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A CRITICAL COMPARISON OF BEEF SEMITENDINOSUS MUSCLE HEATED IN AN OVEN AND IN A WATER BATH

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Pamela Louise Brady

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ABSTRACT

A comparison between characteristics of oven-roasted beef semitendinosus muscle and muscle heated as cylindrical cores in glass tubes in a water bath was conducted. Samples were heated to endpoint temperatures of 60 and 70°C at rates equivalent to heating at oven temperatures of 93 and 149°C. Oven-roasted samples had higher evaporative losses and lower drip losses than water bath samples. The effects of heating system and endpoint temperature on cooking losses and on nonfat dry weight were strongly influenced by heating rate. Expressible moisture index and fiber diameter measurements were not affected by endpoint temperature, heating system, or heating rate. Tenderness, as measured by both penetration and shear tests, was not affected by heating system; however, endpoint temperature resulted in differences in penetration chewiness with fast heating and in penetration hardness and shear firmness when samples were heated at the slow rate. With slow heating dominant wavelength and L-values of the samples were affected by both heating system and endpoint temperature. A sensory panel detected endpoint temperature and heating system differences in samples heated at both rates, but the panel was not able to detect any differences in the tenderness parameters. It was concluded that some characteristics of meat are affected by the heating system, and these effects must be considered when applying results from research involving water bath heating to oven roasting.

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CHAPTER I

INTRODUCTION

Standardization of meat cookery techniques based on research objectives is necessary to enable researchers to compare research data and conclusions. Before standardization is possible, the effects of cooking rate and final internal temperature on meat palatability must be investigated and more completely explained (Cross et al., 1976). Cover et al. (1962a) pointed out that the study of these effects is complicated by the fact that tenderness involves two components--muscle fibers and connective tissue. Cover (1962a) also suggested that juiciness is involved in tenderness, but the effect tended to vary among specific muscles.

Marshall et al. (1960) reported a temperature variation of as much as 60°F within a 10-lb top round roast during the first few hours of cooking. This means that, in a relatively large piece of meat, the time-temperature combinations to which any given point in that piece is subjected during cooking may vary widely (Machlik and Draudt, 1963). For this reason, Machlik and Draudt concluded that small samples, in which heat transfer is rapid, must be used in studies to obtain definitive information on heat effects.

It has been well documented in meat literature that beef roasted at low oven temperatures (66-121°C) for long periods of time is more tender than meat roasted at higher temperatures (149-163°C) for shorter periods of time (Cover, 1943; Griswold, 1955; Bramblett et al., 1959;

Bayne et al., 1973). In an effort to pinpoint components contributing to more tender meat, a number of researchers heated small meat samples in water bath systems designed to simulate oven roasting (Machlik and Draudt, 1963; Laakkonen et al., 1970; Paul et al., 1973; Penfield and Meyer, 1975; Hearne et al., 1978a,b).

Berry (1975) stated that much of the current information regarding heat-related changes in meat was derived from studies of small samples heated in hot water baths. He further suggested a definite need to determine whether results collected in this fashion can be extrapolated to the cookery techniques employed by consumers. The present investigation was designed to compare selected physical, chemical, and sensory characteristics of oven-heated beef roasts with those of cylindrical cores of meat heated in glass tubes in a water bath.

CHAPTER II

REVIEW OF LITERATURE

I. THE EFFECTS OF HEAT TREATMENTS ON MEAT

In general, heating tenderizes collagenous connective tissue by partial hydrolysis of collagen and toughens muscle fibers by denaturation of myofibril proteins (Harrison, 1975). However, the effects of heat treatments are complicated because individual components of meat undergo changes in tenderness and water loss at different temperatures (Draudt, 1972). Numerous studies have been conducted in attempts to elucidate the changes in meat components due to various degrees and methods of heating. Final endpoint temperature and rate of heating have been studied to determine their effect on cooking loss, tenderness, collagen solubilization, muscle fiber components, sensory parameters, and other meat characteristics.

Effects of Endpoint Temperature

Heat-related physical and chemical changes in meat occur in discrete steps (Hamm, 1966). The effects of these steps on the tenderness of meat samples heated in tubes in a water bath were summarized by Draudt (1972). At temperatures below 50°C little change in shear occurred. In the 55-58°C range there was a slow decrease in shear. At approximately 60°C this decrease was accelerated and was reported to be a manifestation of the collagen shrinkage reaction. In the range of 66-70°C, a marked rise in shear values occurred. This hardening was

time dependent and somewhat more variable with respect to temperature than collagen shrinkage. A general downward trend in shear values with heating time became apparent at about 70°C; however, the effects of the earlier hardening reaction persisted even at 90°C.

