AN ABSTRACT OF THE THESIS OF

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Title: INFLUENCE OF MICROWAVE AND BROILING COOKING METHODS ON QUALITY CHARACTERISTICS OF PRE-RIGOR PRESSURIZED VERSUS CONVENTIONALLY PROCESSED BEEF

Abstract approved:

Zoe Ann Holmes

This study investigated the influence of microwave and broiling cooking methods on quality parameters of portion size cuts of beef semitendinosus muscle subjected to pre-rigor pressure treatment. The pre-rigor pressurized beef was compared to conventionally processed portion size cuts. Juiciness, tenderness, and flavor were evaluated by objective and subjective tests. Objective tests included water-holding capacity, total moisture, Warner-Bratzler shear, pH, and color of the raw and cooked beef portions. Total lipids and nitrogen content were measured to determined paired sample muscle uniformity. Cooking losses, temperature/time data and electron micrographs were collected as appropriate. Juiciness, tenderness, ease of fiber separation, and flavor of the

microwaved and broiled beef portions were subjectively evaluated by a six member trained panel of judges.

Pre-rigor pressure treated cooked beef portions showed significantly ($P<0.05$) greater total moisture, pH, exterior a+ color values and subjective tenderness and ease of fiber separation scores than the untreated portions. No significant differences in interior L, a+ and b+ color values were found between pressure treated and untreated samples. Subjective juiciness and flavor scores were not significantly different between treatments. Total moisture, expressible moisture index, Warner-Bratzler shear, pH, and exterior L and a+ color values were not significantly different between the raw pressure treated and untreated beef portions. Pressure treatment resulted in a significantly higher ($P<0.01$) exterior b+ color value for the raw treated meat.

Total moisture, drip cooking loss, interior a+ (redness) color value, and exterior L (lightness) and b+ (yellowness) color values were significantly higher ($P<0.05$) in the microwaved beef portions as compared to the broiled portions. Total and evaporation cooking losses were significantly lower ($P<0.01$) with microwave cooking than broiling in the untreated and pressure treated portions. No significant differences in expressible moisture index, Warner-Bratzler shear, pH, exterior a+ color, and interior L and b+ color values were found between microwave and broiled portions. Panelists evaluation of

juiciness, tenderness, ease of fiber separation, and flavor of the beef portions indicated no significant differences between cooking methods.

Although total moisture, cooking losses, and color values were significantly different between microwaved and broiled beef portions, in general, microwave and broiling cooking methods gave comparable results for quality parameters in pre-rigor pressure treated cooked beef portions. The significantly higher total moisture and tenderness of pre-rigor pressure treated cooked beef portions indicates the feasibility of this process for use by the meat industry.

Influence of Microwave and Broiling Cooking Methods on Quality Characteristics of Pre-Rigor Pressurized versus Conventionally Processed beef

by

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INTRODUCTION

Consumers spend approximately 16.7 percent of their disposable personal income on food, of which 12.2 percent is being eaten at home and 4.5 percent away from home (Gallo, 1981). This represents an annual expenditure of approximately $235 and $88 billion, respectively. Beef accounts for approximately 12 percent of the total food dollar (McDermott, 1982). With the continuing rise in beef prices accompanied by a decline in beef production (Russo, 1981), the percent of per capita disposable income spent on beef is slowly decreasing. A portion of this decrease can be attributed to price increase due to the cost or energy consumption during production, processing, and preparation.

Within the food industry, meat packing is the leading energy consumer with more than 99 trillion BTU consumed in 1973 (Unger, 1975). An accelerated processing system such as pre-rigor pressure (PRP) treatment has the advantage of decreased energy consumption for refrigeration, refrigerated space, labor, transportation and decreased inventory costs (West, 1982). This process involves hot-boning of muscles soon

after slaughter, vacuum packaging, pressure treatment, and chilling of those portions to be consumed (MacFarlane, 1973; Kennick et al., 1980). This minimization of energy consumption through utilization of pre-rigor pressure treatment would have potential economic and energy benefits to the meat industry.

Due to the rising cost of energy, the amount of energy required to cook muscle foods has also become an important factor in choosing equipment and appliances for food processing (Mandigo and Janssen, 1982). The use of microwave ovens is an energy saving processing technique which could reduce utility costs for the food processor, the foodservice industry, and the consumer. Microwave oven usage in restaurants and many other areas of commercial foodservice has grown steadily since the late 1940's when they were first introduced (Snyder, 1981). Home use of microwave ovens in the U.S. has reached a market penetration level of 20 percent (Rubbright, 1981). The combination of marketing of pre-rigor pressurized beef for the institutional and/or retail markets with recommendations for microwave oven cooking presents a feasible potential for energy savings. The development of data on the influence of traditional and newer cooking methods on pre-rigor pressurized muscle may thus further the use of this product in the marketplace.

The objective of this research was to investigate the influence of microwave and broiling cooking methods on the

quality characteristics of portion cuts of pre-rigor pressurized (PRP) beef semitendinosus muscle. The pre-rigor pressurized beef was compared to conventional processed portion sized beef cuts.

REVIEW OF LITERATURE

Muscle Composition and Structure

Conversion of muscle to meat postslaughter involves a series of biochemical and physiological changes in the muscle cell. These changes are influenced by the animal, the conditions under which rigor mortis occurs and conditions of postmortem handling of the meat. A knowledge of muscle composition and structure provides a basis for understanding the influence of these factors on meat quality.

An average piece of beef muscle has approximately 70-73% water, 20-22% protein, 4-8% lipid, 1% ash, and 1% carbohydrate (Hultin, 1976). Of these major components, protein is probably the most important constituent in relation to food quality. About 50-55% of the protein makes up the contractile structures, 10-17% the connective tissue, and 30-35% the sarcoplasmic and subcellular organelles (Lawrie, 1975). These classifications are usually categorized according to their extractability (Goll et al., 1974). Contractile proteins constitute the myofibril and are extracted from muscle with salt solutions of high ionic strength (Bodwell and McClain, 1971; Goll et al., 1970). Sarcoplasmic proteins include enzymes, muscle pigment and myoglobin found in the cytoplasm of the muscle cell and can be extracted with water or dilute salt solutions (Bodwell and McClain, 1971; Goll et al., 1970). Connective tissue is made up

of stroma protein, mainly collagen, elastin and reticulin, which is insoluble after treatment with salt solutions of high ionic strength (Bodwell and McClain, 1971; Goll et al., 1970).

The myofibrillar protein consists of 50-60% thick filament myosin, 15-30% thin filament actin and 20-25% regulatory proteins (Hultin, 1976). Among the regulatory proteins, tropomyosin, troponin, and beta-actinin are associated with the actin filament; C-protein is present in the myosin filament; alpha-actinin is a component of the Z-line; and M-proteins may be the substances composing the M-line. Sarcoplasmic proteins are classified into four subclasses or fractions of structural components: nuclear, mitochondrial, microsomal and cytoplasmic (Asghar and Pearson, 1980). The nuclear fraction is composed of nuclear material and lipoproteins. The mitochondrial fraction consists of the mitochondria, tricarboxylic acid cycle enzymes, and the electron transport system. The microsomal fraction includes the sarcoplasmic reticulum, the T-system, microsomes, and the lysosomes. The cytoplasmic fraction is composed of myoglobin, the enzymes of the glycolytic pathway and gluconeogenesis, and the soluble proteins.

Myoglobin is the oxygen-carrying heme protein primarily responsible for meat color. The blood pigment hemoglobin provides a smaller contribution to color. The color of raw meat is determined mainly by the proportions of purple reduced myoglobin, red oxymyoglobin and brown metmyoglobin (Strange et

al., 1974). The relative amount of oxymyoglobin and metmyoglobin will depend on the partial pressure of oxygen, with metmyoglobin formation favored at low oxygen pressures. The gray-brown color of cooked meat is primarily due to the heme pigment, denatured globin hemichrome.

Connective tissue is a fibrous protein used to support muscle fibers, bones and fat and to regulate and control the extent of contraction. The connective tissue is held together by a ground substance which acts as an undifferentiated cementing matrix in which fibers of collagen and elastin are embedded. Collagen is the principal structural protein of connective tissue constituting approximately 20-25% of the total protein in an animal body. The basic structural unit of collagen is tropocollagen which forms intermolecular crosslinks. Elastin is a highly extensible fibrous protein accounting for less than 3% of the connective tissue and is crosslinked at intervals by thermally stable bonds to give it a rubber-like elasticity (Bourne et al., 1966). The reticulin of connective tissue consists of small fibers which form delicate networks around cells, blood vessels, neutral structures, and the epithelium.

Lipids in meat are deposited within the connective tissue, subcutaneously, intramuscularly, and in adipose cells. They consist primarily of triglycerides and free fatty acids with a smaller proportion from phospholipids and cholesterol. In

general, the subcutaneous fat, and intramuscular fat consists of 42%, 44%, and 47% saturated fatty acids and 57.9%, 55.9%, and 52.8% unsaturated fatty acids, respectively (Anderson et al., 1975). The content and composition of the lipids are dependent upon breed, sex, age, level of nutrition, location of the fat within the animal, and environmental factors (Kinsella et al., 1975; Anderson et al., 1975).

Glycogen, glucose, lactic acid, pentoses, mucopolysaccharides, inorganic ions, and nonprotein nitrogen-containing compounds are present in muscle foods. Although found in small amounts, these compounds may play a significant role in many biochemical and biophysical reactions of the muscle. Lactones, and acyclic sulfur containing compounds composed of sulfur, nitrogen and oxygen are the major classes of flavor compounds in meat with a large flavor impact (Chang and Peterson, 1977).

A number of reports (Bailey, 1972; Blanshard and Derbyshire, 1975; Mannherz and Goody, 1976; Hultin, 1976; Threadgold, 1976) have extensively reviewed the structure of meat. Basically, meat consists of muscle fibers surrounded by a heavy sheath of connective tissue interspersed with nerves, blood vessels, and fat cells. Muscle fibers are long, thin, multi-nucleated cells ensheathed by a delicate membrane, the sarcolemma. The fibers are arranged in a parallel fashion to form bundles surrounded by the perimysium. Groups of fiber

bundles make up a muscle which is surrounded by the epimysium.

The sarcomere is the basic repeating contractile unit of muscle and has an influence on a number of quality parameters. Within skeletal muscle fibers are threadlike structures, the myofibrils (Figure 1), 1 to 2 micrometers in diameter (Jones, 1977). Myofibrils are formed by the ordered arrangement of interdigitated thick myosin filaments (100 angstroms diameter), thin actin filaments (50 angstroms diameter), and some regulatory proteins. This arrangement gives a striated appearance to the myofibril and muscle cell. The dark myosin containing A-band and light actin containing I-band are anchored at the ends of the myofibril by the Z-line, seen microscopically as a dark perpendicular line. In the center of the A-band is the H-zone which is bisected by a darker M-zone. The sarcomere is defined as the material located between and including two adjacent Z-lines.

The contractile mechanism provides the basis for many of the structural changes which occur in postmortem muscle. Huxley and Hanson (1954) proposed the sliding filament theory for muscle contraction. When a muscle is stimulated by a nervous impulse, the projecting myosin cross-bridges reach out to complex with the G-actin and cause a sliding of the filaments past each other. The complex of actin, myosin, tropomyosin, and troponin resulting from the sliding action forms actomyosin. Although actomyosin is a transient compound in the contraction

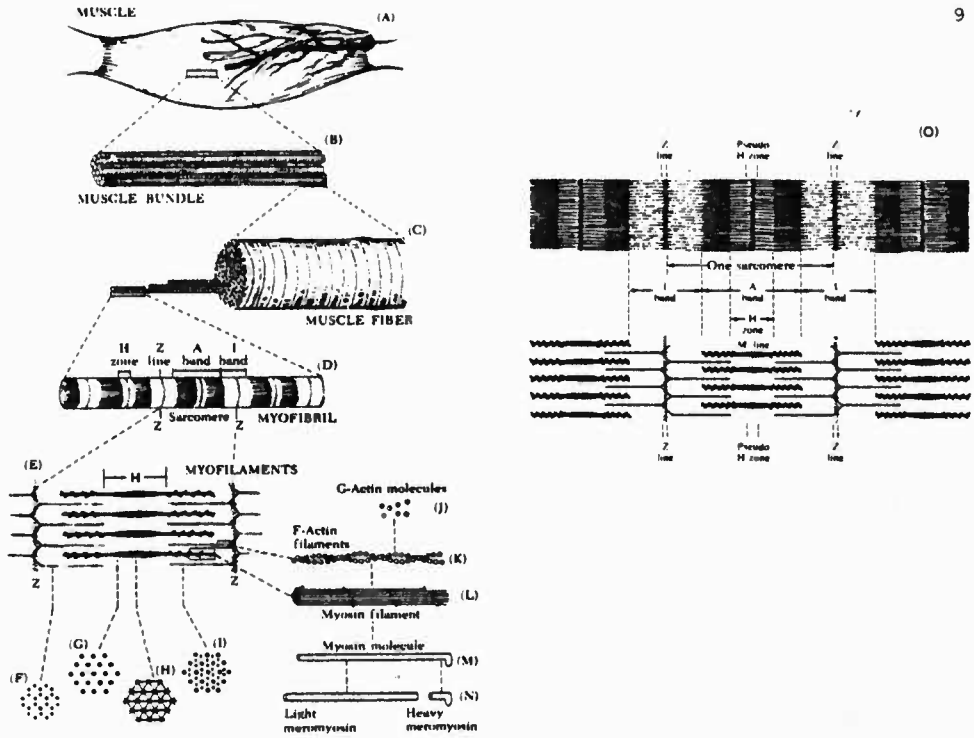

FIGURE 1[1]
Diagram of the organization of skeletal muscle from the gross structure to the molecular level. (A) skeletal muscle, (B) a bundle of muscle fibers, (C) a muscle fiber, showing the myofibrils, (D) a myofibril, showing the sarcomere and its various bands and lines, (E) a sarcomere, showing the position of the myofilaments in the myofibril, (F-I) cross sections showing the arrangement of the myofilaments at various locations in the sarcomere, (J) G-actin molecules, (K) an actin filament, composed of two F-actin chains coiled about each other, (L) a myosin filament, showing the relationship of the heads to the filament, (M) a myosin filament showing the head and tail regions, (N) the light meromyosin (LMM) and heavy meromyosin (HMM) portions of the myosin molecule, and (O) portions of two myofibrils and a sarcomere and a diagram corresponding to the sarcomere, identifying its various bands, zones, and lines. [Modified after Bloom and Fawcett, A Textbook of Histology, 9th ed., W.B. Saunders Company, Philadelphia, p. 273, 1968.]

