. Pre-rigor, 0.51 in. flake	15.77	14.02	6.20^{b}	5.96^{b}	4.65	4.43	2.49^{c}	2.49^{d}	2.57^{b}	26.50^{a}
4. Post-rigor, 0.51 in. flake	15.81	14.13	6.21^{b}	5.90^{b}	4.66	4.46	2.59^{b}	2.59^{bc}	2.57^{b}	24.05^{c}
5. Pre-rigor, 1/2 0.75 in. and 1/2 0.51 in. flake	15.80	14.04	6.18^{b}	5.83^{b}	4.64	4.36^{b}	2.54^{bc}	2.59^{bc}	2.62^{b}	26.41^{a}
6. Post-rigor, 1/2 0.75 in. and 1/2 0.51 in. flake	15.80	14.29	6.22^{b}	5.88^{b}	4.63	4.42	2.57^{bc}	2.59^{bc}	2.59^{b}	24.58^{bc}
7. 1/2 Pre- and 1/2 post-rigor, 0.51 in. flake	15.76	14.18	6.18^{b}	5.93^{b}	4.60	4.46	2.51^{bc}	2.57^{bcd}	2.59^{b}	24.25^{bc}
8. 1/2 Pre- and 1/2 post-rigor, 0.75 in. flake	15.80	14.14	6.21^{b}	5.95^{b}	4.62	4.41	2.49^{c}	2.51^{cd}	2.57^{b}	24.98^{bc}
9. 1/2 Pre-rigor, 0.51 in. flake and 1/2 post-rigor, 0.75 in. flake	15.75	14.08	6.20^{b}	5.95^{b}	4.64	4.49^{a}	2.49^{c}	2.51^{cd}	2.57^{b}	24.78^{bc}
10. 1/2 Post-rigor, 0.51 in. flake and 1/2 pre-rigor, 0.75 in. flake	15.83	14.28	6.19^{b}	5.89^{b}	4.61	4.50^{a}	2.54^{bc}	2.57^{bcd}	2.57^{b}	22.86^{d}

[1]Means of two replications.

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

As mentioned previously, treatment 1 stood alone as the thickest steak at all three measured points (Table 7). The thickness measurements at the small end of the steaks were very similar with the exception of treatment 1.

The pre-rigor, 0.51 inch flake (treatment 3) steaks were significantly ($P<.05$) less thick than the other treatments when measured in the middle. Treatment 3 steaks along with those of treatments 8 and 9 were thinner than other treatments at the large end. Treatment 3 also exhibited the highest percentage cooking loss which could have a direct effect on its reduction in thickness (Table 7).

Cooking loss percentages shown in Table 7 were lower for post-rigor steaks and higher for pre-rigor steaks ($P<.05$). This data agrees with Contreras et al. (1981) and Schoenrock (1985) but disagrees with the findings of Cia and Marsh (1976) and Cross et al. (1979). The highest cooking losses were found in treatments 1, 3, and 5 which were the three exclusively pre-rigor treatments. Treatments 10 and 4 were significantly lower ($P<.05$) in cooking loss percentage than the other treatments. Treatment 4 was post-rigor tissue, flaked 0.51 inch, and treatment 10 was a mixture of post-rigor, 0.51 inch flake, and pre-rigor, 0.75 inch flake.

Objective and subjective color evaluations of the steaks are listed in Table 8. Hunter "L," "a," and "b" values were recorded on four steaks per treatment and no differences ($P>.05$) were noted between treatments for any of these values. The six member panel

TABLE 8. Mean[1] Objective and Subjective Color Evaluations of Restructured Steaks Made From Flaked Pre- and Post-Rigor Cow Beef

Treatments	Hunter Values "L"[2]	"a"[3]	"b"[4]	Color Score[5]	Discoloration Score[6]
1. Pre-rigor, 0.75 in. flake	38.83	10.23	8.33	3.08	6.00
2. Post-rigor, 0.75 in. flake	39.18	11.50	8.98	4.50	6.33
3. Pre-rigor, 0.51 in. flake	39.36	8.86	8.31	2.50	3.25
4. Post-rigor, 0.51 in. flake	38.81	11.71	9.48	4.00	7.00
5. Pre-rigor, 1/2 0.75 in. and 1/2 0.51 in. flake	36.50	9.56	8.33	2.33	3.42
6. Post-rigor, 1/2 0.75 in. and 1/2 0.51 in. flake	39.59	10.10	9.23	5.25	7.42
7. 1/2 Pre- and 1/2 post-rigor, 0.51 in. flake	39.66	8.54	9.41	4.83	6.00
8. 1/2 Pre- and 1/2 post-rigor, 0.75 in. flake	38.69	8.91	8.76	3.25	6.17
9. 1/2 Pre-rigor, 0.51 in. flake and 1/2 post-rigor, 0.75 in. flake	41.00	8.23	9.35	4.67	6.75
10. 1/2 Post-rigor, 0.51 in. flake and 1/2 pre-rigor, 0.75 in. flake	38.21	9.15	9.30	4.42	7.75

[1]Means of two replications.