Laakkonen et al. (1970) simulated conditions at the center of a steamship round roast heated in a 121°C oven by submerging slices of meat sealed in plastic bags in a water bath. The water bath temperature was increased at the same rate as the temperature rise at the center of an intact roast (0.1°C/min). The authors concluded that endpoint temperature of meat is extremely critical with respect to tenderness and weight loss. If the endpoint temperature is below that at which collagen shrinks, a major decrease in tenderness does not occur. If endpoint temperature is higher than the shrinkage temperature of collagen, the more severe coagulation of muscle fibers will cause a higher weight loss and more tightly packed, less tender tissue.

Endpoint temperatures of up to 50°C were reported by Bouton and Harris (1972) to be associated with toughening of meat reflecting a change in water-holding capacity. The authors suggested that tenderness changes during heating between 50 and 60°C were related to connective tissue changes. The increase in toughness observed on heating at temperatures between 60 and 70°C was ascribed to increased moisture loss and fiber shortening with concomitant change in the properties of the connective tissue.

Davey and Gilbert (1974) observed two distinct tenderizing stages in strips of sternomandibularis muscle enclosed in plastic bags and heated in a water bath. The first occurred prior to 65°C and was

described as an aging effect due to specific proteolytic attack on myofibrillar elements. The second generally was observed between 70 and 100°C and involved the destruction of interstitial collagen with little loss of myofibrillar strength. A toughening phase which occurred between the two tenderizing phases was attributed to collagen shrinkage and subsequent squeezing of fluid from the muscle.

As internal temperature of semitendinosus and biceps femoris strips heated in water baths programmed to reproduce the average heating curve of a semitendinosus roast in a 163°C oven increased, significant increases in percent solubilized collagen were observed by Paul et al. (1973). Average shear force decreased with increased temperature in the biceps femoris but not in the semitendinosus. Penetrometer readings decreased with increasing heat treatment suggesting that the muscles became more dense and compact rather than more tender. Significant negative correlation coefficients were observed between penetrometer values and percent connective tissue solubilized for both muscles. The authors hypothesized that increased coagulation of contractile proteins was more important in controlling tenderness than the breakdown of collagenous tissue.

Penfield and Meyer (1975) heated cores from beef semitendinosus muscle in a water bath to endpoint temperatures of 40, 50, 60, and 70°C. A small but significant decrease in shear values occurred as cores were heated from 40 to 50°C. A larger decrease occurred in the 50-60°C interval, but shear values were not significantly affected by heating from 60 to 70°C. As endpoint temperature increased, percent hydroxyproline solubilized increased. In subsequent work, Penfield et al.

(1976) observed that the moisture content of cores decreased as the endpoint temperature of the samples increased from 50 to 60 and from 60 to 70°C. Changes in shear values followed similar patterns to those noted in their previous report.

As internal temperature of oven-roasted steaks increased to 90°C, cooking losses also increased (Cross et al., 1976). This difference in cooking loss was attributed mainly to evaporation. Substantial increases in the cooking losses were observed after the internal temperature of the meat reached 70°C. A trained sensory panel determined that the effect of increased internal temperature on juiciness followed similar patterns. Juicy steaks, those heated to 60 and 70°C, lost less weight during cooking than dry steaks. The taste panel also determined that tenderness of steaks decreased as internal temperature increased from 60 to 80°C. The greatest decrease in tenderness scores occurred between 70 and 80° and maximum toughening resulted at 80°C. A slight increase in tenderness scores was observed at 90°C.

Bailey and Sims (1977) defined the texture of meat primarily in terms of the properties of the denatured actomyosin which constitutes 80% of muscle protein. However, these properties were highly dependent on temperature and on other meat components. They found that when the unheated muscle was compressed during shearing, the actomyosin was pushed aside with very little resistance until the tough collagen fibers were compressed. In contrast, following heating to 40-50°C, the actomyosin was denatured to form a more rigid gel, and there was considerable resistance to shear. This resistance dramatically increased following denaturation of collagen at 65-75°C, although, at this temperature,

mechanical strength of the denatured collagen was greatly reduced in comparison to native collagen.