[1] Figure 1. Adapted from Forrest, Aberle, Hedricks, Judge and Merkel, Principles of Meat Science, Freeman, San Francisco, California, pp. 32-33, 1975.

cycle of the living animal, it is the major form of the myofibril proteins found in postmortem muscle. Muscle relaxation in the living cell is a result of sequestering of the calcium into the sarcolemma. In postmortem muscle there is a loss of calcium sequestering ability of the sarcolemma resulting in a decrease in sarcomere length and a rigid and inextensible system. This stiffening of postmortem muscle is associated with development of rigor mortis.

Over the last several years, there has been an attempt to elucidate the problems of stresses on meat by the use of scanning or transmission electron microscopy. Schaller and Powrie (1971) observed possible changes in the beef sarcoplasmic reticulum with aging of meat. Although no structural change in transverse elements was noted after 6-days postmortem storage at 3 C, the transverse elements were collapsed in commercially-aged bovine longissimus dorsi muscle. Eino and Stanley (1973) used scanning electron microscopy (SEM) to follow the effect of cathepsin and collagenase activity in both beef and rabbit muscle. Varriano-Marston et al. (1976) used SEM to examine the fine structure of the sarcolemma of free and restrained muscle over a period of twelve days. They found the structure degenerated from a relatively smooth membrane around the fiber to a collection of randomly distributed aggregations of protein. The importance of fixation prior to fracturing and dehydration of freshly slaughtered and aged bovine muscle examined by SEM

was reported by Jones et al. (1976).

Quality Characteristics of Meat

Tenderness, juiciness, flavor, and color are quality characteristics indicating the basic nature of the meat or its degree of excellence (Lawrie, 1974; Bratzler, 1971). Chemical and physical test methods are used in conjunction with sensory analysis to elucidate the factors influencing quality parameters.

Tenderness

Tenderness is an important textural characteristic with a considerable influence on consumer acceptance of meat. The actomyosin complex of the contractile apparatus and the collagen of connective tissue are two structural components determining meat tenderness. The effect on tenderness from these components will be influenced by a number of antemortem and postmortem factors.

A number of investigators (Wierbicki et al., 1954; Davey and Gilbert, 1969; Bouton et al., 1975; Locker et al., 1977; Marsh, 1977) related tenderness to the role of contractile proteins. When red muscles in the pre-rigor state are exposed to chill temperatures during the initial postmortem period they are stimulated to shorten. This "cold shortening" of the muscles results in extensive overlap and cross-linking between the myosin and actin filaments with a decrease in sarcomere length and an accompanying toughness.

Rapid chilling of the carcass in the pre-rigor state at low temperatures (<15°C) perpetuates the cold shortening effect by damaging the sarcoplasmic reticulum and its ability to sequester calcium ions. Myofibrillar ATPase activity is also stimulated at temperatures below 15°C. Lockner et al. (1980) reported rapid chilling during the first 2-4 hours postmortem resulted in cold shortening with a marked toughening effect. However, they found the enhanced tenderness of slowly chilled beef is not primarily due to the prolonged avoidance of shortening inducive temperatures but to the retardation of cooling during the first 2-4 hours postmortem.

The ability of muscle to shorten decreases with time postmortem. If the actin and myosin filaments "lock" into rigor before the muscle is cooled below 15°C, cold shortening and hence, toughness, can be minimized. Processes which accelerate the rate of postmortem glycolysis will reduce this time for onset of rigor mortis. Electrical stimulation (Cross, 1979; Taylor et al., 1981) and pre-rigor pressurization (Kennick et al., 1980) have been suggested as promising approaches which accelerate the rate of postmortem glycolysis.

The contribution from collagen of connective tissue to tenderness is influenced by changes in collagen structure related to animal age, orientation of collagen in relation to myofibril contraction state, and heat-induced changes in collagen. As the animal matures, the heat-labile crosslinks of

collagen are replaced with thermally-stable links which may account for the tendency of meat from older animals to be tougher (Bailey et al., 1970). Rowe (1977) suggested that the collagen fiber geometry changes in relation to myofibril contraction state. He found the reverse relationship between meat toughness and contraction state is invoked by a firmer consistency for the muscle fibers which then act as fill between the collagen network fibers and hold them at an angle relative to the line of applied force. Rowe (1977) attributed the increased tenderness associated with 50% shortening to a decrease in the collagen component strength. The conversion of collagen to gelatin with sufficient heat treatment also increases the tenderness of meat (Goll et al., 1964).

Aging of meat postslaughter has been described as "resolution of rigor" and defined as meat stored at chill temperatures for 10 to 14 days (Lawrie, 1974). Davey and Gilbert (1969) suggested the tenderization which accompanies aging is due to weakening and eventual disintegration of Z-lines and decreased myofibrillar tensile strength. Disintegration of the Z-line has been attributed to the action of catheptic enzymes (Eino and Stanley, 1973), attack on alpha-actinin by calcium-activated sarcoplasmic factor (Busch et al., 1972; Penny, 1974), and mechanical stretching (Davey and Dickson, 1970). The attack of calcium-activated factor on the integrity of the gap filaments in the sarcomere has been reported to

increase tenderness during aging (Davey and Grafhaus, 1976; Locker et al., 1977; Asghar and Yeates, 1978). Asghar and Yeates (1978) also stated that collagen fibrils become more soft and pliable with aging. The rate of these changes depends on the temperature at which aging of the carcass is allowed to proceed.

The Warner-Bratzler shear device has been the most widely used instrument to assess meat tenderness (Moller, 1981). This instrument measures the maximum peak force required to shear through a meat sample of fixed cross-sectional area, at right angles to the muscle fiber direction. Peak shear force values relate more closely to the myofibrillar component of toughness than to the connective tissue (Cross et al., 1973; Penfield and Meyers, 1975). Davey and Gilbert (1975) proposed that the lateral force transmission in meat is a result of lateral inter-fiber connections provided by the sarcoplasmic reticulum and transverse tubular system. Bouton et al. (1975) hypothesized that a deforming force applied to cooked meat structure would be borne initially by the myofibrillar structure which has been coagulated and stiffened by cooking and then by the denatured connective tissue. Moller (1981) attributed connective tissue strength as the main contributor to maximum yield of shear force at an endpoint temperature of 60°C, whereas at 80°C the hardening of the myofibrillar proteins was considered to be the main component of peak force.

Juiciness

Cover et al. (1962) described juiciness as being made up of two effects: the impression of moisture released during chewing and increased salivation produced by flavor factors. Both bound water and the entrapped bulk phase water described by Hamm (1975) contribute to overall juiciness. Approximately 5% of the total water of muscle is bound water with most of the remainder as entrapped bulk phase water (Hamm, 1975). The amount of immobilized water will depend upon the physical configuration of the actin and myosin filaments. As the state of contraction of muscle fibers increases with greater overlap of the actin and myosin filaments, the amount of immobilized water decreases. If the muscle fibers are relaxed, there is greater immobilization of water due to the open structure of the filaments (Goll et al., 1977).

Hamm (1960) defined water-holding capacity (WHC) as the ability of muscle to immobilize free water during the application of any force. He noted a positive correlation between cooked meat juiciness and the ability of muscle to immobilize water. During the heating of meat, the water-holding capacity decreases due to heat denaturation of the proteins and a decrease in the diameter of the fibers (Laakkonen, 1973). Coagulation of the myofibrillar proteins allows the release of the bulk phase water from the tissue. However, heat denaturation and surface dehydration cause a surface layer to be

formed which retards loss of fluids. Bouton et al. (1971) noted an increase in water-holding capacity and decreased cooking losses in beef with increasing pH.

A number of methods are utilized to measure water-holding capacity. This includes the capillary volumeter method (Hofmann, 1976), microwave heating (Tsai and Ockerman, 1981), the centrifuge method (Wierbicki et al., 1957), and the standard press technique (Wierbicki and Deatherage, 1958). Tsai and Ockerman (1981) found the standard press technique was a sensitive method of measuring water-holding capacity. Bouton (1975) suggested expressible moisture measurements are positively correlated with juiciness in cooked meat if the pH of the raw meat is less than 5.8.

Flavor

The evaluation of flavor in meat is complex and highly subjective in nature, encompassing both taste and odor sensations. Factors such as breed, sex, animal age, feed ingredients in the diet, processing operations, as well as panelist preferences may influence meat flavor (Sink, 1979). The flavor of raw meat is weak and salty with a bloodlike aroma (Wasserman, 1979; Bratzler, 1971). Volatile flavor substances in cooked meat are generated from water-soluble or fat-soluble nonvolatile precursors present in the raw meat (Dwivedi, 1975). Some of these water-soluble precursors include amino acids, nucleotides, peptides, and water-soluble components from adipose

tissue. Sink (1979) reported that breed, sex, and the animal's diet primarily affects lipid-soluble components, while animal age affects the water/salt soluble components of flavor in muscle foods.

Color

Color is an important quality characteristic of meat. Giddings (1977) stated the bright red appearance of oxymyoglobin is the paramount point-of-purchase quality attribute. The color of raw meat is principally affected by pH through its influence on the myofibrils, mitochondria, and the metmyoglobin-reducing system (Hultin, 1976). The physical state of the myofibrils affects the reflection of light from muscle. The mitochondria compete with myoglobin for oxygen influencing the form of the pigment.

Godvindarajan (1973) noted the effect of preslaughter conditions, packaging parameters, light, and microorganisms on fresh meat color. Preslaughter conditions including animal breed, maturity, feed, and stress susceptibility of the animal influence raw meat color. The dark-cutting flesh of some beef animals is associated with abnormally high pH values arising from stress conditions prior to slaughter. The major consideration in designing packaging material is the susceptibility of myoglobin to oxidation at low partial pressures of oxygen. The type of light used in the display case may affect color principally through dehydration and enhanced

production of oxidized pigment. Godvindarajan (1973) concluded that microorganisms play a role in meat discoloration by reducing oxygen tension of the surface tissue.

Objective measurement of color may be utilized as an estimate of visual appearance. The Hunter color difference meter is a tricolorimetric system particularly suited for this function. This instrument produces results in terms of L, which is a lightness function; a, which predicts redness; and b, which predicts yellowness. The Gardner Color Difference Meter and the Color Eye are also frequently used in meat research. A brief review of color measurement has been reported by Clydesdale (1969).

Pre- and Post-rigor Pressure Treatment of Muscle

MacFarlane (1973) found many variables which affect the response of muscle to pressure including the actual pressure applied, the temperature during pressurization, the rate of pressure increase or decrease, the duration of pressurization, restriction on muscle contraction, the time delay between slaughter and pressurization, the muscle pressurized, and the animal species from which the muscle was obtained. Alterations in these variables influence subsequent biochemical reactions and the contraction state of the muscle.

The effect of pressure on muscle may be influenced by the process utilized. Elgasim and Kennick (1980) subjected warm pre-rigor muscle to a pressure of 103.5 MNm-2 for two minutes.

Bouton et al. (1977a) applied a pressure of 100 MNm-2 for 2.5 minutes to post-rigor muscle heated to 40-60°C. These processes may affect muscle contraction, myofibril structure, the sarcoplasmic reticulum, and chemical and biochemical reactions in the muscle.

The degree of muscle contraction at the time of rigor has a major impact on the tenderness of cooked meat. Marsh and Leet (1966) found three shortening: 1) up to 20% shortening there is little or no toughening, 2) from 20-40% shortening a several fold increase in toughness occurs, 3) beyond 40% a rapid increase in tenderness results until at 60% shortened the meat has the same tenderness as that which is unshortened. Super-contraction of the sarcomeres with major internal rupturing may increase tenderness (Marsh, 1977).

Pre-rigor pressurization causes muscle contraction of 50% or less of the original length without an accompanying decrease in tenderness. Johnson and Eyring (1970) reported increases or decreases of tension in muscle with pressurization depending upon the temperature at which the muscle was pressurized. Johnson et al. (1954) reported the greatest tension increase with increasing pressure up to 9,000 psi at 20°C and lower tension development at 15, 10, 5, and 1°C. MacFarlane (1973) found the tension-temperature relationship is influenced by animal species. He reported an increase in tenderness for ox semitendinosus muscle with pressures of 103-138 MNm-2 at

30-35°C. In contrast, sheep semitendinosus muscle did not show a significant increase in tenderness under the same conditions. Muscle shortening of 40-50% with an accompanying increase in tenderness was found in bovine muscle (Bouton et al., 1977a; Kennick et al., 1980).

Post-rigor pressurization has variable effects on tenderness depending on whether the muscle is in the stretched or contracted state. Bouton et al. (1977b) reported post-rigor pressure heat treatment did not affect contraction state although shear and tensile results were similar to those obtained with pressure treatment pre-rigor. They found the maximum tenderizing effect by post-rigor pressure heat treatment of 150 MNm-2 at 60°C for 30 minutes is achieved when bovine samples are heated at 45°C for 45-180 minutes immediately before application of the treatment. MacFarlane et al. (1981) reported no significant effect on shear values of post-rigor pressure treated beef samples with short sarcomeres without prior heat treatment at 25 or°50 C. Subjection of sheep muscle to post-rigor pressures of 90 MNm-2 to 138 MNm-2 at 25°C for 1-8 minutes without prior heat treatment did not affect tenderness or contraction state (MacFarlane, 1973).

The influence of pressure treatment on changes in the myofibrillar structural component of muscle may have a major impact on tenderness. MacFarlane (1973) proposed two explanations for the tenderizing effect with pre-rigor

pressurization. Either the myofibrillar structure is broken down by myosin filaments of the severely contracted muscle being forced into the Z-line or the actin filaments are weakened by a pressure-induced F-G transformation. Using a phase contrast microscope, Kennick et al. (1980) found large quantities of globular material which agreed with a possible F-G transformation of actin. Bouton et al. (1977a) reported severe disruption of the myofibrillar structure with pre-rigor pressure treatment.