[2]100 is perfect white, 0 is black (Anonymous, 1980).

[3]Higher numbers indicate greater redness (Anonymous, 1980.

[4]Higher numbers indicate greater yellowness (Anonymous, 1980).

[5]Subjective color values: n = 6/replication; 1 = black 9 = light pink.

[6]Subjective discoloration values: n = 6/replication; 1 = 100% discoloration 9 = no discoloration.

of individuals experienced in evaluating beef color evaluated the same four steaks per treatment to provide subjective data. Although differences were noted, none were significant (P>.05), which was due to the high coefficient of variation for both subjective color scores and subjective discoloration scores. The post-rigor treatments (2, 4, and 6) showed higher Hunter "a" values indicating greater redness than their pre-rigor counterparts (1, 3, and 5). Likewise, these three treatments (2, 4, and 6) were rated higher in color score by the subjective panel than the pre-rigor samples (1, 3, and 5). Moreover, the mixtures of pre-rigor and post-rigor meat (treatments 7-10) were rated higher for color by the panel. The subjective discoloration scores also favored the post-rigor treatments and mixtures thereof.

The means of the shear values are listed in Table 9. Treatments 1 and 5 had the highest shear scores (treatment 1 is 0.75 flake size, pre-rigor meat, and treatment 5 is a mixture of pre-rigor muscle of 0.51 and 0.75 in. flake sizes). Taylor et al. (1981) and Hollingsworth et al. (1982) also found higher L.E.E. Kramer Shear scores associated with the use of pre-rigor meat in the formation of restructured steaks. Treatments 4, 6, 7, and 10 (post-rigor treatments or mixtures thereof) had scores significantly (P<.05) lower than the other treatments. The differences in these scores were affected by differences in cooking loss percentage. Treatments 1 and 5 had higher cooking losses whereas treatments 4, 6, 7, and 10 had lower cooking losses.

The highest bind values (P<.05) for both large and small ends of the steaks were found in treatments 1, 4, and 6 (Table 9).

TABLE 9. Means[1] of Shear and Certain Physical Characteristics of Restructured Steaks Made From Pre- and Post-Rigor Cow Beef

Treatments	Shear (kg/g)	Bind (kg)[3]		Hardness (kg)[4]			Cohesiveness[5]			Chewiness[6]
		Small end	Large end	Large end	Midline	Small end	Large end	Midline	Small end	
1. Pre-rigor, 0.75 in. flake	3.879^{a}	0.960^{a}	0.931^{bc}	1.100^{abc}	1.169^{a}	1.288^{a}	0.154	0.353^{a}	0.181	0.271^{a}
2. Post-rigor, 0.75 in. flake	3.295^{de}	0.781^{ab}	0.806^{cde}	0.898^{abc}	0.831^{ab}	1.016^{b}	0.139	0.136^{b}	0.218	0.151^{b}
3. Pre-rigor, 0.51 in. flake	3.447^{cd}	0.803^{ab}	0.888^{c}	0.806^{bc}	0.818^{ab}	0.928^{b}	0.141	0.114^{b}	0.175	0.126^{b}
4. Post-rigor, 0.51 in. flake	2.9089	0.969^{a}	1.200^{a}	1.025^{abc}	1.025^{ab}	1.000^{b}	0.190	0.178^{b}	0.140	0.175^{b}
5. Pre-rigor, 1/2 0.75 in. and 1/2 0.51 in. flake	3.740^{ab}	0.668^{b}	0.625^{e}	1.275^{a}	1.088^{ab}	0.969^{b}	0.206	0.173^{b}	0.165	0.208^{ab}
6. Post-rigor, 1/2 0.75 in. and 1/2 0.51 in. flake	2.939^{fg}	0.965^{a}	1.056^{b}	0.881^{abc}	0.750^{b}	0.9769^{b}	0.156	0.096^{b}	0.133	0.116^{b}
7. 1/2 Pre- and 1/2 post-rigor 0.51 in. flake	3.085^{efg}	0.784^{ab}	0.699^{de}	0.738^{c}	0.763^{b}	0.775^{b}	0.120	0.204^{b}	0.158	0.124^{b}
8. 1/2 Pre- and 1/2 post-rigor, 0.75 in. flake	3.598^{bc}	0.683^{b}	0.698^{de}	1.069^{abc}	0.850^{ab}	0.819^{b}	0.204	0.195^{b}	0.209	0.189^{b}
9. 1/2 Pre-rigor, 0.51 in. flake, 1/2 post-rigor, 0.75 in. flake	3.248^{de}	0.779^{ab}	0.650^{de}	0.898^{abc}	0.869^{ab}	0.875^{b}	0.143	0.143^{b}	0.175	0.132^{b}
10. 1/2 Post-rigor, 0.51 in. flake, 1/2 Pre-rigor, 0.75 in. flake	3.146^{ef}	0.796^{ab}	0.823^{cd}	1.175^{ab}	1.025^{ab}	1.015^{b}	0.179	0.156^{b}	0.146	0.177^{b}