Total and soluble collagen were found to be a major factor in the variation in tenderness of meat samples heated for 20 min in a 60°C water bath (Dransfield, 1977). Variation in collagen content accounted for 45% of the variation in tenderness. With heating at 75°C for 1 hr, the collagen contribution to variations in tenderness was 34%. This contribution was only slightly greater than the combined contributions of fat, moisture, sarcomere length, and pH (28%). Following severe heat treatment, 90°C for 3 hr, none of the factors significantly influenced tenderness.

Hearne et al. (1978a) observed changes in shear and muscle fiber measurements of beef semitendinosus cores heated to endpoint temperatures of 40, 50, 60, and 70°C. Cores heated to 50°C had significantly smaller shear values than cores heated to 40°C. A greater decrease occurred with heating from 50 to 60°C, but no apparent changes in shear values were observed due to heating from 60 to 70°C. Fiber diameters decreased with increased endpoint temperature to 60°C, but little change occurred from 60 to 70°C. Fiber disintegration increased with increased endpoint temperature.

Effects of Heating Rate

Very low oven temperatures, necessitating long cooking periods, have been shown by a number of researchers to yield very tender beef. Bramblett et al. (1959) suggested that the tenderizing effect was due to the length of time the meat temperature was in the range of 57 to 60°C

and that this extended low temperature heating tended to soften connective tissue without hardening muscle fibers.

When meat was roasted uncovered to a final internal temperature of 85°C in 121 and 149°C ovens, Griswold (1955) found that meat heated at 149°C was more juicy than meat heated at 121°C. However, the 121°C samples had lower shear values than those roasted at the higher temperature. Beef roasted at 121°C appeared dark and hard on the surface, dry and mealy inside, and was so tender it was difficult to cut. Griswold concluded that, except for the dry appearance, roasting at 121°C was better.

Bramblett and Vail (1964) reported that meat cooked to an endpoint temperature of 65°C in a 69°C oven shrank less and was more tender than meat heated to the same endpoint temperature at 93°C. They pointed out that these findings emphasized the important effects of time, temperature, and their interaction on shrinkage of connective tissue and muscle fiber. Cooking time was two to four times longer at 121 than at 149°C. Average taste panel scores were similar for samples heated at the two temperatures.

Bayne et al. (1971) roasted paired semitendinosus muscles to an endpoint temperature of 70°C at 93 and 149°C. Roasts cooked at 93°C required longer cooking times, had higher cooking losses, and were more tender than their pairmates cooked at 149°C. The alkali insoluble collagen content of the muscles was reduced significantly by cooking at either oven temperature, however. The alkali insoluble collagen content of the cooked roasts and the percent solubilized with heating were similar at both heating temperatures.

In later work, Bayne et al. (1973) heated beef rib roasts at oven temperatures of 107 and 163°C to endpoint temperatures of 60, 70, and 77°C. Cooking time was longer and cooking losses were lower at the lower oven temperature. As endpoint temperature increased, cooking time and cooking loss increased with a resultant decrease in juiciness. Shear values indicated that roasts heated at 107°C to endpoint temperatures of 70 or 77°C were more tender than roasts heated at other combinations of oven and endpoint temperature.

Meat cores in glass tubes heated in a water bath "programmed" to simulate oven heating of top round roasts at 93 and 149°C were studied by Penfield and Meyer (1975). The cores heated at 149°C were less tender than those heated at 93°C. More hydroxyproline was solubilized at the lower oven temperature than at the higher one. There was a significant relationship between shear values and percent hydroxyproline solubilized during heating, but there seemed to be limitations to this relationship. A small but significant decrease in shear value from 40 to 50°C was not accompanied by a significant increase in hydroxyproline solubilized. A significant increase in solubilization of hydroxyproline from 50 to 60°C was accompanied by a significant decrease in shear values.

In a study of heat and mass transfer during oven roasting, Bengtsson et al. (1976) found that the meat surface remained wet during most of the heating cycle and that weight loss by evaporation was directly proportional to the heating time. They found that, for a given wet surface temperature, the driving force of heat transfer to the

interior was the same irrespective of oven temperature. In experiments performed at 175 and 225°C oven temperatures, the wet surface temperature was higher at 225°C than at 175°C which, in turn, resulted in steeper temperature gradients, shorter heating times, and larger weight losses at the 225°C oven temperature. These authors observed that drip loss was significant only at internal meat temperatures above about 65°C and thus could be minimized by using heating conditions where this temperature was not exceeded. The authors pointed out that one way to achieve this was to use low temperature-long time heating methods which result in an oven humidity similar to that found at higher temperatures and also results in the thermal driving force of the higher temperature.