In post-rigor muscle, the thin filaments maintain continuity between the thick filaments of longitudinally adjacent sarcomeres and the Z-lines. MacFarlane et al. (1981) reported a loss of integrity of I-band filaments and a loss of material from the region of the M-line with post-rigor pressure treatment. They attributed increasing toughness to an increasing incidence of sarcomeres in which thick filaments have been compressed onto the Z-line. Bouton et al. (1977a) suggested, with post-rigor pressure heat treatment, the myofibrillar proteins are heat denatured and unable to associate, accounting for increased tenderness. Bouton et al. (1977b) concluded that post-rigor pressure heat treatment primarily affects myofibrillar structure since treated beef samples did not show the increase in shear force values for cooking temperatures greater than 60°C associated with

myofibrillar hardening.

Pressure treatment of pre-rigor muscle enhances the rate of glycolysis and may have an effect on the sarcoplasmic reticulum (SR). The SR controls the calcium concentration in the sarcoplasm thereby regulating muscle contraction and myofibrillar ATPase activity. Of the two ATPases present in the SR, basal ATPase is a Mg+2 dependent enzyme while the extra ATPase provides energy for calcium uptake by the SR and is activated when micromolecular concentrations of calcium are added to the basal assay system. Horgan (1979) studied the effect of pre-rigor pressurization on the ATPase activity in the SR of rabbit longissimus dorsi and bovine sternomandibularis muscles. He found a loss of extra ATPase activity while basal ATPase activity remained intact. In a later publication, Horgan (1981) reported pre- and post-rigor pressurization caused denaturation of the extra ATPase and proteolytic digestion of some SR proteins, including calsequestrin. The yield of SR protein was greatest in the muscles with high concentrations of extra ATPase and calcium uptake activities. It was postulated that destruction of the sarcoplasmic reticulum with pressurization releases Ca2+ into the sarcoplasm which in part accounts for the enhanced rate of glycolysis.

Pressure may influence the extent of hydration of myofibril proteins. MacFarlane (1974) suggested that pressure increased protein hydration, leading to more tightly bound and decreased

volume of water molecules. Some investigators (MacFarlane et al., 1976; Kennick et al., 1980) reported pre-rigor pressurization of muscle decreased water-holding capacity and cooking losses in comparison to control samples. In contrast, application of pressure increases water-holding capacity and promotes solubilization of proteins of meat homogenates in saline solution (MacFarlane, 1974).

Application of pressure affects the pH and stability of proteins. Johnson et al. (1954) noted that an increase in pressure results in a decrease in volume of a system which favors the process of ionization. Pressure treatment may cause a loss of free protons as a result of redistribution of ions from increased ionization. MacFarlane (1973) found the changes in muscle pH following pressurization, are dependent on pressure, temperature during pressurization, and duration of pressurization.

MacFarlane (1973) noted an immediate post-pressurization pH drop in pre-rigor ox muscle subjected to pressures of 103 MNm-2 at 30°C for 4 minutes. However, he found the ultimate pH measured two days postslaughter did not differ significantly between the pressurized and non-pressurized sample. Kennick et al. (1980) noted a pH drop one hour after pressure treatment in pre-rigor beef semitendinosus muscles. After 24 hours, the pH did not differ significantly between the pressurized and control beef samples. It was suggested that glycolysis may be

near-completion shortly after termination of pressure treatment in pre-rigor muscles.

The utilization of pre-rigor pressurized beef muscle may have economic and nutritional significance. Schumann et al. (1982) reported a favorable comparison between pre-rigor pressurization and conventional methods of processing beef carcasses in the yield of total usable meat. Elgasim and Kennick (1980) indicated that pre-rigor pressurization of beef semitendinosus muscle did not effect the apparent biological value (BV) or net protein utilization (NPU), but significantly improved protein digestibility.

Heat Induced Changes in Beef Meat

Heating of muscle tissue influences the structural, chemical, and palatability characteristics of meat. In general, the changes in meat with heating are due to denaturation and coagulation of proteins, translocation of fat and water, alteration in pH and water-holding capacity, and chemical changes in heat labile compounds (Asghar and Pearson, 1980; Paul, 1972). The type and extent of changes in meat upon heating vary with the composition of the meat, the cooking method, and the extent of heating.

Effect of Heating on Muscle Proteins

Of the myofibrillar proteins, alpha-actinin is the most heat labile, becoming insoluble at 50°C (Cheng and Parrish, 1979). Cheng and Parrish (1979) found actin, tropomyosin, and

the troponin complex were relatively heat stable. Actin became insoluble between 70 and 80°C, whereas tropomyosin and the troponins were precipitated above 80°C.

Most of the sarcoplasmic proteins coagulate between 40 and 60°C (Hamm, 1966). Laakkonen et al. (1970) reported a large part of the sarcoplasmic proteins are still soluble at 50°C, whereas at 80°C they all become insoluble. Using rabbit longissimus dorsi muscles, Paul et al. (1966) reported increased sarcoplasmic protein solubility between 50 and 60 C when heated 2-10 hours. They attributed the increased solubility to the proteolytic enzymes naturally present in the muscle tissue. Grau and Lee (1963) observed that the sarcoplasmic proteins with the greatest velocity in an electric field are denatured most quickly during cooking of meat. Lee and Grau (1966) found the cathod proteins were more thermostable than the anod ones. This may explain the strong influence of pH of meat on the loss of water-holding capacity.

Heat also alters the properties of stroma proteins in muscle. Penfield and Meyer (1975) observed an increase in the proportion of soluble collagen with increasing internal temperatures during cooking of meat. Bayne et al. (1971) found only the alkali insoluble collagen of interstitual conective tissue decreased during cooking, while the salt-soluble fraction was unaffected. Similar results have been observed for endomysial collagen (Jones et al., 1977). Solubilization of the

endomysial collagen of bovine muscle is initiated at 60°C and completed at approximately 70°C. Elastin is most resistant to breakdown by heat, although it tends to shrink and become rigid (Lawrie, 1968). Deethardt and Tuma (1971) observed a decrease in the visible amount of reticular fibers at 85°C. In general, the denaturation of muscle collagen occurs at higher temperatures than that of myofibrillar proteins.

Changes in Microscopic Structure of Beef Muscle

Changes in the fine structure of beef muscle upon heating include shrinkage in the contractile fibers with shortening of the sarcomeres and in collagen fibers (Jones, 1977). The shrinkage of the muscle is due to a decrease in muscle fiber diameter, thermal shrinkage of the collagen fibers in the connective tissue, and translocation of water, lipids, and dissolved materials out of the muscle (Leander et al., 1980). Hostetler and Landmann (1968) reported a gradual decrease in width of muscle fiber fragments up to 45°C with a rapid decrease from 45 to 62°C. Shrinkage in length was rapid and extensive between 55 and 65°C, but less marked between 65 and 80°C. The 55 to 70°C range corresponds to the region in which the rate of heating changes in meat during dry heating. Gustavson (1956) showed that thermal shrinkage of collagen is due to rupturing of interchain cross-linkages. Collagen shrinks to about one-quarter of its original length at about 58°C (Verzar, 1964) and begins conversion to gelatin at around 63°C (Hamm, 1966).

Schmidt and Parrish (1971) reported that increasing internal temperature of steaks by broiling from 50 to 90°C causes progressive connective tissue fiber shrinkage and myofibrillar protein coagulation.

Schmidt and Parrish (1971) observed degradation of the Z-line when beef longissimus muscle was heated to 50°C. At 60°C, the thin filaments began to disintegrate and the thick filaments to coagulate. By 80°C, the filaments became amorphous, although banding corresponding to the original sarcomeres remained. Leander et al. (1980) observed disintegration of filaments in the I-band and shrinkage of filaments in the A-band of beef longissimus and semitendinosus muscles heated to 63°C. Heating to high temperatures (90°C) caused fracturing at fiber surfaces and at Z-lines (Jones, 1977). Fracturing at fiber surfaces was attributed to dissolved or softened collagen at 90°C.

Cheng and Parrish (1976) observed heating of beef muscle degrades collagen from the fibrous to the granular form. Using light, phase, and electron microscopy, Schmidt and Parrish (1971) observed initial shrinkage of endomysial connective tissue in beef longissimus at 50°C with completion near 70°C. Perimysial connective tissue shrinkage in beef longissimus muscle begins at 70°C, while in beef semitendinosus some of the fibrous character is retained after heating at 90°C for 45 minutes (Carroll et al., 1978; Cheng and Parrish, 1976).

Changes in Composition

The shrinkage of muscle upon heating with an accompanying loss of extractives is mainly responsible for the changes in the composition of meat. Thus, a decrease in moisture content and an increase in the protein and lipid content are observed in cooked meat.

Heating of meat decreases the water content since the free water is squeezed out of the tissue as the protein structure shrinks. The released water carries with it the water-soluble materials such as salts, sarcoplasmic proteins and nonprotein nitrogenous compounds. The losses due to shrinkage with cooking will depend on the method, time and temperature of cooking, pH, and water-holding capacity (Paul, 1972). Some of these cooking losses will represent non-aqueous fluid, since high temperatures will melt fat and tend to alter the structures retaining it (Lawrie, 1974). Using bovine longissimus dorsi muscle, Taki (1965) concluded that a faster rate of heating causes increased weight loss. Cooking losses will also increase as the internal temperature of the meat increases (Laakkonen et al., 1970).

The fat in meat undergoes a number of changes with heat treatment. The texture of the fat becomes more soft or liquid with neutral fat melting out of the fat cells, aromatic compounds are volatilized, and the lipids undergo chemical changes such as hydrolysis and oxidation (Allen and Foegeding, 1981). Since cooking reduces the weight of the meat, primarily

through removal of water, the lipid content increases when expressed as a percentage of the cooked weight. A number of studies indicate that cooking increases the amount of either extractable material in the lean tissue over that found in raw meat on a dry weight basis. Several theories have been suggested to account for this change. Wang et al. (1954) noted that fat from intramuscular deposits tends to flow in droplets along the path of the heat-degraded collagenous fibers. Alteration in muscle proteins after heating also might account for improved extractability of the fat in cooked meat. Rhee et al. (1982) showed that cooked beef meat has a higher fat content than raw meat with the lipid content being significantly affected by the amount of marbling.

Changes in nitrogen content of meat during cooking are relatively small but dependent upon cooking method. Nitrogen losses are found in the drippings with dry heat cooking methods and in the cooking liquids with moist heat cooking methods. Doty and Pierce (1961) reported that 2.0 to 2.5% of the total nitrogen was found in the drippings from broiled beef steaks, mostly in nonprotein nitrogen-compounds including some free amino acids. Baldwin et al. (1976) found free amino acid content tended to be greater in conventionally cooked meat than in that cooked by microwaves, but total protein did not differ significantly. Baldwin and Tettambel (1974) reported significantly more nitrogen in the drip of conventionally cooked

rib-eye steaks than those cooked by microwaves.

Changes in pH and Water-holding Capacity

The heating of muscle tissue normally increases the pH value by about 0.3 units (Fogg and Harrison, 1975). With increasing temperature, the isoelectric point (pI) also shifts to a higher pH (Hamm and Deatherage, 1960). This shift in both the pH and pI to higher levels with heating (50 to 80°C) may be attributed to exposure of imidazolium groups of histidine after unfolding of actomyosin molecules (Hamm, 1966; Asghar and Pearson, 1980). Heating of tissue and myofibrils at temperatures above 80°C decreases the number of basic groups possibly due to Maillard-type reactions (Pearson et al., 1962).

The decreased water-holding capacity (WHC) accompanying the heating of meat with release of juices is due to tightening of the myofibrillar network by the heat denaturation of the proteins. The influence of thermal treatment on the WHC mainly concerns the "free" water which becomes freely movable and is released from the tissue (Hamm, 1966). Bouton et al. (1971) found correlations between increased pH and both increase in water-holding capacity and decreased cooking losses in beef.

Water-holding capacity will be influenced by the final internal temperature. Roberts and Lawrie (1974) found a larger proportion of juice is released between 30 to 50°C as compared to the range of 55 to 90°C. Ritchey and Hostetler (1964) reported the changes of free and bound water in beef longissimus

and biceps femoris muscles heated to internal temperatures of 61, 68, 74, and 80°C. Overall losses of free and bound water occurred at each rise in temperature with the greatest change between 74 and 80°C. At 61°C, bound water was converted to free water faster than free water was lost from the steak. From 68 to 85°C, the rate of loss of free water exceeds the rate of conversion from the bound to free state, resulting in increased loss of total moisture (Ritchey, 1965).

The changes in water-holding capacity of meat on heating appear to occur in two primary phases: the first phase being between 30 and 50°C, and the second between 60 and 90°C (Hamm, 1966; Bouton and Harris, 1972). Changes in the first phase are due to the heat coagulation of the actomyosin system. The second phase is due to denaturation of the collagenous system and/or to the formation of new stable cross-linkages within the coagulated actomyosin system. Between 50 to 55°C, negligible changes occur (Bouton and Harris, 1972).

Changes in Meat Flavor and Color

Heating promotes reaction among the water- and fat-soluble flavor precursors to produce the characteristic flavor and aroma of the cooked meat. The compounds believed to be responsible for meat flavor were mentioned previously. Recent evidence suggests the amine-carbonyl (Maillard) reaction plays an important role in flavor development during cooking of meat (Bodrero et al., 1981a). Wilson et al. (1973) reported on the

role of sulfur containing amino acids as precursors for meat flavor components. At high temperatures (>120°C) the sulfhydryl groups in beef proteins change and hydrogen sulfide is formed. The role of hydrogen sulfide in reacting with saturated aldehydes, thiols, and other volatile compounds to produce compounds with a characteristic meaty aroma has been shown to be important to flavor (Bodrero et al., 1981a).

Flavor changes that occur during cooking of meat are influenced by the amount and kind of heat applied. Dry-heat cooking methods tend to retain more flavor than moist-heat cooking. With moist-heat, flavor components are leached into the broth or drippings (Paul, 1972). In dry-heat methods, the meat surface is exposed to high temperatures causing fluid and soluble flavor components within the meat interior to move toward the surface. As a result, the concentration of flavor materials increases on the surface (Paul, 1972).