[1]Means of two replications.

[2]L.E.E. Kramer shear value (kg)/weight of 3.5 x 6 cm sheared block (g).

[3]Measure of bind by breaking a steak across a 66 mm bridge.

[4]Peak force to insert a 0.63 cm diameter penetrometer 80% into a steak.

[5]Ratio of work done during a second penetration of a 0.63 cm diameter penetrometer to that performed on the first penetration.

[6]The product of cohesiveness and hardness.

a,b,c,d,e,f,g Means in the same column with different superscripts are significantly different at P<.05.

Treatments 4 and 6 were post-rigor and treatment 1 was pre-rigor. Treatment 5 was lower in bind ($P<.05$) for both large and small ends and treatment 8 had lower bind at the small end. Treatment 5 also had lower ($P<.05$) bind value at the large end. Pepper and Schmidt (1975) and Coon (1982) stated that the utilization of pre-rigor tissue resulted in greater binding capacity. The results of this study are inconclusive, but seem to contradict Pepper and Schmidt (1975) and Coon (1982) as post-rigor treatments 4 and 6 had the highest bind values. However, treatment 1 (pre-rigor, 0.750 inch flake size) was also higher in bind than other treatments ($P<.05$).

The hardness of the steaks was measured at three points for four steaks per treatment and these scores are shown in Table 9. Values differ throughout the measured points of the steaks. The large end hardness values were highest for treatments 5 and 10. The large end values were lowest for treatments 3 and 7. Both the midline and small end hardness values were highest for treatment 1, exclusively. The values for small end hardness were similar for all of the treatments with the exception of treatment 1. Midline hardness values were lowest for treatments 6 and 7. Hardness values were highest for the pre-rigor treatment of the large flake size (treatment 1).

The only difference in cohesiveness measurements (Table 9) was the measurement at the midpoint of the steaks. Treatment 1 was higher than all other treatments. These values were affected by very high coefficients of variation (large end: 51-45; midline: 74-34; and small end: 52-92).

Treatments 1 and 5 (both pre-rigor) had higher chewiness scores however only treatment 1 was significant (Table 9). This should be expected since treatment 1 had some of the higher hardness and cohesiveness values and chewiness is the product of those values. These values were also affected by a high coefficient of variation (39.75).

Table 10 shows orthogonal contrast probability levels for physical dimensions of restructured steaks. None of the contrasts showed significant differences in length of raw or cooked steaks. The large end width of the raw and cooked steaks was affected by flake size as shown by the probability levels for contrasts 2 and 11. These two contrasts compared the effects of using the 0.75 inch to 0.51 inch flake sizes.

The contrasts used did not show a significant difference in the small end width of raw or cooked steaks (Table 10). However, probability levels for contrasts 2 and 11 showed there was a difference in steak thickness at all three points of measurement. In other words, the larger flake size resulted in thicker steaks (Tables 7 (page 50) and 10). Greater small end thickness measurements were also found when steaks were made of pre-rigor meat or a mixture thereof as shown by the low probability levels of contrasts 1 and 9.

The probability levels for any of the orthogonal contrasts affecting the cooking loss values were very high.

Table 11 shows the orthogonal contrast probability levels of shear and certain physical characteristics of restructured steaks.

TABLE 10. Orthogonal Contrast Probability Levels of Physical Dimensions and Cooking Loss of Restructured Steaks Made From Pre- and Post-Rigor Cow Beef