In summary, meat heated at low oven temperatures for long periods of time is more tender than meat heated at higher temperatures for shorter times. Differences in tenderness have been related to the effects of the longer heating period on collagen solubilization and myofibrillar hardening. The extent of these effects and the factors governing them, however, remain to be clearly defined.

II. MEASURES OF MUSCLE TENDERNESS

Measurement of meat tenderness has been studied extensively because tenderness is important in determining consumer reaction to meat quality. Although chemical and histological assessments of meat tenderness have been developed, a majority of the tenderness studies reported in the literature involve physical test procedures (Voisey, 1976). Most meat researchers recognize that meat tenderness is a sensory parameter (Kapsalis and Szczesniak, 1976), and thus it must

ultimately be evaluated either by a sensory panel or by use of a test that correlates with sensory evaluation.

Objective Methods

Various instrumental measurements of tenderness can best be understood when one assumes that meat behavior is similar to a structure composed of parallel rods (myofibrillar structure) joined together by a three-dimensional network of connective tissue (Bouton et al., 1975a). A tensile force applied along the fibers must be borne by both the rods and the network. Since the myofibrillar structure of cooked post-rigor meat cannot change shape easily, free expansion of the network under load is partially inhibited. When force is applied perpendicular to the meat fibers (adhesion measurement), the myofibrillar structure would not have to yield for the network to expand, and its only effect would be indirect due to its interstitial presence.

Warner-Bratzler shear measurements are markedly different from both tensile and adhesion measurements (Bouton et al., 1975a). As the straight edge of the shear blade contacts the sample, either it compresses the fibers underneath and tightens those that are stretched, or the sample distorts. The total force, then, is made up of a compression component and a tensile component which, when resolved along the lines of the limited number of meat fibers affected, produce the necessary strains.

Pool and Klose (1969) observed similar actions taking place when poultry meat was sheared. They found that shear strength was a small part of resistance to separation since the flexible material subjected

to a shearing stress was immediately distorted and a portion of the force transformed into a component of tensile stress in the stressed fibers. Tensile rather than shear force caused fiber separation. The force applied to the surface fibers was transmitted, in turn, not across the shear plane, but into the sample below and adjacent to the line of stress. For this reason, only those fibers in immediate contact with the shearing member received the maximum vertical component of the stress, and compression of the area under the knife took place before the failure of the meat fibers.

Voisey and Larmond (1974) stated that as an empirical test the Warner-Bratzler has a serious drawback because the readings combine two properties that may or may not be dependent on each other. Firmness, a viscoelastic property of the meat, is indicated by the compressed area of the sample. Tenderness, a tensile rupturing property of the meat, is indicated by the maximum applied force. The first property is measured transversely to the meat fibers (compression) and the latter along the fiber axis (tension).

A method for breaking shear measurements into firmness and tenderness components was described by Larmond and Petrasovits (1972). When the force-deformation curve of a Warner-Bratzler shearing operation was recorded, it was found that the initial part of the curve represented a compression phase and provided an index of force to produce a given deformation. From a sensory viewpoint the authors considered this to be a measure of firmness, which, according to the definition of Szczesniak (1963), is a popular term for hardness which is defined as the force necessary to attain a given deformation. For convenience,

because the initial part of the curve is typical for a viscoelastic material, i.e., nonlinear, the slope of a line between the origin and peak was used. The peak force, indicative of rupturing of the sample, was defined as an index of cohesiveness of the material.

While shearing devices, which cut across the muscle fibers and the surrounding connective tissue, have been used in a majority of the meat tenderness studies, it is also possible to use direct tensile measurements of the muscle fibers to assess tenderness. Parameters resulting from tensile tests include maximum force required to rupture the meat, breaking strength, and work done (Penfield et al., 1976). Comparisons of these parameters with Warner-Bratzler shear tests suggested that breaking strength was more sensitive to changes in shear than to changes in tenderness.