Using flavor dilution evaluation of beef longissimus dorsi roasts, Bodrero et al. (1980b) found that flavor development occurs more rapidly in beef cooked by microwaves than conventional roasting. However, conventionally roasted beef had a more intense and preferred flavor than microwave roasted beef. They suggested that the initial flavor compounds formed on heating are not the most meaty, while secondary reaction products are largely responsbile for the meaty flavor. Further, the flavor of the conventionally roasted meat may have been due

to a large number of flavor compounds at lower individual concentrations than was the case with microwave cookery.

The flavor changes with increasing degree of doneness, becoming unpleasant if protein and fat decomposition are carried too far. The major cause of off-flavor in cooked meat may be oxidation of lipids. Siu and Draper (1978) found lipid oxidation was minimal in beef cooked for short periods of time. Cooking meats to higher temperatures decreases lipid oxidation, possibly due to partial heme pigment destruction and formation of antioxidant substances in the meat (Zipser and Watts, 1961; Huang and Greene, 1978).

Heating brings about changes in the myoglobin molecule which alters the color of the meat. When the meat is heated, the globin portion of myoglobin is denatured and the iron of the heme ring is oxidized to the ferric state. The resulting cooked meat pigment is a reducible ferric complex (Giddings, 1977) which has a tan-brown color and is generally called denatured globin hemichrome. However, Giddings (1977) also indicated that uncertainty continues to surround the exact nature of the cooked meat pigment(s). The carbonyl-amine (Maillard) browning reaction also contributes to the color of cooked meat, especially when the surface of the meat is dry and high temperatures are achieved.

The color of cooked meat is used as an index of doneness since it indicates the degree of conversion of the pigments and

the extent to which the meat proteins have been coagulated (Lawrie, 1974). Beef cooked to an internal temperature of 60°C has a bright red interior; that cooked to 70°C has a pink interior; and cooking to 80°C results in a tan-brown color (Charley, 1982). If traces of carbon monoxide or sulfur compounds are present, undesirable bright pink or greenish pigments may be produced (Paul, 1972).

Meat Cooking Methods

Traditionally, dry heat methods of cooking were recommended for tender cuts of meat where coagulation of proteins is the objective. Moist-heat methods were used for less tender cuts to hydrolyze and soften collagen in connective tissue. Heating is hot air or fat is a dry cooking method which includes roasting, broiling, panbroiling, and frying. Heating in steam or water in a saucepan, pressure saucepan, foil wrap, or plastic bag are moist cooking methods. Electronic or microwave heating is a newer method based upon different principles from the traditional methods. The method of cooking employed will influence chemical, structural, and quality parameters of the cooked meat.

Broiling is a traditional dry-heat cooking method which primarily uses radiant energy as the heat source. Air convection and conduction from the rack or pan supporting the meat contribute minor amounts of heat. Heat is conducted from the meat surface to the interior with the rate of heat transfer

being proportional to the temperature difference between the outer surface and inner portion. A number of studies have reported the influence of broiling on meat quality (Cross et al., 1979; Carpenter et al., 1972; Batcher and Deary, 1975). Broiling temperature is related to the distance of the meat from the broiling unit, and thus affects the time required to cook the meat. In general, thin cuts are broiled so the heat can penetrate to the center of the cut before the surface is overcooked. Thicker cuts of meat (1 to 2 inches) are placed farther from the heat source to allow uniform cooking.

In contrast to broiling, meat cooked by microwave involves heat generated from within the meat through a series of molecular vibrations (Cross and Fung, 1982). Microwaves are high frequency radiations with the ability to ionize other compounds. Goldblith (1966) described the heating principle as an attempt by asymmetric dielectric molecules to align themselves with the rapidly changing alternating electric field. As microwaves penetrate the food they cause oscillation of polar molecules around their axes in response to reversal of the electric field that occurs 915 or 2450 million times/second. This oscillation creates intermolecular friction that cooks the food (Copson, 1975). Microwaves heat the entire volume of food simultaneously by conduction and direct molecular agitation. Consequently, heating rates can be greatly increased (Curnutte, 1980).

The amount of heat created with microwaves is complicated by a gradual decrease of intensity as the energy is absorbed by successive layers of material and by differing dielectric properties of the various materials. Even heating in the meat is further complicated by reflection and refraction of microwaves at interfaces between different food components and the influence of spatial arrangements of regions with high and low dielectric constants. Since meat is naturally nonhomogeneous, hot spots may develop (Rosen, 1972).

The extent of heating with microwaves is affected by some of the same factors which influence doneness in conventional cooking such as initial temperature of meat, holding time, the specific and latent heats, and loss of moisture by evaporation. There are also factors specific for the microwave method of cooking. These include the dielectric properties of the meat, depth of penetration of the microwaves, dipolar molecular action, electromagnetic frequency of the oven used, the size and distribution of the load in the oven, shape of the food, and vapor pressure in the oven (Van Zante, 1973).

One of the greatest advantages of microwave cooking is the time saving factor. Most microwave ovens require only 20% of the time used by conventional ovens (Cross and Fung, 1982). However, some research on cooking meat in a microwave oven indicate greater cooking losses of meat as compared to conventional methods. A number of investigators (Kylen et al.,

1964; Carpenter et al., 1968; Ream et al., 1974; Korschgen et al., 1976; Baldwin et al., 1979; Moore et al., 1980) have reported increased cooking losses and decreased juiciness in beef cooked by microwaves as compared to broiling or roasting cooking methods. Apgar et al. (1959) suggested that increased losses with microwave cooking may be due to a greater rise in temperature of the food after removal from the oven. Carpenter et al. (1968) attributed greater cooking losses to internal heating and denaturation which cause the juices to be forced out of the muscle. Ruyack and Paul (1972) postulated that the effect of microwaves on polar water molecules within the meat may account for the increased cooking losses in meat cooked electronically as compared to its conventionally cooked counterpart. The constant change in magnetic field with oscillation of the water molecules may affect the bonding of the bound water and result in greater ease of moisture loss.

Roberts and Lawrie (1974) compared the effect of conventional and microwave heating on the relative percentage of sarcoplasmic and crude myofibrillar proteins. Protein denaturation was assessed through measurements of nitrogen distribution between sarcoplasmic and crude myofibrillar fractions. Values for insoluble sarcoplasmic and myofibrillar proteins increased sharply in conventionally heated meat at temperatures between 50 and 70°C, whereas microwave heated meat showed a more gradual increase. They suggested that the total

time/temperature combination sustained by the proteins with conventional heating is greater and thus, has a greater denaturing effect than with microwave heating.

Hutton et al. (1981) compared ultrastructural changes in beef semitendinosus muscle cooked by conventional heat and microwave energy to endpoint temperatures of 40, 50, 60, and 70°C. As endpoint temperature increased from 40 to 60°C, there were significant increases in separation of the endomyosium from muscle fibers, the number of interfibrillar spaces, fiber fragmentation, and the occurrance of nonfibrous connective tissue for both cooking methods. However, at 70°C, the microwaved meat was more fragmented, flattened, and coagulated than the conventionally cooked meat. Using scanning electron microsocopy and transmission electron microscopy, Hsieh et al. (1980) examined pre-rigor beef sternomandibularis muscle cooked by microwaves and roasting to an endpoint temperature of 70°C. They found that microwave cookery produced smaller and less dense supercontraction nodes with less tearing and fragmentation but more fiber separation. In contrast, Cia and Marsh (1976) observed intense supercontraction bands separated by fragmented areas in pre-rigor beef samples cooked by microwaves.

Some investigators have associated an increased amount of fiber fragmentation to increased tenderness of the meat (Cheng and Parrish, 1976; Hearne et al., 1978). However, most

investigators have found a decrease in tenderness with microwave cooking as compared to conventional heating. Hutton et al. (1981) found that conventionally heated beef cooked to an endpoint temperature of 70°C were significantly more tender than microwaved beef. Carpenter et al. (1968) and Moore et al. (1980) also found decreased tenderness with microwave cooking as compared to conventional heating at endpoint temperatures of 75 and 65°C, respectively. Hutton et al. (1981) postulated that microwave cooking causes increased tenderness with increased fragmentation to a point beyond which further increases in fragmentation cause a decrease in tenderness. Beyond this point, the overcoagulation of proteins and fluid loss may have a greater impact on tenderness than fragmentation of the muscle fibers.

Microwave and broiling cooking methods may affect the constituents of meat in different patterns. As previously reviewed, meat cooked by microwaves tends to retain more nitrogen than that cooked conventionally. Gat'Ko (1965) attributed the greater retention of nitrogen in microwave cooked meat as compared to conventionally cooked meat to additional water losses with microwave cooking. Janicki and Appledorf (1974) found that microwave cooked beef patties had a greater loss of crude fat than patties cooked by broiling. They also noted a tendency of increasing total cholesterol in microwave cooked samples, while decreases in the total cholesterol content

were observed with broiling. Mai et al. (1980) indicated that microwave cooking does not change the fatty acid pattern of the lipids nor cause isomerization of the unsaturated fatty acids.

Evaluation of meat color can determine the extent of heating, Moore et al. (1980) found that microwave cooking produced uneven heating within beef top round steaks. They observed a "ring" effect where the outer circle of the steak appeared well done, whereas the inner portion was rare. This uneven cooking of the meat is due to the uneven distribution of energy in the microwave oven.

EXPERIMENTAL PROCEDURE

Sample Preparation

Samples were obtained from 6 beef cattle (approximate weight 510 kg) slaughtered at Oregon State University Meat Science Laboratory. Eye-of-Round muscle (semitendinosus) from one side of each carcass was excised immediately after washing of the beef carcasses (approximately 25 min after slaughtering), vacuum packed in Cry-O-Vac bags, inserted in a pressure chamber (10.2 cm in diameter and 30.5 cm long) which was then tightly closed and a pressure of 103.5 MNm-2 (15,000 lb/sq in) was applied for 2 minutes. Matching muscles on the opposite sides were left on the carcasses and chilled at 0 $\pm$ 1°C according to commercial practices. On the seventh day the matching muscles from the control sides were removed from the carcasses, vacuum packed, and stored at -18°C along with the treated samples until required for further study.

Samples for the microwave and broiling treatments were obtained by cutting each frozen semitendinosus muscle into a 6 x 5 x 3 cm piece (approximately 86 g). These were individually wrapped and frozen until use. Prior to cooking all frozen samples (-18°C) were defrosted one hour at 25°C (Precision Scientific Low Temperature Incubator Freas 815) and 17 hours at 5°C.

Cooking Methods

The defrosted pre-rigor pressurized and control samples (5°C) for each treatment were randomly assigned to the microwave or broiling treatments. When sample was available, duplicate samples of each replication were prepared. Each sample was individually microwave or broil cooked.

The defrosted pre-rigor pressurized sample and control sample were placed on a Pyrex casserole dish and microwave cooked 1.08 minutes (endpoint temperature approximately 80°C ± 6°C). A Sharp Carousel Microwave Oven, model R-6770, 2450 MHz, 455 Watts (Sharp Electronics Corp., Paramus, N. J.) was used with the variable cooking control on ROAST. Final internal temperature was recorded in the mid-portion of the semitendinosus sample.

The defrosted sample was broiled in a preheated Magic Chef Self-Cleaning Electric Oven set on broil. Samples were placed on a wire rack in an aluminum pan 25 cm from the broiling unit. Each sample was cooked to 80°C ± 2°C for approximately 24 and 25 minutes for pre-rigor pressurized and control samples, respectively.

Objective Testing Methods

Water-holding capacity, total moisture, color, tenderness, pH and nitrogen content were determined on all cooked and raw beef meat. Lipid content from selected samples was also done on raw beef meat. Cooking losses, temperature/time data and micrographs were collected as appropriate.

Water-holding capacity, tenderness data and electron microscopy was obtained with the appropriate excised intact muscle sample. Total moisture, pH, total nitrogen, and total lipids were done on the powdered muscle. The raw or cooked samples were frozen in liquid nitrogen and ground (Osterizer Cycle Blender) into powder for 30 seconds at "liquify speed".

Water-holding capacity. The method by Wierbicki and Deatherage (1958) was used to measure the water-holding capacity of the meat. A meat sample of approximately 0.3 g was placed on filter paper (Whatman No. 1) which was placed between Plexiglass sheets and pressed for 5 minutes at 5000 psi by a Carver Laboratory Press (Fred S. Carver, Inc.; Menomonee Falls, Wisconsin). The areas were measured with a Licor Area Meter (Model 3100) and the expressible moisture index was calculated by the following equation:

$$\text{Expressible Moisture Index} = \frac{\text{Meat Area}}{\text{Juice Area}}$$

Total Moisture. Moisture content was determined according to the AOAC vacuum oven method (Horwitz, 1980). Duplicate 5 g samples from each replication and treatment of liquid nitrogen-powdered beef meat were dried in a vacuum oven (Napco Oven, National Appliance Co., Portland, Oregon). The moisture was calculated as the loss in percent of wet weight. Weights

were determined to the nearest 0.001 g on an Electronic Mettler PC 180 balance (Mettler Instrument Co., Hightstown, New Jersey).

Cooking Loss and Temperature/Time Data. Total, drip and evaporation cooking losses were calculated using cooking weight loss of meat and drip weight, when appropriate. Cooking losses were determined using the following formulas:

$$\text{Percent Total} = \frac{(\text{weight raw sample} - \text{weight cooked sample})}{(\text{weight raw sample})} \times 100$$

$$\text{Percent Drip} = \frac{(\text{final pan + drip weight} - \text{initial pan weight})}{(\text{raw sample weight})} \times 100$$

Percent Evaporation = percent total loss - percent drip loss

Heating temperatures and time for the broiled samples were monitored with a Leeds and Northrup W12 Temperature Recorder. Endpoint temperature of the microwaved samples was obtained by inserting thermocouples in the mid-portion of the beef samples immediately after removal from the oven.

Color. Color difference values were measured on the interior and exterior surfaces of the cooked and/or raw beef samples using a Hunter Color Difference Meter (Model D25P-2) standardized against a white ceramic tile with calculated values of L (lightness), 94.0; a+ (redness), -0.9; and b+ (yellowness), 1.2. Samples were placed in a plexiglass cell and duplicate measurements were made for each color difference factor. A 0.5

cm slice was cut from the cooked meat surface to obtain interior color values.

pH measurement. Duplicate 2 g liquid nitrogen-powdered meat samples were mixed with 10 mL deionized water. pH was determined (Orion Research Microprocessor Ionanalyzer/901, Orion Research Inc., Cambridge, Massachusetts) after calibration (buffer pH 6.84 and pH 4.00).