Contrasts[1]	Length		Width, raw		Width, cooked		Thickness			Cooking loss
	Raw	Cooked	Large end	Small end	Large end	Small end	Large end	Midline	Small end	
1	0.215	0.104	0.186	0.536	0.133	0.282	0.173	0.156	0.032	0.243
2	0.648	0.658	0.084	0.884	0.021	0.976	0.077	0.029	0.022	0.192
3	0.902	0.595	0.376	0.769	0.456	0.275	0.579	0.834	0.486	0.269
4	0.743	0.500	0.376	0.640	0.596	0.660	0.693	0.863	1.000	0.873
5	0.404	0.980	0.422	0.486	0.756	0.323	0.144	0.331	0.148	0.783
6	0.967	0.428	0.455	0.891	0.928	0.556	0.806	0.655	0.698	0.931
7	0.954	0.315	0.749	0.771	0.514	0.835	0.545	0.412	1.000	0.749
8	0.881	0.254	0.494	0.477	0.497	0.520	0.852	0.534	0.984	0.417
9	0.894	0.975	0.268	0.2665	0.059	0.873	0.093	0.135	0.053	0.931
10	0.727	0.739	0.861	0.242	0.801	0.970	0.543	0.924	0.814	0.196
11	0.333	0.768	0.017	0.329	0.005	0.936	0.007	0.005	0.003	0.563

[1]Contrasts are shown in Table 3, page 42.

TABLE 11. Orthogonal Contrast Probability Levels of Shear and Certain Physical Characteristics of Restructured Strip Steaks

Contrasts[1]	L.E.E. Kramer Shear	Bind		Hardness			Cohesiveness			Chewiness
		Small end	Large end	Large end	Midline	Small end	Large end	Midline	Small end	
1	0.003	0.538	0.592	0.576	0.471	0.339	0.660	0.011	0.924	0.046
2	0.219	0.565	0.865	0.078	0.012	0.080	0.316	0.001	0.417	0.0003
3	0.0004	0.175	0.042	0.249	0.621	0.814	0.653	0.899	0.655	0.163
4	0.362	0.398	0.174	0.496	0.921	0.167	0.327	0.021	0.655	0.726
5	0.574	0.258	0.208	0.100	0.396	0.245	0.084	0.101	0.786	0.628
6	0.042	0.336	0.099	0.950	0.384	0.892	0.329	0.372	0.394	0.541
7	0.004	0.346	0.264	0.257	0.263	0.790	0.191	0.507	0.251	0.025
8	0.009	0.353	0.344	0.871	0.500	0.978	0.605	0.409	0.206	0.266
9	0.010	0.607	0.418	0.049	0.012	0.008	0.161	0.162	0.897	0.0004
10	0.352	0.943	0.948	0.204	0.147	0.993	0.282	0.615	0.220	0.254
11	0.019	0.461	0.861	0.181	0.018	0.021	0.729	0.0002	0.911	0.0001

[1]Contrasts are shown in Table 3, page 42.

The lowest probability levels of L.E.E. Kramer shear values were contrasts 1, 3, 7, and 8. These contrasts show that steaks made of pre-rigor meat and 0.75 inch flakes were less tender. Contrasts 6 and 9 also showed low probability levels, as they compared a mixture of pre-rigor and post-rigor muscle, 0.75 inch flake, to all pre-rigor and all post-rigor steaks of the same flake size. Pre-rigor steaks and the combination steaks were less tender than the post-rigor steaks (Tables 9 and 11).

The only orthogonal contrast which had a low probability level for bind was contrast 3 (Table 11). This contrast compared a pre-rigor mixture of the two flake sizes to a post-rigor mixture of the two flake sizes. Bind value for the large end of the steaks was greater for those made of post-rigor meat (Tables 9 and 11).

The lowest probability levels for hardness (Table 11) at all three points of measurement were found in contrast 9 (pre-rigor and post-rigor muscle of 0.75 inch flake size contrasted against a mixture of pre-rigor and post-rigor tissue of 0.75 flake size). The all pre-rigor steaks were harder (Table 9). Contrast 2 had relatively low probability levels for all hardness values which meant the steaks made with 0.75 in. flakes were harder (Tables 9 and 11). Contrast 11 also had low probability levels for midline and small end hardness due to greater hardness values for steaks containing 0.75 in. flakes. Contrasts 2 and 11 had low probability levels for midline cohesiveness which was due mostly to the greater value of pre-rigor steaks with 0.75 in. flakes (Tables 9 and 11). Contrast 1 (pre-rigor vs post-rigor) also had a low probability level for midline cohesiveness.

Contrasts 2, 9, and 11 had the lowest probability levels for chewiness. Contrasts 2 and 11 compared flake sizes and contrast 9 compared a mixture of pre-rigor and post-rigor meat of 0.750 inch flake size. Contrasts 1 (pre-rigor and post-rigor meat) and 7 (mixture of pre-rigor and post-rigor muscle and different flake sizes) also had low probability levels for chewiness. These results should be expected since the steaks made of pre-rigor meat and larger flake sizes were generally harder and more cohesive and chewiness is the product of those two traits.