Still another approach to studies of meat tenderness, penetration, has been reported (Bouton et al., 1971; Bouton and Harris, 1972; Bouton et al., 1975b). In this test a plunger attached to an Instron was driven 80% of the way through samples presented so that the direction of plunger penetration was perpendicular to the muscle fibers. The plunger was driven into the meat twice at each location and the work-force curves recorded. Results were expressed as hardness, the force for the first penetration; cohesiveness, the work during the second stroke divided by the work during the first stroke; and chewiness, the product of hardness and cohesiveness. The authors found that Warner-Bratzler shear correlated better with muscle fiber properties, and penetrometer measurements correlated well with connective tissue properties. They also found that the relative contributions of

compression (connective tissue) and Warner-Bratzler shear (myofibrillar toughness) differed markedly with the manner of sample presentation. This was an important difference because it confirmed that in thin slices of meat from roasts, which would be cut perpendicular to the fibers, shear measurements would not adequately describe tenderness.

Sensory Evaluation

Sensory evaluation is the ultimate method of measuring meat tenderness, and all other methods are assessed by how well they relate to sensory evaluation (Larmond, 1976). Investigators using sensory techniques are faced with the problem of whether to have panelists separate the components of tenderness or make an overall tenderness evaluation.

In an effort to have the sensory panel describe the overall tenderness of samples, the technique of profiling was developed. The profiling technique most often applied to meat is that developed by Cover et al. (1962a,b,c) who separated meat textural characteristics into six components: softness to tooth pressure, softness to tongue and cheek, ease of fragmentation, mealiness, apparent adhesion between fibers, and amount/firmness of connective tissue. In this type of test, trained panelists judge each component on a 9-point scale.

The General Foods Texture Profile system is another example of the profiling technique (Brandt et al., 1963; Szczesniak, 1968; Civille and Liska, 1975). This system involves a detailed analysis of the food in terms of mechanical, geometrical, fat and moisture characteristics, the degree of each present, and the order in which they appear from

first bite through complete mastication. This system uses highly trained judges who are able to perceive, analyze, and quantify a large number of textural properties of a food.

Rogers and Ritchey (1969) used the six components described by Cover to evaluate differences in steaks heated at 177°C for 20, 23, 26, and 29 min. The judges detected differences in all six sensory factors between steaks cooked 20 and 26 min but were unable to detect any statistically significant differences between steaks cooked 26 and 29 min. Juiciness, softness to tongue and cheek, softness to tooth pressure, fragmentation, adhesion, and amount of connective tissue decreased as cooking time increased. Softness of connective tissue and mealiness increased as cooking time increased.

A number of researchers have attempted to determine whether six parameters are necessary for complete sensory evaluation of meat. Horsfield and Taylor (1976) reported that they obtained a complete sensory portrait of meat samples by asking panelists to evaluate only three parameters--toughness, succulence, and flavor.

Harries et al. (1972) allowed their trained panel to identify the components of texture they felt needed to be judged. The seven characteristics identified were resistance to initial chewing, wetness, juiciness, cohesiveness, hardness, overall texture, and chew count. Factor analysis of the results of tests on 68 samples of beef roasts showed that all but 5% of the variation in the texture of the meat could be described by two scales, toughness-tenderness and juiciness. The authors felt that more elaborate subdivisions of sensations in the mouth did not appreciably add to the precision of sensory assessment.

Based on these findings, the authors concluded that cooked meat is a considerably simpler system texturally than most foods since it lacks such characteristics as hardness, brittleness, gumminess, oiliness, lumpiness, and graininess.

Harries and coworkers (1963) cautioned against assessing consumer quality of meat using a trained panel. The authors observed that trained panels could assess eating quality, but they could not measure acceptability to consumers since consumers may vary in the importance they attach to various parameters, and they also may vary in their conception and perception of optimum intensities of the parameters. Thus, in order to relate the results of analytical taste panels to consumer acceptance, it would be necessary to make direct comparisons between the results of the panel and those of consumer acceptance studies.

Comparisons Between Objective Methods and Sensory Evaluations

Kapsalis and Szczesniak (1976) defined texture (or tenderness) of meat as a sensory parameter and stated that a meaningful instrumental test must show a high correlation with sensory evaluation. They went on to point out that the literature abounds with reports of instrumental/sensory correlations ranging from highly significant to totally non-significant. Both Sharrah et al. (1965) and Szczesniak (1968) attempted to draw together the findings of a number of studies, and both reached the conclusion that there was really no way to say with certainty which, if any, instrumental measurements are related to sensory panel evaluations.