Tenderness. Tenderness was evaluated using a 1/2-inch core meat sample on a Warner-Bratzler Shear Apparatus. A 25 kg x 50 g dynamometer scale was used to measure the force to shear the meat in kilograms.

Total Nitrogen. Nitrogen content was determined according to the microkjeldahl method (Horwitz, 1980). Duplicate 0.150 $\pm$ 0.05 g samples from each replication and treatment of liquid nitrogen-powdered beef meat were weighed and tested for total nitrogen. Powdered beef meat was oxidized in hot concentrated sulfuric acid with a catalyst mixture of HgO and K2SO4. The ammonia sulfate in the digest was then decomposed in NaOH-Na2S2O3 solution, and the ammonia was distilled into 20 mL of 4% boric acid containing methyl red-methylene blue solution as the indicator. The nitrogen content was determined by back titration with 0.02 N HCl solution. Nitrogen was expressed as percent of wet weight and dry weight. Percent nitrogen on a dry weight basis indicated paired sample muscle uniformity.

Total Lipids. Total lipids of the duplicate raw beef

samples were extracted by a modification of the Folch et al. (1957) procedure. Two to 2.5 g of liquid nitrogen-powdered beef meat were weighed into a 25 mL flask and 20 mL of chloroform-methanol (2:1) were added and stoppered with a rubber stopper.

After mixing for 30 seconds, the flask was vortexed with a Deluxe Mixer (Scientific Products Co., Evanston, Illinois) at speed 7 for 2 minutes. The resulting slurry (beef meat and chloroform-methanol) was filtered through Whatman #1 filter paper into a 50 mL plastic graduated centrifuge tube. Flasks were rinsed with 24 mL of chloroform:methanol (2:1). The rinsed flasks were shaken 10 times and filtered into the 50 mL plastic graduated centrifuge tube with the initial slurry. The volume of the filtrate in the graduated centrifuge tubes was measured and 0.05% CaCl2.2H2O was added (cloroform:methanol:CaCl2.2H2O = 8:4:3 v/v). This mixture was stirred 10 times and chloroform-methanol was used to rinse the glass stirring rod.

Centrifuge tubes of the filtrate (the filtrate of beef meat slurry:chloroform-methanol:CaCl2.2H2O) were centrifuged (Sorvall Superspeed RCZ-B; Refrigerated Centrifuge, Ivan Sorvall Inc., Newtown, Connecticut) for 15 minutes at 3000 rpm (4°C). Total volume of the two layers in the centrifuge tubes was recorded and the upper layer was discarded by aspiration. The volume of this aspirated layer was replaced with a chloroform:methanol:0.05% CaCl2.2H2O (3:48:47 v/v) mixture and

stirred 10 times with a glass stirring rod which was subsequently rinsed with 0.5 mL of additional solution. The centrifuge tubes were centrifuged again (3000 rpm, 15 minutes, 4°C). The upper layer was discarded by aspiration. Chloroform was added to the bottom layer to a certain volume for ease of calculating and total volume of bottom layer was recorded. Total lipid content was expressed on a wet weight and dry weight basis. Percent lipid on a dry weight basis substantiated the accuracy of the protein, moisture and lipid measurements.

Scanning (SEM) and Transmission (TEM) Electron Microscopy. Excised muscle pieces were removed from the raw and/or cooked beef meat and placed in glutaraldehyde and refrigerated until prepared for microscopy. Samples for SEM's were critical point dried and fastened to aluminum planchets with colloidal silver paint (Pelco #1603-4, Pelco, Inc., Tustin, CA). Prepared planchets were fastened in a rotation tilting device (Fullam #1253, Ernest Fullam, Inc., Schenectady, NY) in a vacuum evaporator (Varian VE-10, Varian Vacuum Division, Los Altos, CA). Scanning electron micrographs were obtained using an AMRAY 1000A scanning electron microscope. Magnifications of 50x and 300x were recorded.

Samples for TEM were stained enblock with osmium and uranyl acetate, dehydrated with acetone, infiltrated and embedded in Spurrs plastic. Longitudinal sections of the tissue were microtomed and post-stained with lead citrate before viewing.

Transmission electron micrographs were obtained using a Philips 344 electron microscope at magnifications of 3,600x.

Subjective Testing Methods

Panelists were selected by their performance during screening sessions, and then trained for sensory evaluation of the treatment samples. The trained panel of six Oregon State University faculty and staff members evaluated the tenderness, fiber separation, juiciness, and flavor of one 1.5 cm cubed sample from each treatment per replication. The 6-point scorecard shown in Figure 2 was used. The samples were evaluated using established procedures (ASTM, 1977).

Experimental Design and Data Analysis

The experimental design was developed to be congruent with the available meat supply, personnel's schedule and the investigation's test setting. An incomplete block design was used. Statistical analysis was done utilizing the expertise of the Statistics Consulting Service (Oregon State University). A one-way analysis of variance for raw samples and a two-way analysis of variance for the cooked samples (APPLE Statistical Package, SIPS) was used to evalute all data. Correlations were evaluated for that data deemed appropriate (see Appendix). Significance was determined at the 5% level of probability. Detailed data for the cooked and raw values for each replication are presented in the Appendix.

Thank you for helping with our study.

SENSORY EVALUATION
DEPARTMENT OF FOODS AND NUTRITION
OREGON STATE UNIVERSITY

AES 428

NAME _____

DATE _____

PLEASE PUT ALL THE MEAT IN THE MOUTH AT ONCE TO EVALUATE. RECORD THE SCORES ALWAYS AT THE SAME POINT BEFORE SWALLOWING.

SAMPLE CODE	TENDERNESS	FIBER SEPARATION	JUICINESS	FLAVOR	COMMENTS

TENDERNESS
6 = extremely tender
5 = very tender
4 = moderately tender
3 = moderately tough
2 = very tough
1 = extremely tough

EASE OF FIBER SEPARATION
6 = extremely easily separated fibers
5 = very easily separated fibers
4 = easily separated fibers
3 = separable fibers
2 = slightly separable fibers
1 = no separable fibers

JUICINESS
6 = extremely juicy
5 = very juicy
4 = moderately juicy
3 = moderately dry
2 = very dry
1 = extremely dry

FLAVOR
6 = extremely pronounced meaty flavor
5 = very pronounced meaty flavor
4 = meaty flavor
3 = slightly meaty flavor
2 = very little meaty falvor
1 = no meaty flavor

Figure 2. Scoresheet for sensory evaluation of beef semitandinosus portions.

RESULTS AND DISCUSSION

Expressible moisture index (EMI) measurements for the cooked and raw beef semitendinosus portions are presented in Tables 1 and 2. The lower EMI values indicate higher water-holding capacity (WHC). Microwave and broiling cooking methods were not significantly different in EMI values. EMI measurements were significantly lower ($P<0.05$) for pressure treated than untreated beef portions regardless of cooking method (Tables 1,3). However, no significant differences due to type of treatment were found in the raw beef portions (Table 2), although the pressure treated meat also tended to have slightly lower EMI values. These higher values for water-holding capacity, otherwise lower EMI values, in the current study do not coincide with work reported by Kennick et al. (1980). They determined lower water-holding capacity in raw and cooked pressurized beef semitendinosus muscle. Possibly the higher water-holding capacity observed for the cooked and raw beef portions in this study, in contrast to other investigators, is due to differences in animal characteristics, techniques in determining water-holding capacity, or improvement in the sample pressurization process.

Hawley (1971) stated that moderate pressures of 101 MNm-2 may stabilize the native form of the protein. This would increase the temperature required for heat denaturation. If the

Table 1. Mean values of proximate composition and quality characteristics of microwaved and broiled untreated and pressure treated beef semitendinosus portions.

Parameters	Microwaved		Broiled	
	Untreated	Pressure Treated	Untreated	Pressure Treated
Total Nitrogen				
Wet Weight	4.824±0.36[a]	4.511±0.32	5.206±0.32	4.671±0.19
Dry Weight	12.209±1.53	13.364±1.18	13.137±0.70	12.802±0.74
Shear Value	3.63±0.49	2.50±0.40	3.92±1.20	2.13±0.62
Total Moisture (%)	62.243±2.19	66.216±1.46	60.310±1.90	61.323±4.48
Expressible Moisture Index (EMI)	0.342±0.05	0.250±0.02	0.353±0.08	0.262±0.04
Initial Wt. Steaks (g)	83.130±4.66	84.666±2.95	84.535±5.55	86.090±6.86
Endpoint Temperature (°C)	82.2±6.1	77.5±6.7	-	-
Cooking Losses (%)				
Total	26.193±6.12	18.018±1.41	36.865±3.00	32.314±2.28
Drip	15.392±5.93	7.917±1.18	3.339±0.78	2.108±0.74
Evaporation	10.800±0.73	10.101±0.78	33.526±3.14	30.206±2.74
pH	5.778±0.05	5.814±0.09	5.692±0.04	5.932±0.12
Color Evaluation				
Exterior				
L^+	44.2±1.7	43.7±2.9	31.4±2.7	31.2±2.6
a^+	4.4±0.05	5.2±0.8	4.7±0.9	5.1±0.2
b^+	10.1±0.4	9.9±0.5	8.1±1.4	8.1±1.4
Interior				
L^+	48.8±1.9	47.5±3.7	49.5±2.7	46.1±2.6
a^+	3.7±1.0	4.3±0.8	2.4±0.5	2.5±0.3
b^+	9.2±0.4	9.1±0.5	9.6±0.2	9.3±0.5
Sensory Evaluation				
Tenderness	2.83±0.59	3.74±0.52	2.62±0.61	3.31±0.40
Fiber Separation	2.64±0.49	2.84±0.58	2.29±0.52	2.99±0.45
Juiciness	3.27±0.60	3.38±0.38	3.23±0.67	2.85±0.51
Flavor	3.44±0.55	3.21±0.46	3.65±0.64	3.22±0.41

[a]Values represent mean ± S.D.

Table 2. Mean and F-values of proximate composition and quality characteristics of raw untreated and pressure treated beef semitendinosus portions.

Parameters	Treatment		
	Untreated	Pressure Treated	F-value[a]
Total Nitrogen			
Wet Weight	3.439±0.30[b]	3.253±0.29	1.160
Dry Weight	12.423±1.01	11.939±1.29	0.523
Shear Value	5.92±1.77	5.66±1.88	0.060
Total Moisture (%)	72.260±0.79	72.697±1.19	0.563
Expressible Moisture			
Index (EMI)	0.419±0.06	0.364±0.06	2.741
Total Lipids			
Wet Weight	3.896±0.42	3.304±1.34	1.072
Dry Weight	14.035±1.28	11.939±4.38	1.264
pH	5.526±0.02	5.514±0.05	0.309
Color Evaluation			
Exterior			
L^+	32.4±1.7	31.0±1.7	1.946
a^+	10.3±1.3	9.7±1.3	0.611
b^+	8.1±0.9	6.6±0.4	12.577*

[a] F-values were significant if F-value was $\geq$ 4.96 (5%*).

[b] Values represent mean ± S.D.

Table 3. Treatment, cooking method and interaction F-values used to evaluate microwaved and broiled untreated and pressure treated beef semitendinosus portions.

Parameters	F-values[a,b]		
	Treatment	Cooking Method	Interaction
Total Nitrogen			
Wet Weight	11.691	4.774	0.802
Dry Weight	0.170	0.850	2.806
Shear Value	23.015	0.019	1.161
Total Moisture (%)	4.869	9.122	1.716
Expressible Moisture			
Index (EMI)	19.205	0.281	0.000
Cooking Losses (%)			
Total	18.099	69.671	1.467
Drip	12.050	50.724	6.197
Evaporation	5.239	594.921	2.228
Initial Wt. Steaks	0.529	0.443	0.000
Endpoint Temperature	1.551	-	-
pH	16.643	0.222	9.118
Color Evaluation			
Exterior			
L_+	0.100	152.326	0.019
a_+	4.465	0.023	0.586
b	0.088	19.889	0.066
Interior			
L_+	3.985	0.068	0.828
a_+	2.050	26.979	0.663
b^+	1.295	1.763	0.324
Sensory Evaluation			
Tenderness	13.436	2.125	0.256
Fiber Separation	4.600	0.224	1.473
Juiciness	0.290	1.527	1.103
Flavor	2.490	0.285	0.245

[a] F-values were statistically significant at $p \leq .05$ if F-value was ≥ 4.35.

[b] F-values were statistically significant at $p \leq 0.1$ if F-value was ≥ 8.10.

cooked pressure treated samples are more stable to heat denaturation this may in part account for the increased ability to immobilize water. Heat denaturation begins the tightening of the myofibrils which results in less space to retain water. The pH also influences WHC through its effect on protein net charge. Proteins with a positive or negative net charge allow repulsion of filaments with greater immobilization of water due to the open structure. Bouton et al. (1971) noted an increase in WHC with increasing pH. The significantly greater ($P<0.01$) pH of the cooked pressure treated beef semitendinosus portions in the current study in comparison to the untreated samples may account for the increased WHC (Table 1).

Total moisture values were significantly greater ($P<0.05$) for the pressure treated samples when either broiled or microwave cooked (Tables 1,3). Microwave cooking of the meat significantly ($P<0.05$) retained a greater amount of moisture than broiling in both the untreated and pressure treated samples (Tables 1,3). Janicki and Appledorf (1974) found greater total moisture in broiled beef patties than microwaved patties. However, the difference in water content and size between beef patties and beef portions may account for variations in total moisture. Microwave cooking may be the preferred method over broiling for cooking the pressurized beef portions to attain greater total moisture content. Total moisture was not significantly different for the two treatments in the raw

samples (Table 3).