CHAPTER V

CONCLUSION

Even though treatment 1 (pre-rigor, 0.75 inch flake) exhibited the greatest distortion and a high degree of cooking loss, it had the highest combined shear, bind, hardness, cohesiveness and chewiness scores. The larger flake size using pre-rigor meat yielded a product more nearly typifying an intact muscle product.

However, post-rigor muscle flaked to 0.51 flake size (treatment 4) showed little distortion and a low cooking loss percentage. Mixtures of 0.51 inch flake, post-rigor muscle mixed with pre-rigor, 0.75 inch flake size (treatment 10) showed little distortion and the least cooking loss percentage. However, treatment 10 was only average for shear, bind, hardness, cohesiveness and chewiness scores.

If one of the objectives in making restructured steaks is to produce a product with textural properties similar to a whole muscle or intact muscle cut it seems that the use of pre-rigor muscle cut into larger flakes is advisable. Additional work needs to be done to compare other flake sizes of pre- and post-rigor meat for obtaining optimal textural properties.

LIST OF REFERENCES

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Abernathy, J. D. 1982. Medical significance of dietary sodium. Proc. Meat Ind. Res. Conf.

Acton, J. C. 1972. The effect of meat particle size on extractable protein, cooking loss, and binding strength in chicken loaves. J. Food Sci. 37:240.

Acton, J. C. and R. L. Saffle. 1969. Preblended and pre-rigor meat in sausage emulsions. Food Technol. 23:367.

Addis, P. B., S. Tsai, S. W. Park, S. E. Kindom, and A. S. Csallany. 1983. Recent studies on lipid oxidation. Proc. Meat Ind. Res. Conf.

Andres, C. 1982. FDA estimates 40% of food will carry sodium content label by spring. Food Process. 43(2):75.

Anonymous. 1976. Steak . . . at a 40% savings. Food Engr. 48(12): ef-6.

Anonymous. 1980. Hunter Lab Tristimulus Colorimeter Instruction Manual. Hunter Associates Laboratory, Inc. Reston, VA.

Anonymous. 1981. Is low sodium processing a realistic goal for industry? Meat Ind. 12:15.

Apple, J. M. 1981. Concepts of packaging pre-rigor meat. Proc. 34th Recip. Meats Conf. 34:85.

Behnke, J. R. and O. Fennema. 1973. Quality changes in pre-rigor beef muscle at -3°C. J. Food Sci. 38:539.

Behnke, J. R., O. Fennema, and R. G. Cassens. 1973. Rates of postmortem metabolism in frozen animal tissue. J. Agri. Food Chem. 21:5.

Belohlavy, R. and R. W. Mandigo. 1974. The influence of mixing time on chemical and physical properties of flaked, formed, and sectioned meat. J. Ani. Sci. 39:16 (Abstr.).

Bendall, J. R. 1972. Consumption of oxygen by the muscles of beef animals and related species, and its effects on the colour of meat. I. Oxygen consumption in pre-rigor muscle. J. Sci. Food Agric. 23:61.

Berry, B. W., J. J. Smith, and J. L. Secrist. 1985. Effects of fat level on sensory, cooking, and instron properties of restructured beef steaks. J. Anim. Sci. 60:434.

Bodwell, C. E. and P. E. McClain. 1971. The Science of Meat and Meat Products. W. H. Freeman and Co., San Francisco, CA.

Booren, A. M. and R. W. Mandigo. 1981. Maximizing color in restructured steaks. Meat Ind. 10:36.

Booren, A. M., R. W. Mandigo, D. G. Olson, and K. W. Jones. 1981a. Effect of muscle type and mixing time on sectioned and formed beef steaks. J. Food Sci. 46:1665.

Booren, A. M., K. W. Jones, R. W. Mandigo, and D. G. Olson. 1981b. 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.

Bouton, P. E., P. V. Harris, and W. R. Shorthose. 1971. Effect of ultimate pH upon the water-holding capacity and tenderness of mutton. J. Food Sci. 36:435.

Bowling, R. A., G. C. Smith, T. R. Dutson, and Z. L. Carpenter. 1978. Effects of pre-rigor conditioning treatments on lamb muscle shortening, pH, and ATP. J. Food Sci. 43:502.

Brady, P. L. and M. E. Hunecke. 1985. Correlations of sensory and instrumental evaluations of roast beef texture. J. Food Sci. 50:300.

Breidenstein, B. C. 1982. Intermediate value beef products. Restructured beef products. National Livestock and Meat Board. Chicago, IL.

Cassens, R. G. and R. P. Newbold. 1967. Temperature dependence of pH changes in ox muscle postmortem. J. Food Sci. 32:13.

Chesney, M. S., R. W. Mandigo, and J. F. Campbell. 1978. Properties of restructured pork product as influenced by meat particle size, temperature, and comminution method. J. Food Sci. 43:1535.