Rhodes et al. (1972) reported that Warner-Bratzler shear values accounted for 30-60% of panel variation in tenderness assessments. They then attempted to develop a compression system in an effort to account for more of the variation. The system developed resulted in 10 characteristics of texture but still only accounted for 50% of the textural variation in hot samples and 75% in cold ones. The authors concluded that a single instrumental measurement was not sufficient to predict a panel's response.

Bouton et al. (1971) developed a compression test system for use with the Instron. In testing mutton, they found that hardness, or the force required to achieve the first penetration, was highly correlated ($r = 0.88$, $P < 0.001$) with the panel evaluations of a factor they called initial impression of tenderness. Cohesiveness, defined as the ratio of work done during the second penetration at a location to that performed during the first, correlated well ($r = 0.90$, $P < 0.001$) with the panel's evaluation of residual impression. Results from Warner-Bratzler shear measurements and from compression tests were correlated, but the degree of correlation varied with the heat treatment the samples had received. The two instruments were more highly correlated when testing samples heated in a water bath at 90°C for 1 hr than when testing those heated in a similar system at 65°C for 1 hr. The authors proposed that the poorer correlation for tests on samples receiving the lower heat treatment was probably due to difficulty in cutting these comparatively wet and easily deformed samples to precise dimensions.

When the components of Warner-Bratzler shear, cohesiveness and firmness, were compared with panel evaluations of tenderness, Larmond

and Petrasovits (1972) found that the panel was influenced more by cohesiveness, as measured by maximum peak height, than by firmness, measured as the rate of rise of force, i.e., the curve's slope. When one sample was both firmer and more cohesive than another, the panel found that sample to be tougher 76% of the time. However, when one sample was more cohesive (greater peak height) and the other was firmer (greater slope), approximately 65% of the time the panel judged as tougher the sample that was more cohesive.

In another comparison of Warner-Bratzler shear measurements and sensory data, Dutson et al. (1976) determined that the Warner-Bratzler is a measurement of both connective tissue and muscle fiber components of tenderness. Sensory panels, on the other hand, are able to separate differences in tenderness of muscle fibers and connective tissue.

Khan et al. (1973) stated that a major problem in correlating shear with taste panel data is the lack of homogeneity of muscle. Thus samples for shear and those for panel use are not necessarily the same. These authors found that shear differences of 0.5 kg or more among samples were readily detected by the taste panel regardless of the level of tenderness or the method of cooking. The lack of an effect of level of tenderness seemed to suggest that factors other than shear might be related to the judgment of tenderness. The panel discriminated more readily between samples from different muscles than between samples from the same muscle suggesting that texture differences accentuated shear differences.

Difficulties arise when one uses mechanical parameters as substitutes for what the human perceives as textural parameters such as

tenderness, chewiness, and fibrousness (Kapsalis and Szczesniak, 1976). Comparisons between sensory and objective tests are complicated by the fact that human subjects measure and integrate sensory chewing perceptions on a material that undergoes continuous transformation. Thus, it is as if sensory testing is done on a long series of different samples which are produced not only by the mechanical destruction of the original structure but also by the biochemical conditions in the mouth.

Szczesniak (1968) summarized the problems involved in comparing sensory and objective tests. She stated that the manner in which objective tests are performed and the results expressed, the psychological, physiological and methodological factors influencing sensory evaluation, and the heterogeneity or time-induced changes in the test sample may all influence the nature and degree of correlation between sensory and instrumental texture measures. She went on to say that much more needs to be learned about the optimum ways in which objective and sensory measurements should be performed before valid comparisons between the two types of tests can be made.

CHAPTER III

PROCEDURE

Changes observed during tube heating of cylindrical cores of meat in a water bath were compared with changes occurring in a beef roast during oven heating. Heating at rates equivalent to two oven temperatures provided examples of both fast and slow heating rates. Two endpoint temperatures, 60 and 70°C, were studied with each heating rate.

I. SOURCE OF MEAT

Paired beef semitendinosus muscles were obtained from the Department of Food Technology and Science, The University of Tennessee, Knoxville. Muscles were from choice grade steers having carcass weights of 400-500 lb. Following excision, muscles were wrapped in freezer paper, blast frozen at -30°C, then stored in a freezer at -15°C until used.