Total, drip, and evaporation cooking loss values (Table 1) were affected by both treatment and cooking method. Total cooking losses were significantly greater ($P<0.05$) for the cooked untreated and the broiled beef portions (Table 3). Drip cooking losses were significantly greater ($P<0.05$) for untreated and microwaved beef portions. Evaporation cooking losses were significantly greater ($P<0.05$) for cooked untreated beef portions. Broiling resulted in significantly greater ($P<0.05$) evaporation cooking losses in the beef portions than microwave cooking. The lower cooking losses in the pressure treated beef portions may indicate greater water retention upon heating which is supported by the increased water-holding capacity and total moisture values. Kennick et al. (1980) found lower cooking losses and lower water-holding capacity for pressure treated beef semitendinosus muscles as compared to untreated controls. MacFarlane (1973) attributed decreased cooking losses in pre-rigor pressurized ox muscle to exposure of hydrophilic groups in the myofibrillar proteins resulting in greater hydrogen bonding of water.

The higher drip cooking loss with microwave cooking is consistent with results by other investigators (Korschgen et al., 1976; Moody et al., 1978; Moore et al., 1980). Increased drip cooking loss with microwave cooking may be due to decreased evaporation in the cool oven cavity. Moore et al. (1980) and

McCrae and Paul (1974) also found lower evaporation cooking loss in microwave cooked beef steaks as compared to conventional methods of cookery. These investigators attributed lower volatile losses with microwave cooking to decreased cooking time and the surrounding low oven temperature in the microwave oven. From this research, the microwave cooking of the pressure treated beef portions results in decreased cooking losses in comparison to broiled untreated or pressure treated portions.

Bouton et al. (1975) positively correlated expressible moisture measurements with cooked meat juiciness. In the current study, juiciness may be a function of total moisture content as indicated by the correlation ($r = +.92$; $P<0.05$) of the sensory score to the total moisture for the microwave untreated beef portions (Table 4). Although a positive correlation exists between these two parameters, the greater total moisture content of microwave cooked beef portions was not reflected in the panelists juiciness evaluations. Panelists did not detect any significant differences in juiciness due to treatment or cooking method (Tables 1,3). In contrast, other investigators have reported decreased juiciness and moisture content in beef meat subjected to pressure treatment or microwave cooking (Kennick and Elgasim, 1981; Kylen et al., 1964; Moore et al., 1980).

Hunter color difference values for the interior and exterior surface of the cooked and raw beef portions are

Table 4. Correlation coefficients between selected parameters used for evaluation of beef semitendinosus portions.

Correlated Parameters	Coefficient of Correlation	Significance
Warner-Bratzler shear & panel tenderness	-.17	N.S.
Microwave untreated	-.37	N.S.
Microwave treated	-.94	$p < 0.01$
Broiled untreated	-.09	N.S.
Broiled untreated		
Warner-Bratzler shear & ease of fiber separation		
Microwave untreated	+.35	N.S.
Microwave treated	+.01	N.S.
Broiled untreated	+.31	N.S.
Broiled treated	-.82	$p < 0.05$
Panel tenderness & ease of fiber separation		
Microwave untreated	+.76	N.S.
Microwave treated	+.55	N.S.
Broiled untreated	-.15	N.S.
Broiled treated	+.46	N.S.
EMI (cooked) & panel juiciness		
Microwave untreated	+.40	N.S.
Microwave treated	-.74	N.S.
Broiled untreated	-.60	N.S.
Broiled treated	-.50	N.S.
Total moisture (cooked) & panel juiciness		
Microwave untreated	+.92	$p < 0.01$
Microwave treated	-.48	N.S.
Broiled untreated	-.65	N.S.
Broiled treated	+.13	N.S.
Total moisture (cooked) & panel tenderness		
Microwave untreated	-.08	N.S.
Microwave treated	+.04	N.S.
Broiled untreated	-.43	N.S.
Broiled treated	+.38	N.S.
% drip cooking loss & panel flavor		
Microwave untreated	-.36	N.S.
Microwave treated	-.74	N.S.
Broiled untreated	+.17	N.S.
Broiled treated	+.09	N.S.
EMI (raw) & pH (raw		
Untreated	+.19	N.S.
Treated	+.16	N.S.
EMI & pH (cooked)		
Microwave untreated	+.57	N.S.
Microwave treated	-.03	N.S.
Broiled untreated	+.18	N.S.
Broiled treated	+.53	N.S.
EMI (raw) & panel flavor		
Microwave untreated	-.06	N.S.
Microwave treated	+.28	N.S.
Broiled untreated	+.88	$p < 0.05$
Broiled treated	+.18	N.S.
EMI (cooked) & panel flavor		
Microwave untreated	+.41	N.S.
Microwave treated	-.20	N.S.
Broiled untreated	+.83	$p < 0.05$
Broiled treated	+.59	N.S.
EMI (cooked) & panel ease of fiber separation		
Microwave untreated	+.11	N.S.
Microwave treated	-.19	N.S.
Broiled untreated	+.94	$p < 0.01$
Broiled treated	+.45	N.S.
% drip cooking loss & pH (cooked		
Microwave untreated	-.18	N.S.
Microwave treated	-.68	N.S.
Broiled untreated	-.38	N.S.
Broiled treated	-.06	N.S.
% total cooking loss & pH (cooked)		
Microwave untreated	-.10	N.S.
Microwave treated	-.23	N.S.
Broiled untreated	-.82	$p < 0.05$
Broiled treated	-.33	N.S.
Exterior b^+ color (cooked) & pH (raw)		
Microwave untreated	+.72	N.S.
Microwave treated	+.54	N.S.
Broiled untreated	+.82	$p < 0.05$
Broiled treated	+.56	N.S.

Table 4. (Continued)

Correlated	Coefficient of Correlation	Significance	Correlated Parameters	Coefficient of Correlation	Significance
% drip cooking loss & panel flavor					
Microwave untreated	-.36	N.S.	Interior a+ color & pH (cooked)		
Microwave treated	-.74	N.S.	Microwave untreated	-.01	N.S.
Broiled untreated	+.17	N.S.	Microwave treated	+.10	N.S.
Broiled treated	+.09	N.S.	Broiled untreated	-.03	N.S.
% drip cooking loss & panel juiciness			Broiled treated	-.80	N.S.
Microwave untreated	-.68	N.S.	Interior b+ color & pH (cooked)		
Microwave treated	-.87	p 0.05	Microwave untreated	-.03	N.S.
Broiled untreated	+.54	N.S.	Microwave treated	-.32	N.S.
Broiled treated	+.34		Broiled untreated	+.17	N.S.
pH (cooked) & panel flavor			Broiled treated	-.29	N.S.
Microwave untreated	+.94	$p < 0.01$	Panel juiciness & tenderness		
Microwave treated	+.93	$p < 0.01$	Microwave untreated	-.04	N.S.
Broiled untreated	+.30	N.S.	Microwave treated	+.60	N.S.
Broiled treated	+.09	N.S.	Broiled untreated	+.70	N.S.
Panel juiciness and ease of fiber separation			Broiled treated	-.57	N.S.
Microwave untreated	+.16	N.S.			
Microwave treated	+.30	N.S.			
Broiled untreated	-.70	N.S.			
Broiled treated	-.85	$p < 0.05$			

presented in Tables 1 and 2. Interior color measurements for L (lightness) in the cooked beef portions were not significantly different between the untreated and pressure treated beef portions or the microwaved and broiled beef samples (Table 3). Type of treatment or cooking method also did not significantly influence interior b+ (yellowness) values in the cooked samples. The interior a+ (redness) values of the cooked beef portions were not significantly different between the untreated and pressure treated samples (Table 3). However, the microwave beef portions had significantly greater ($P<0.05$) a+ values than the broiled samples. The higher a+ values in the microwave beef portions indicates less heat denaturation of the myoglobin pigment. Subjective observations of the microwave beef portions revealed uneven heating which may account for variations in a+ values between microwaved and broiled samples; otherwise, there was considerable replication variation.

Exterior surface color measurements for the cooked beef portions were significantly different ($P<0.05$) between cooking methods for the L and b+ color values (Table 3). Broiling resulted in lower L and b+ values than microwave cooking. Pressure treatment did not significantly affect the exterior L and b+ values of the cooked beef portions. The a+ color values were not significantly different between the microwaved and broiled beef portions. However, the a+ values in the cooked pressure treated portions were significantly higher ($P<0.05$)

than for the untreated portions. The lower color values of the broiled beef portions indicate greater browning due to oxidation or denaturation of the meat pigments or from the carbonyl-amine browning reaction. The different principles of heating for each cooking method may account for variations in the extent of browning. Broiling involves heat conduction from the meat surface to the interior, whereas microwave cooking causes heat to be generated from within the meat. The exterior b+ color value for the raw untreated beef portions was significantly ($P<0.05$) higher than that of the raw pressure treated portions (Table 3).

The presssure treated cooked beef portions showed a significantly higher ($P<0.05$) pH than the untreated samples regardless of cooking method (Tables 1,3). The pH was not significantly different between the microwaved and broiled beef portions. However, there was a significant interaction between type of treatment and cooking method. No significant differences in pH were found between raw untreated and pressure treated meat (Table 2). Kennick and Elgasim (1981) also found that pressure treatment had no significant effect on the ultimate pH of beef semitendinosus muscle. MacFarlane and McKenzie (1976) stated that pressure treatment favors the release of imidazolium groups of histidine. This may account for the significantly higher pH of the pressure treated beef portions upon cooking.

Warner-Bratzler shear force values for the raw and cooked beef portions are presented in Tables 1 and 2. Shear values were significantly lower ($P<0.05$) for the cooked pressure treated beef portions than the untreated portions regardless of cooking method (Tables 1,3). Lower Warner-Bratzler shear values reflect an increase in tenderness for the cooked pressure treated beef portions. Shear values tended to be lower in raw pressure treated than for untreated muscle, although the difference was not significant. Other investigators also reported lower Warner-Bratzler shear values with pressure treated versus untreated raw and cooked beef semitendinosus muscle (Bouton et al., 1977a; Bouton et al., 1977b; Kennick and Elgasim, 1981). Bouton et al. (1977a) attributed the lower Warner-Bratzler shear values with pressure treatment primarily to changes in the myofibrillar component of toughness. Warner-Bratzler shear values were not significantly different between the microwaved and broiled beef portions (Table 3). Hostetler and Dutson (1978) reported no significant differences in average shear force values between microwaved and broiled beef semimembranosus muscle.

Panelists evaluation of tenderness indicated that pressure treated beef portions were significantly ($P<0.05$) more tender than corresponding untreated portions (Tables 1,3). No significant differences in tenderness values were found between the microwaved and broiled beef portions. Other investigators

have also reported greater tenderness in beef semitendinosus muscle subjected to pre-rigor pressure treatment (Bouton et al., 1977b; Kennick and Elgasim, 1981). The tenderizing effect from pre-rigor pressure treatment may be attributed to breakdown of the myofibrillar structure, early release of lysosomal enzymes, creation of breaks in fiber structure as a result of massive contractions, and/or F-G transformation of actin (Kennick and Elgasim, 1981). Tenderness scores and Warner-Bratzler shear values in the current study were significantly correlated ($r = -.94$; $P<0.05$) for the broiled untreated beef portions (Table 4). The subjective and objective results indicate the potential use of pre-rigor pressure treatment to improve the tenderness of tougher cuts of meat.

Panel scores for ease of fiber separation in the cooked beef portions are presented in Table 1. Ease of fiber separation was a subjective measurement of tenderness as indicated by the significant correlation ($r = -.82$; $P<0.05$) between Warner-Bratzler shear values and ease of fiber separation in the broiled pressure treated beef portions (Table 4). The pressure treated cooked beef portions received significantly higher ($P<0.05$) scores for ease of fiber separation than the untreated portions (Tables 1,3). No significant differences in the ease of fiber separation were found between the microwaved and broiled beef portions regardless of type of treatment. Panelists tenderness and ease

of fiber separation scores agreed with the objective Warner-Bratzler shear values in showing a significant effect from pressure treatment but no signficant influence from cooking method on tenderness.

Panel flavor evaluation scores of the beef portions were not significantly different for treatment or cooking method (Table 3). Kennick and Elgasim (1981) also reported no significant differences in flavor scores between control and pressure treated eye-of-round cuts. The nonsignificant differences in flavor scores of beef cooked by microwave and broiling methods in the current study is in agreement with work reported by Baldwin et al. (1979). They found that differences in sensory scores with microwave and conventional cooking of meat were a function of treatment differences rather than cooking method. Since samples for sensory analysis in the current study were obtained from the interior of the beef portions, the amine-carbonyl (Maillard) reaction had a smaller role in flavor development.

Preliminary investigation using the scanning electron microscope (SEM) and transmission electron microscope (TEM) indicated differences in ultrastructure due to cooking method and pressure treatment (Figures 3, 4, and 5). Observation of the raw pressure treated beef semitendinosus muscle reveals extensive fraying of fibers in contrast to the untreated muscle (Figures 3,4). Kennick et al. (1980) also reported extensive

Figure 3. Scanning electron micrograph (50x) of beef semitendinosus muscle: (A) Microwave untreated portion; (B) Broiled untreated portion; (D) Broiled pressure treated portion; (E) Raw untreated beef muscle; (F) Raw pressure treated muscle.