Cia, G. and B. B. Marsh. 1976. Properties of beef cooked before rigor onset. J. Food Sci. 41:1259.

Contreras, S., D. L. Harrison, D. H. Kropf, and C. L. Kastner. 1981. Electrical stimulation and hot-boning: Cooking losses, sensory properties and microbial counts of ground beef. J. Food Sci. 46:457.

Coon, F. P. 1982. The utilization of pre-rigor muscle in sectioned and formed meat products. M.S. Thesis, Univ. of Nebraska, Lincoln.

Cordray, J. C. and D. L. Huffman. 1983. Restructuring of hot processed meat. Proc. 36th Recip. Meats Conf. 36:74.

Costello, C. A., M. P.Penfield, and M. J. Riemann. 1985. Quality of restructured steaks: Effects of days on feed, fat level, and cooking method. J. Food Sci. 50:685.

Costello, W. J., S. C. Seideman, J. D. Michaels, and N. M. Quenzer. 1981. Effect of comminution method and pressure on restructured beef steaks. J. Food Prot. 44:425.

Cross, H. R., B. W. Berry, and L. H. Wells. 1980. 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., S. C. Seideman, and J. D. Crouse. 1981. Grading system for pre-rigor meat. Proc. 34th Recip. Meats Conf. 34:91.

Cross, H. R. and M. S. Stanfield. 1976. Consumer evaluation of restructured beef steaks. J. Food Sci. 41:1257.

Dalrymple, R. H. and R. Hamm. 1975. Postmortem glycolysis in pre-rigor ground bovine and rabbit muscle. J. Food Sci. 40:850.

Davey, C. L. 1983. Postmortem chemical changes in muscle-meat aging. 36th Recip. Meats Conf. 36:108.

Davey, C. L. and K. V. Gilbert. 1974. The mechanism of cold-induced shortening in beef muscle. J. Food Technol. 9:51.

Davey, C. L. and K. V. Gilbert. 1976. Thaw contracture and the disappearance of Adenosine triphosphate in frozen lamb. J. Sci. Food Agr. 27:1085.

Drainsfield, E. and D. N. Rhodes. 1975. Texture of beef M. semitendinosus heated before, during, and after development of rigor mortis. J. Sci. Food Agr. 26:483.

Drerup, D. L., M. D. Judge, and E. D. Aberle. 1981. Sensory properties and lipid oxidation in prerigor processed fresh pork sausage. J. Food Sci. 46:1659.

Durland, P. R., S. C. Seideman, W. J. Costello, and N. M. Quenzer. 1982. Physical and sensory properties of restructured beef steaks formulated with various flake sizes and mixing times. J. Food Prot. 45:127.

Dutson, T. R. 1983. The measurement of pH in muscle and its importance to meat quality. Proc. 36th Recip. Meats Conf. 36:92.

Farrington, A. E. 1975. Flaked, formed, and frozen lamb products. Proc. 28th Recip. Meats Conf. 28:140.

Fennema, O. R. 1971. Rates of chemical deterioration in frozen foods. Proc. Meat Ind. Res. Conf., p. 35.

Fenters, W. and J. V. Ziemba. 1971. New way to fabricate meats. Food engineer. (43(1):64.

Fischer, C., K. O. Honikel, and R. Hamm. 1980. Influence of the velocity of freezing pre-rigor beef on muscle metabolism and water-holding capacity. Zeitschr. Lebensmitt. Untersuch. Forsch. 171:105.

Forrest, J. C., E. D. Aberle, H. B. Hedrick, M. D. Judge, and R. A. Merkel. 1975. Principles of Meat Science. W. H. Freeman and Co., San Francisco, CA.

Fukazawa. T., Y. Hashimoto, and T. Yasui. 1961. Effect of storage conditions on some physiochemical properties in experimental sausage prepared from fibrils. J. Food Sci. 26:331.

Gokalp, H. Y., H. W. Ockerman, and R. F. Plimpton. 1979. Effect of packaging methods on the sensory characteristics of frozen and stored cow beef. J. Food Sci. 44:147.

Hamm, R. 1960. Biochemistry of meat hydration. Adv. Food Res. 10:355.

Hamm, R. 1977. Postmortem breakdown of ATP and glycogen in ground muscle. A review. Meat Sci. 1:15.

Hamm, R. 1982. Postmortem changes in muscle affecting the quality of comminuted meat products. In Developments in Meat Science. Applied Publishers.

Hamm, R. and J. Van Hoof. 1971. Influence of grinding of beef muscle on the breakdown of adenosine triphosphate and glycogen postmortem. Zeitschr. Lebensmitt. Untersuch Forsch. 147:193.

Henrickson, R. L. 1975. Hot boning. Proc. of the Meat Ind. Res. Conf. American Meat Inst., Washington, D.C., p. 25.

Hollingsworth, C. A., R. W. Mandigo, and C. R. Calkins. 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., C. Fischer, A. Hamid, and R. Hamm. 1981a. Influence of postmortem changes in bovine muscle on the water-holding capacity of beef. Postmortem storage of muscle at 20°C. J. Food Sci. 46:1.

Honikel, K. O., A. Hamid, C. Fischer, and R. Hamm. 1981b. Influence of postmortem changes in bovine muscle on the water-holding capacity of beef. Postmortem storage of muscle at various temperatures between 0 and 30°C. J. Food Sci. 46:23.

Honikel, K. O. and R. Hamm. 1978. Influence of cooling and freezing on minced pre-rigor muscle on the breakdown of ATP and glycogen. Meat Sci. 2:181.

Huffman, D. L. 1980. Processing effects on fresh and frozen meat color. Proc. 33rd Recip. Meats Conf. 33:4.

Huffman, D. L. and J. C. Cordray. 1979. Restructured fresh meat cuts from chilled and hot processed pork. J. Food Sci. 44:1564.

Huffman, D. L., H. R. Cross, K. J. Campbell, and J. C. Cordray. 1981. Effect of salt and tripolyphosphate on acceptability of flaked and formed hamburger patties. J. Food Sci. 46:34.

Johnson, R. G. and R. L. Henrickson. 1970. Effect of treatment of pre- and post-rigor porcine muscles with low sodium chloride concentrations on the subsequent extractability of proteins. J. Food Sci. 35:268.

Jolley, P. D., K. O. Honikel, and R. Hamm. 1981. Influence of temperature on the rate of postmortem metabolism and water-holding capacity of bovine neck muscles. Meat Sci. 5:99.

Judge, M. D. and E. D. Aberle. 1980. Effect of pre-rigor processing on the oxidative rancidity of ground light and dark porcine muscles. J. Food Sci. 45:1736.

Kastner, C. L., R. L. Hendrickson, and R. D. Morrison. 1973. Characteristics of hot boned bovine muscle. J. Anim. Sci. 36:484.

Kramlich, W. E., A. M. Pearson, and F. W. Tauber. 1973. Processed Meats. The AVI Publishing Co., Inc., Westport, CN.

Kropf, D. H. 1984. Objective measures of meat color. Proc. 37th Recip. Meats Conf. 37:24.

Lawrie, R. A. 1979. Meat Science (3rd Ed.). Pergamon Press, New York.

LeMaire, W. H. 1978. At McDonald's . . . Engineered steak. Food Engin. 50(3):ef-13.

Locker, R. H. 1960. Degree of muscle contraction as a factor in tenderness of beef. J. Food Sci. 25:304.

Locker, R. H. and G. J. Daines. 1976. Tenderness in relation to the temperature of rigor onset in cold shortened beef. J. Sci. Food Agr. 27:193.

Locker, R. H. and C. J. Hagyard. 1963. A cold shortening effect in beef muscles. J. Sci. Food Agr. 14:787.

Macfarlane, J. J., G. R. Schmidt, and R. H. Turner. 1977. Binding of meat pieces: A comparison of myosin, actomyosin, and sarcoplasmic proteins as binding agents. J. Food Sci. 42:1603.

Maesso, E. R., R. C. Baker, and D. V. Vadehra. 1970. The effect of vacuum packaging, pH, and meat types on the binding ability of poultry meat. J. Poultry Sci. 49:697.

Mandigo, R. W. 1974. Restructured meat. Proc. 27th Recip. Meats Conf. 27:403.

Mandigo, R. W. 1975. Restructured meat. Proc. Meat Ind. Res. Conf. American Meat Inst., Washington, D.C., p. 43.

Mandigo, R. W., K. R. Hansen, and M. S. Chesney. 1973. Effect of salt content and flaking temperature on flaked, formed, and sectioned meat products. J. Anim. Sci. 37:269.

Marsh, B. B. 1954. Rigor-mortis in beef. J. Sci. Food Agr. 5:70.

Marsh, B. B. 1977a. Symposium: The basis of quality in muscle foods. The basis of tenderness in muscle foods. J. Food Sci. 42:295.

Marsh, B. B. 1977b. Temperature and postmortem change: Energy use and meat quality. Proc. Meat Ind. Res. Conf. American Meat Inst., Washington, D.C., p. 13.

Marsh, B. B. and W. A. Carse. 1974. Meat tenderness and the sliding filament hypothesis. J. Food Technol. 9:129.