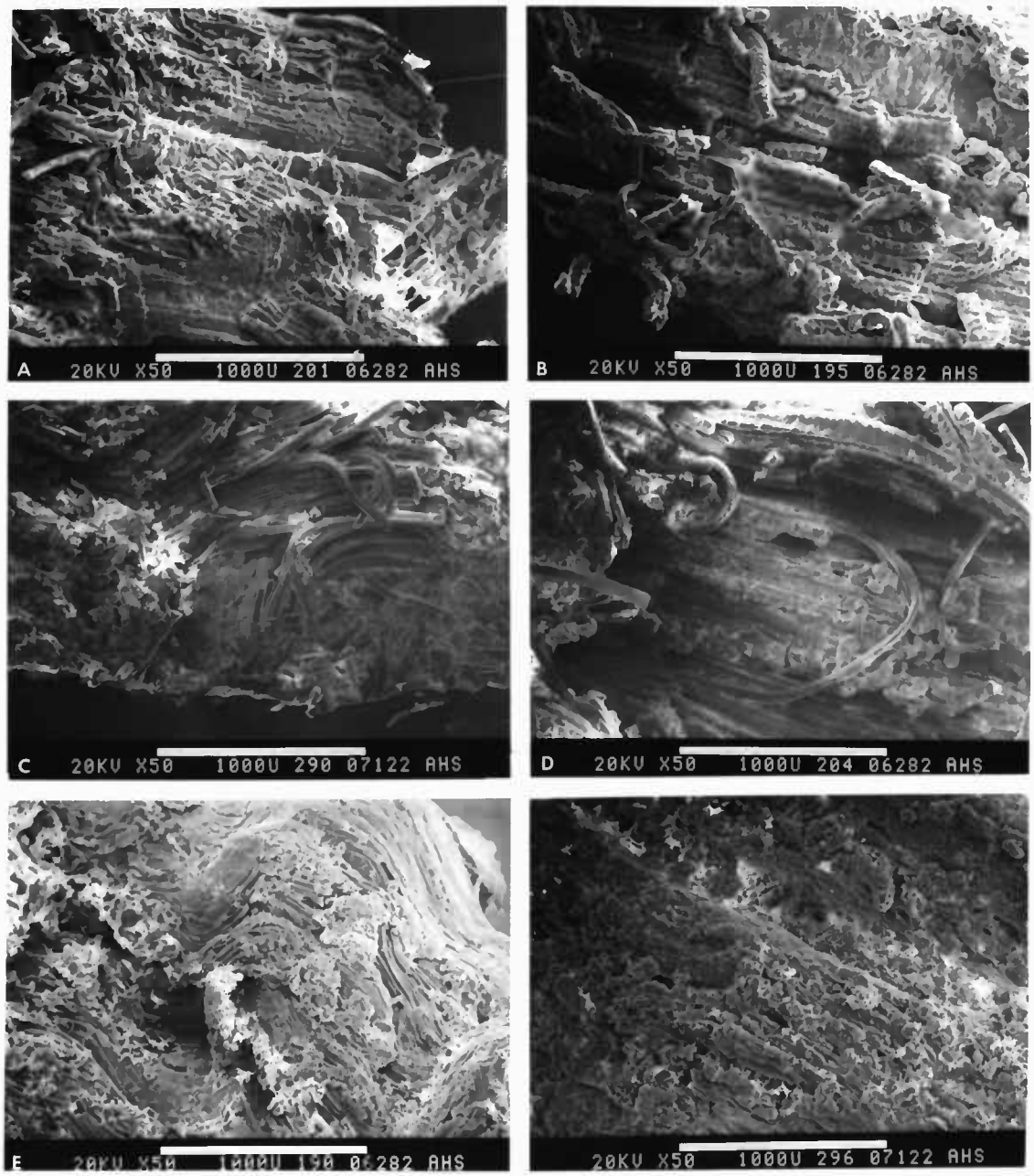
A 20KV X50 1000U 201 06282 AHS
B 20KV X50 1000U 195 06282 AHS
C 20KV X50 1000U 290 07122 AHS
D 20KV X50 1000U 204 06282 AHS
20KV X50 1000U 296 07122 AHS

Figure 3.

Figure 4. Scanning electron microscope micrograph (300x) of beef semitendinosus muscle: (A) Microwave untreated portion; (B) Microwave pressure treated portion; (C) Broiled untreated portion; (D) Broiled pressure treated portion; (E) Raw untreated beef muscle; (F) Raw pressure treated beef muscle.

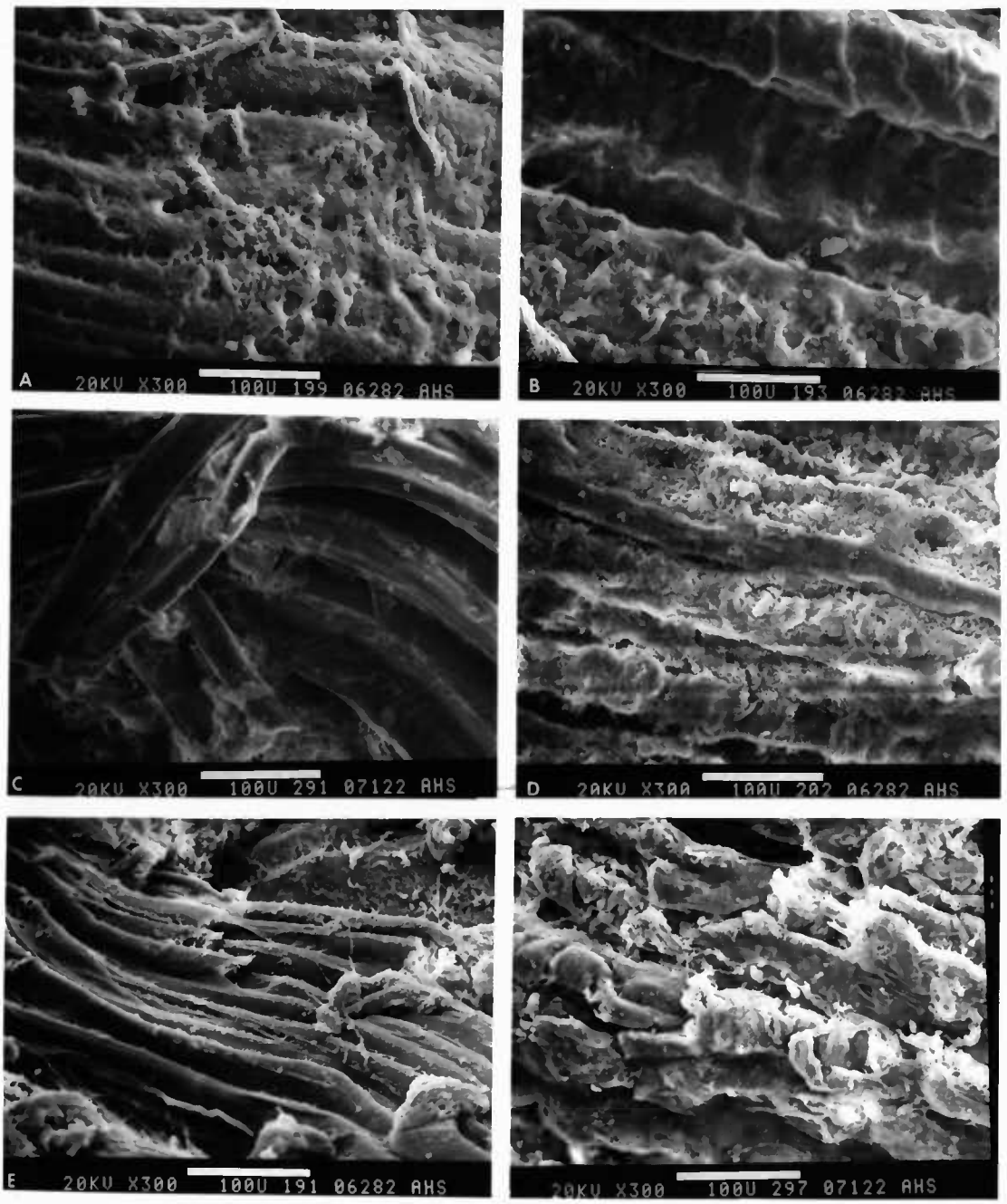
A 20KV X300 100U 199 06282 AHS
B 20KV X300 100U 193 06282 AHS
C 20KV X300 100U 291 07122 AHS
D 20KV X300 100U 202 06282 AHS
E 20KV X300 100U 191 06282 AHS
20KV X300 100U 297 07122 AHS

Figure 4.

Figure 5. Transmission electron microscope micrograph (3,600x) of beef semitendinosus muscle: (A) Microwave untreated portion; (B) Microwave pressure treated portion; (C) Broiled untreated portion; (D) Broiled pressure treated portion; (E) Raw untreated beef muscle.

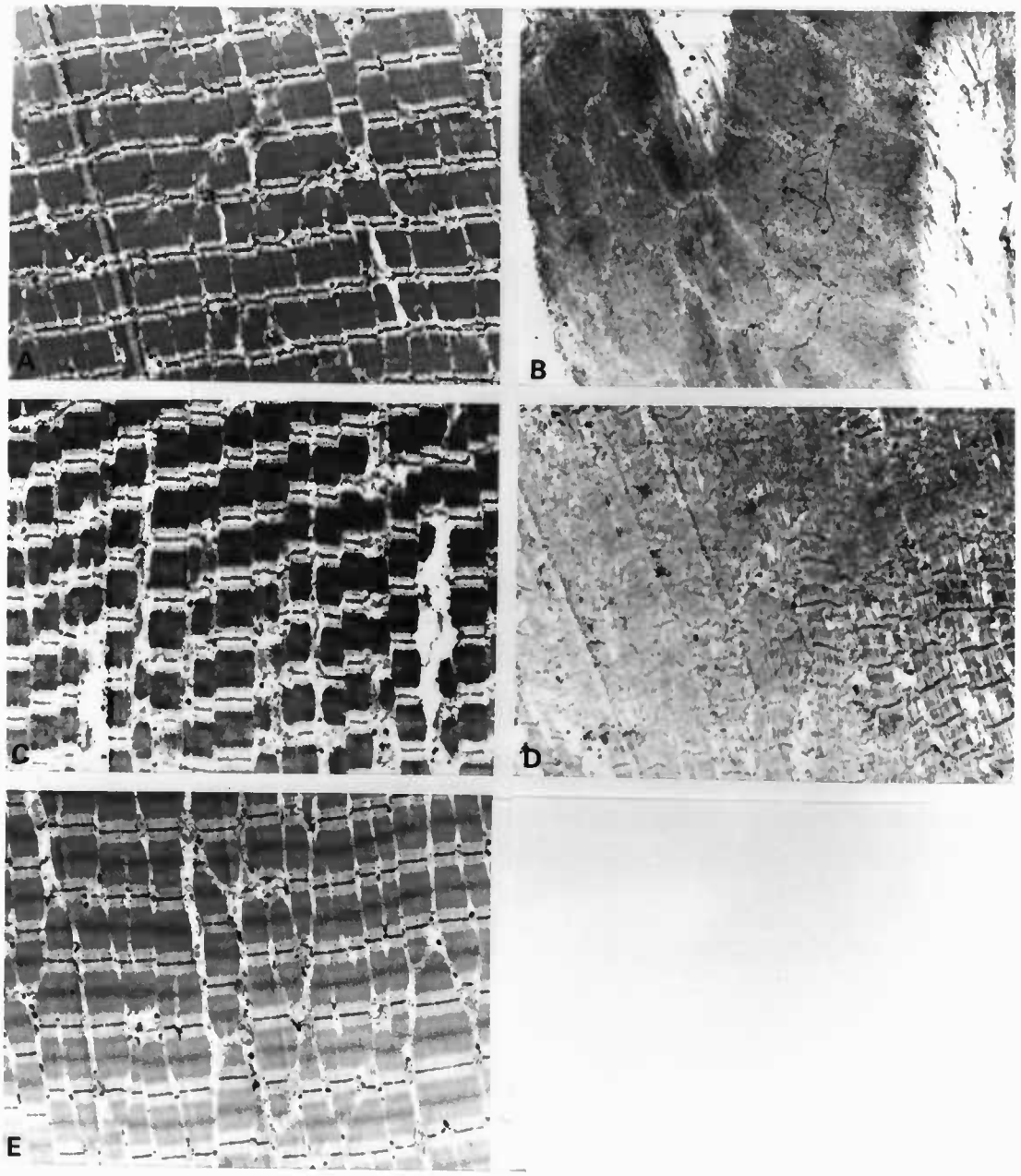

Figure 5.

fiber fraying and disruption of the sarcolemma with pre-rigor pressure treatment of beef semitendinosus muscle. Through examination of the SEM micrographs, such as those in Figures 3 and 4, it appears that pressure treatment resulted in greater myofibrillar fragmentation of the cooked beef portions. More granular material which may be a mixture of heat denatured collagen and coagulated sarcoplasmic protein was observed in the broiled pressure treated than untreated beef portions. Microwave cooked beef portions showed more fiber fragmentation and granulated material than the broiled beef portions. Hutton et al. (1981) also found greater fiber fragmentation and coagulated material in microwaved beef semitendinosus muscle cooked to a 70°C endpoint temperature as compared to conventionally heated muscle. In the current study, examination of TEM micrographs such as those in Figure 5 indicate extensive change in the ultrastructure of the cooked beef portions with pressure treatment. The sarcomeres were more distinct in the cooked untreated beef portions than the pressure treated portions. Microwave cooking of the pressure treated beef portions appeared to result in greater changes in myofibril structure than broiling. Further work is needed on sampling and interpretation of electron micrographs.

SUMMARY AND CONCLUSIONS

This study investigated the influence of microwave and broiling cooking methods on quality parameters of portion size cuts of beef semitendinosus muscle subjected to pre-rigor pressure treatment. Although total moisture, cooking losses, and color were significantly different between microwaved and broiled beef portions, in general, microwave and broiling cooking methods gave comparable results for quality parameters in pre-rigor pressurized beef portions. Pre-rigor pressure treatment of cooked beef portions resulted in significantly higher total moisture, pH, exterior a+ color vlues and subjective tenderness and ease of fiber separation scores than untreated portions. Expressible moisture index, total and evaporation cooking losses, and Warner-Bratzler shear values were significantly lower for pressure treated cooked beef portions. The significantly higher total moisture and tenderness of pre-rigor pressure treated cooked beef portions indicates the feasibility of this process for use by the meat industry.

Specifically, expressible moisture index (EMI) was significantly lower ($P<0.01$) and total moisture significantly higher ($P<0.05$) for pressure treated than untreated beef portions. Total moisture was significantly greater ($P<0.01$) in the microwaved beef portions than the broiled portions, while

EMI was not significantly different between cooking methods. Pressure treatment had no significant effect on total moisture or EMI of the raw beef semitendinosus muscle. Type of treatment or cooking method did not significantly affect panelists evaluation of juiciness in the cooked beef portions. Total, drip, and evaporation cooking losses were significantly lower ($P<0.01$) for pressure treated than untreated beef portions. Total and evaporation cooking losses were significantly greater ($P<0.01$) for broiled than microwaved beef portions. Microwave cooked beef portions showed significantly greater ($P<0.01$) drip loss values than broiled portions.