Marsh, B. B. and N. G. Leet. 1966. Studies in meat tenderness. III. The effects of cold shortening on tenderness. J. Food Sci. 31:450.

Marsh, B. B., N. G. Leet, and M. R. Dickson. 1974. The ultrastructure and tenderness of highly cold-shortened muscle. J. Food Technol. 9:141.

Marsh, B. B. and J. F. Thompson. 1958. Rigor mortis and thaw rigor in lamb. J. Sci. Food Agr. 9:417.

Neer, K. L. and R. W. Mandigo. 1977. Effects of salt, sodium tripolyphosphate, and frozen storage time on properties of a flaked, cured pork product. J. Food Sci. 42:738.

Newbold, R. P. and P. V. Harris. 1972. The effect of pre-rigor changes on meat tenderness. A review. J. Food Sci. 37:337.

Paquette, M. W. 1982. Go slow on reducing salt levels until all the facts are in. The Natl. Provisioner. 186(10):16.

Pepper, F. H. and G. R. Schmidt. 1975. Effect of blending time, salt, phosphate and hot-boned beef on binding strength and cooked yields of beef rolls. J. Food Sci. 40:227.

Popenhagen, G. R. and R. W. Mandigo. 1978. Properties of restructured pork as affected by flake size, flake temperature, and blend combination. J. Food Sci. 43:1641.

Reagan, J. O. 1983. Hot processing of pork whole muscle cuts. Proc. 36th Recip. Meats Conf. 37:71.

Saffle, R. L. and J. W. Galbreath. 1964. Quantitative determination of salt-soluble protein in various types of meat. Food Technol. 18:1943.

Schmidt, G. R. 1977. Why massage or tumble? Meat Ind. 11:40.

Schnell, P. G., D. V. Vadehra, and R. C. Baker. 1970. Mechanism of binding chunks of meat. I. Effect of physical and chemical treatments. Can. Inst. of Food Science Technol. Four. 3:44.

Schwartz, W. C. and R. W. Mandigo. 1976. Effect of salt, sodium tripolyphosphate, and storage on restructured pork. J. Food Sci. 41:1266.

Stryer, L. 1981. Biochemistry (2nd Ed.). W. H. Freeman and Co., San Francisco, CA.

Swift, C. E., C. Locket, and A. J. Fryer. 1961. Comminuted meat emulsions-The Capacity of meats for emulsifying fat. Food Technol. 15:468.

Swift, C. E., and W. L. Sulzbacher. 1963. Comminuted meat emulsions: Factors affecting meat proteins as emulsion stabilizers. Food Technol. 17:224.

Taylor, A. A., B. G. Shaw, and D. B. MacDougall. 1981. Hot deboning of beef with and without electrical stimulation. Meat Sci. 5:109.

Theno, D. M., D. G. Siegal, and G. R. Schmidt. 1978a. Meat massaging: Effects of salt and phosphate on the microstructural composition of the muscle exudate. J. Food Sci. 43:483.

Theno, D. M., D. G. Siegal, and G. R. Schmidt. 1978b. Meat massaging: Effects of salt and phosphate on the ultrastructure of cured porcine muscle. J. Food Sci. 43:488.

Theno, D. M., D. G. Siegal, and G. R. Schmidt. 1978c. Meat massaging: Effects of salt and phosphate on the microstructure of binding junctions in sectioned and formed hams. J. Food Sci. 43:493.

Trautman, J. C. 1964. Fat-emulsifying properties of prerigor and postrigor pork proteins. Food Technol. 18:1065.

Van Hoof, J. and R. Hamm. 1973. Influence of sodium chloride on the breakdown of adenosine triphosphate and glycogen in ground beef muscle postmortem. Zeitschr. Lebensmitt. Untersuch. Forsch. 150:282.

Walker, H. W. 1980. Effects of microflora on fresh meat color. Proc. 33rd Recip. Meats Conf. 33:33.

West, R. L. 1983. Chilling of prerigor meat. Proc. 36th Recip. Meats Conf. 36:82.

Wiebe, W. R., Jr. and G. R. Schmidt. 1982. Effects of vacuum mixing and pre-cooking on restructured steaks. J. Food Sci. 47:386.

Wierbicki, E., V. R. Cahill, and F. E. Deatherage. 1957. Effects of added sodium chloride, potassium chloride, calcium chloride, magnesium chloride, and citric acid on meat shrinkage at 70°C and of added sodium chloride on drip losses after freezing and thawing. Food Technol. 11:74.

Williams, S. C. 1978. Hot-boning. Food Technol. in Australia. 30(12):495.

Winger, R. J., O. Fennema, and B. B. Marsh. 1979. Rate of pH decline in beef muscle stored at, above, and below freezing temperatures. J. Food Sci. 44:1681.

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