Pressure treatment of the cooked beef portions resulted in significantly lower ($P<0.01$) Warner-Bratzler shear values regardless of cooking method. Shear values were not significantly different between the microwaved and broiled beef portions or for type of treatment in the raw muscle. Panelists evaluation of tenderness and ease of fiber separation in the cooked portions indicated significantly higher scores ($P<0.05$) for the pressure treated than untreated samples. Tenderness and ease of fiber separation scores were not significantly different between microwaved and broiled beef portions. Type of treatment or cooking method did not significantly effect panelists evaluation of flavor in the cooked beef portions.

The cooked pressure treated beef portions had a significantly higher ($P<0.01$) pH than the untreated beef

samples. The pH of the beef portions was not significantly different between cooking methods. Pressure treatment did not significantly effect the pH in the raw beef muscles.

Interior L (lightness), a+ (redness), and b+ (yellowness) color values were not significantly affected by type of treatment in the cooked beef portions. Microwaved portions showed a significantly greater ($P<0.01$) interior a+ color value than broiled beef portions. Exterior L and b+ color values were significantly lower ($P<0.01$) for the broiled than microwaved portions. Pressure treatment resulted in a significantly higher ($P<0.05$) exterior a+ color value in the cooked portions. Type of treatment did not significantly affect exterior L and a+ color values in the raw muscles. However, the exterior b+ color value was significantly lower in the raw pressure treated muscle as compared to the untreated sample.

The results determined in this study indicate the potential of pre-rigor pressure treatment and microwave cooking. However, the data also indicate areas where future research is needed.

The water-holding capacity data in this study conflict with other researchers. This may be due to the methodology used to determine the function and content of water in a food. Thus, improved techniques for evaluating water-holding capacity need to be developed. Further research might be conducted to determine if and how pre-rigor pressurization changes the meat protein structure and chemistry which influences water-holding

capacity. A second area for future research is the development of the technique to integrate the SEM'S and TEM'S for determination of structural changes. The initial work indicates this is an area of tremendous potential. In association, further work on the molecular level would help elucidate what is occuring during pre-rigor pressure treatment. Finally, research utilizing other cookery methods besides those in the current study may indicate the optimum cooking method for pre-rigor pressure treated meat.

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APPENDIX

Table 5. Nitrogen content (% of weight and dry weight) of microwaved and broiled beef semitendiosus portions.

Replication	Wet Weight Basis				Dry Weight Basis			
	Microwaved		Broiled		Microwaved		Broiled	
	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated
1	4.601	4.994	5.128	4.760	12.070	14.802	12.546	11.688
2	4.780	4.293	5.282	4.382	12.071	13.286	13.458	9.458
3	5.286	4.219	5.686	4.934	13.462	12.063	13.514	13.663
4	5.254	4.281	4.772	4.662	13.605	11.915	11.992	12.823
5	4.481	4.452	5.002	4.547	13.331	13.858	13.746	13.348
6	4.542	4.826	5.368	4.740	12.274	14.260	13.567	12.294
Mean	4.824	4.511	5.204	4.671	12.802	13.364	13.137	12.209
Standard Variation	0.36	0.32	0.32	0.19	1.53	1.18	0.70	0.74

Table 6. Nitrogen and lipid content (% of wet weight and dry weight) of raw beef semitendinosus portions.

Replication	Nitrogen Content				Lipid Content			
	Wet Weight Basis		Dry Weight Basis		Wet Weight Basis		Dry Weight Basis	
	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated
1	2.904	3.567	11.031	12.578	3.364	3.613	12.711	12.757
2	3.568	3.154	12.688	11.550	3.788	4.372	13.469	15.883
3	3.388	2.987	12.122	10.234	4.569	5.234	16.311	18.000
4	3.758	2.869	13.587	10.759	4.092	2.659	14.651	9.950
5	3.662	3.440	13.451	13.174	3.614	2.034	13.312	7.738
6	3.352	3.503	11.656	13.336	3.946	1.909	13.754	7.306
Mean	3.439	3.253	12.423	11.939	3.896	3.304	14.035	11.939
Standard Deviation	0.30	0.29	1.01	1.29	0.42	1.34	1.28	4.38

Table 7. Warner-Bratzler shear values (0.05 kg) for microwaved and broiled beef semitendinosus portions.

Replication	Microwaved		Broiled	
	Untreated	Pressure Treated	Untreated	Pressure Treated
1	3.40	2.60	3.12	2.28
2	2.90	2.10	3.10	1.90
3	4.28	3.20	4.80	2.35
4	4.05	2.15	2.35	2.30
5	3.55	2.35	5.05	2.90
6	3.62	2.60	5.10	1.05
Mean	3.63	2.50	3.92	2.13
Standard Variation	0.49	0.40	1.20	0.62

Table 8. Warner-Bratzler shear value and pH of raw beef semitendinosus portions.

Replication	Shear Value		pH	
	Untreated	Pressure Treated	Untreated	Pressure Treated
1	3.63	4.60	5.528	5.450
2	4.64	4.50	5.520	5.500
3	8.00	7.30	5.541	5.516
4	8.00	8.60	5.500	5.565
5	5.58	5.23	5.557	5.581
6	5.68	3.75	5.511	5.469
Mean	5.92	5.66	5.526	5.514
Standard Deviation	1.77	1.88	0.02	0.05

Table 9. Total moisture (% of total weight) of microwaved and broiled beef semitendinosus portions.

Replication	Microwaved		Broiled	
	Untreated	Pressure Treated	Untreated	Pressure Treated
1	61.875	66.130	59.022	59.194
2	60.400	67.804	60.670	53.513
3	60.626	65.110	57.958	63.974
4	61.286	64.169	60.176	63.663
5	66.297	67.870	63.572	66.055
6	62.972	66.211	60.464	61.541
Mean	62.243	66.216	60.310	61.323
Standard Variation	2.19	1.46	1.90	4.48

Table 10. Expressible moisture index of microwaved and broiled beef semitendinosus portions.

Replication	Microwaved		Broiled	
	Untreated	Pressure Treated	Untreated	Pressure Treated
1	0.353	0.256	0.288	0.210
2	0.279	0.256	0.288	0.304
3	0.290	0.251	0.313	0.209
4	0.398	0.239	0.405	0.272
5	0.378	0.277	0.339	0.275
6	0.355	0.223	0.485	0.300
Mean	0.342	0.250	0.353	0.262
Standard Deviation	0.048	0.018	0.078	0.042

Table 11. Total moisture and expressible moisture index of raw beef semitendinosus portions.

Replication	Total Moisture		Expressible Moisture Index	
	Untreated	Pressure Treated	Untreated	Pressure Treated
1	73.534	71.668	0.368	0.284
2	71.878	72.732	0.452	0.369
3	71.982	70.907	0.338	0.367
4	72.002	73.289	0.485	0.325
5	72.848	73.711	0.401	0.450
6	71.315	73.875	0.469	0.387
Mean	72.260	72.697	0.419	0.364
Standard Deviation	0.79	1.19	0.059	0.056

Table 12. Initial weight (microwaved and broiled) and endpoint temperature (microwaved) of beef semitendinosus portions.

Replication	Initial Weight				Endpoint Temperature	
	Microwaved		Broiled		Microwaved	
	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated
1	84.509	87.120	85.473	88.794	80.4	77.5
2	90.055	85.505	94.109	83.232	79.9	89.5
3	85.502	85.155	86.922	94.565	85.5	80.2
4	77.124	86.136	80.189	92.156	92.5	72.0
5	79.045	78.835	79.996	80.873	80.2	71.5
6	82.547	85.242	80.519	76.918	74.5	74.5
Mean	83.130	84.666	84.535	86.090	82.2	77.5
Standard Deviation	4.66	2.95	5.55	6.86	6.1	6.7

Table 13. Total, drip and evaporation cooking losses of microwaved and broiled beef semitendinosus steaks (% of initial weight of portions).

Replication	Total				Drip				Evaporation			
	Microwaved		Broiled		Microwaved		Broiled		Microwaved		Broiled	
	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated
1	28.136	18.649	37.587	32.089	17.658	9.470	3.207	3.279	10.478	9.179	34.380	28.810
2	26.074	18.335	34.518	34.666	16.079	7.836	4.501	1.592	9.995	10.499	30.017	33.074
3	31.153	17.590	40.356	34.912	20.636	7.076	3.440	1.359	10.517	10.514	36.916	33.553
4	33.641	16.681	34.830	31.200	21.589	6.559	3.731	2.588	12.052	10.122	31.099	28.612
5	20.125	20.315	33.580	28.785	8.881	9.196	2.148	2.252	11.244	11.119	31.432	26.533
6	18.026	16.540	40.320	32.230	7.511	7.367	3.008	1.577	10.515	9.173	37.312	30.653
Mean	26.193	18.018	36.865	32.314	15.392	7.917	3.339	2.108	10.800	10.101	33.526	30.206
Standard Deviation	6.12	1.41	3.00	2.28	5.93	1.18	0.78	0.74	0.73	0.78	3.14	2.74

Table 14. pH of microwaved and broiled beef semitendinosus portions, untreated and pressure treated.

Replication	Microwaved		Broiled	
	Untreated	Pressure Treated	Untreated	Pressure Treated
1	5.730	5.673	5.680	5.848
2	5.701	5.775	5.683	6.072
3	5.800	5.892	5.641	5.831
4	5.817	5.932	5.728	5.914
5	5.804	5.844	5.742	6.094
6	5.816	5.767	5.677	5.832
Mean	5.778	5.814	5.692	5.932
Standard Deviation	0.05	0.09	0.04	0.12

Table 15. Color evaluation (with l, a^+, b^+) of exterior and interior from microwaved and broiled beef semitendinosus portions.

Replication	Color Parameter	Exterior				Interior			
		Microwaved		Broiled		Microwaved		Broiled	
		Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated
1	L	45.1	44.0	33.7	28.1	47.9	47.8	49.9	46.2
	a^+	4.2	5.2	3.5	5.0	4.8	4.7	2.3	2.7
	b^+	10.4	9.6	7.3	6.3	9.6	9.2	9.7	8.7
2	L	41.6	42.0	27.7	27.9	47.1	43.5	46.5	42.7
	a^+	4.7	4.6	4.8	4.9	2.9	4.6	2.7	2.5
	b^+	9.9	9.2	7.1	6.6	9.0	8.7	9.3	8.5
3	L	44.7	42.0	30.4	32.1	49.6	44.9	47.0	43.1
	a^+	4.1	6.0	4.3	5.2	2.8	4.8	2.7	2.9
	b^+	10.5	9.8	8.4	9.7	9.0	8.6	9.6	9.3
4	L	46.2	40.3	30.3	34.0	52.2	44.2	48.6	48.2
	a^+	3.7	6.3	4.1	4.9	2.6	5.1	2.7	2.3
	b^+	9.9	9.7	7.3	9.1	9.8	8.8	9.3	9.6
5	L	42.8	48.2	35.3	31.5	47.1	51.7	52.0	47.3
	a^+	4.8	4.1	5.7	5.3	3.9	2.8	2.2	2.0
	b^+	10.3	10.8	10.8	8.4	9.1	9.8	9.8	9.5
6	L	44.6	45.7	30.7	33.4	48.6	52.7	53.1	49.0
	a^+	5.1	5.1	5.7	5.0	4.9	3.9	1.5	2.8
	b^+	9.5	10.0	7.7	8.4	8.8	9.6	9.6	9.9
Mean	L	44.2	43.7	31.4	31.2	48.8	47.5	49.5	46.1
	a^+	4.4	5.2	4.7	5.1	3.7	4.3	2.4	2.5
	b^+	10.1	9.9	8.1	8.1	9.2	9.1	9.6	9.3
Standard Deviation	L	1.7	2.9	2.7	2.6	1.9	3.7	2.7	2.6
	a^+	0.5	0.8	0.9	0.2	1.0	0.8	0.5	0.3
	b^+	0.4	0.5	1.4	1.4	0.4	0.5	0.2	0.5

Table 16. Color evaluation (with L, a^+, b^+) of exterior raw beef semitendinosus portions.

Replication	Untreated			Pressure Treated		
	L	a^+	b^+	L	a^+	b^+
1	32.1	10.6	8.1	31.9	11.2	7.0
2	30.0	12.3	9.0	29.5	8.8	6.5
3	31.6	10.8	8.0	28.9	10.9	6.1
4	32.2	9.5	9.1	30.3	10.1	6.8
5	33.4	9.8	6.9	31.9	9.1	6.1
6	34.9	8.5	7.2	33.5	7.9	7.1
Mean	32.4	10.3	8.1	31.0	9.7	6.6
Standard Deviation	1.7	1.3	0.9	1.7	1.3	0.4

Table 17. Panel evaluation of tenderness and fiber separation for microwaved and broiled beef semitendinosus portions.

Replication	Tenderness				Fiber Separation			
	Microwaved		Broiled		Microwaved		Broiled	
	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated
1	3.33	3.50	2.83	3.15	2.67	2.17	1.67	3.00
2	2.57	4.00	3.00	3.00	2.14	3.29	2.17	3.20
3	2.33	3.20	2.40	2.90	2.80	2.80	2.00	2.60
4	2.75	3.83	3.50	4.00	2.50	2.17	2.50	3.33
5	2.25	3.33	1.80	3.33	2.25	3.00	2.20	2.33
6	3.75	4.60	2.20	3.50	3.50	3.60	3.20	3.50
Mean	2.83	3.74	2.62	3.31	2.64	3.84	2.99	2.29
Standard Deviation	0.59	0.52	0.61	0.40	0.49	0.58	0.52	0.45

Table 18. Panel evaluation of juiciness and flavor for microwaved and broiled beef semitendinosus portions.

Replication	Juiciness				Flavor			
	Microwaved		Broiled		Microwaved		Broiled	
	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated	Untreated	Pressure Treated
1	3.33	2.83	3.67	3.33	3.00	2.67	3.33	2.83
2	2.57	3.29	3.33	2.80	2.57	3.00	3.50	3.00
3	3.20	3.40	3.80	3.00	3.80	3.40	3.00	2.80
4	2.75	3.80	3.75	2.33	3.50	4.00	4.50	3.83
5	4.25	3.17	2.60	3.50	3.75	3.17	3.20	3.33
6	3.50	3.80	2.20	2.25	4.00	3.00	4.40	3.50
Mean	3.27	3.38	3.23	2.87	3.44	3.21	3.65	3.22
Standard Deviation	0.60	0.38	0.67	0.51	0.55	0.46	0.64	0.41