II. HEATING

Three muscle pairs were randomly assigned to each heating rate. In an effort to minimize variations caused by differences in the meat itself, frozen muscles were divided in half across the muscle fibers. One half was designated for heating as an intact roast in an oven, and the other half was designated for core heating in a water bath system.

One muscle from each pair was assigned to an endpoint temperature of 60°C and the other to a 70°C endpoint temperature.

Oven Roasting

Each intact roast was thawed 48-72 hr in a refrigerator (4°C). Epimysial connective tissue and adhering fat were removed, and the roast was placed in a weighed roasting pan containing a metal rack. The pan was reweighed to determine raw roast weight. A copper-constantan thermocouple attached to a Honeywell temperature recorder was inserted into the geometric center of the roast, and the pan and roast were placed in an unheated electric oven equipped with an appliance meter for monitoring power consumption during heating. A second thermocouple was placed in the oven to monitor oven temperature. The oven control was adjusted to achieve the designated temperature. Heating temperatures of 93 and 149°C were used and will be referred to as slow and fast, respectively.

Each roast was removed from the oven when the thermocouple registered the desired endpoint temperature. Roasts were allowed to cool in the pans at room temperature to 26°C and then were weighed to determine evaporative loss. The roasts were removed from the pans and the pans and racks reweighed to determine drip loss. Total loss was calculated as the sum of evaporative and drip losses.

Following overnight refrigerator storage, roasts were cut across the fibers into 5.7-cm segments. Cylindrical cores, 2.5 cm in diameter, were removed for analysis. Cores were cut parallel to the muscle fibers.

Water Bath Heating

On the day of heating, the muscle half designated for core heating was cut into 5.7-cm long sections across the fibers. The meat was allowed to partially thaw to permit the removal of cores 2.5 cm in diameter cut parallel to the muscle fibers.

Each raw core was placed in a preweighed 50-ml Pyrex centrifuge tube containing two glass marbles, and the tube was reweighed to determine raw core weight. Tubes containing cores were placed randomly in a shaker water bath containing cold water (2-5°C). The water bath was "programmed" according to the procedure described by Penfield (1973). Programming consisted of adjusting the water bath temperature control every 8 min so that the heating of the cores matched the heating curve graphed from the temperature recorder charts of the heating of the intact roast from the same muscle. Core temperature was monitored by a thermocouple inserted in the center of one core while the water bath temperature was monitored by a thermocouple suspended into the water.

When the thermocouple in the core registered the desired endpoint temperature, the tubes were removed from the water bath. Tubes were cooled at room temperature to 26°C then weighed to determine evaporative loss. Cores were removed from tubes, adhering drip returned to the tubes, and the tubes reweighed to determine drip loss. Total loss was calculated as the sum of drip and evaporative losses. Cores were wrapped in foil and refrigerated overnight prior to further analysis.

III. METHODS OF EVALUATION

Raw Muscle

Epimysial connective tissue and adhering fat were removed from raw muscle tissue remaining after core removal. Samples were removed for fiber diameter measurements; then the muscle was ground once with the grinding attachment of an Oster Power Unit. The attachment had a plate with 4-mm holes. The ground material was mixed thoroughly. Samples were taken for moisture-fat analysis. Duplicate 5-g samples from each muscle were homogenized 30 sec with 50 ml distilled water for pH determinations (Rogers et al., 1967). A Corning Scientific Instruments pH Meter Model 5, standardized against a buffer solution of pH 7.0, was used for the determination.

Penetration

A 0.63-cm diameter flat-end plunger attached to an Instron, Model 1130, was driven vertically 80% of the way through a core of the cooked meat. The samples were presented so that fibers were perpendicular to the direction of plunger penetration (Bouton et al., 1971). The plunger was driven into the meat twice at each location, and two locations on each of three cores per heating treatment were evaluated. A 50-kg load cell was used with a range setting of 5 or 10, a crosshead speed of 100 mm/min, and a chart speed of 50 mm/min. The work-force penetration curve for each cycle was recorded (Figure 1).

Parameters determined included "hardness," "cohesiveness," and the secondary parameter "chewiness." "Hardness," or the force in kilograms required to achieve the first penetration, was measured as

Load cell: 50 kg

Range: 5

Crosshead speed: 100 mm/min

Chart speed: 50 mm/min

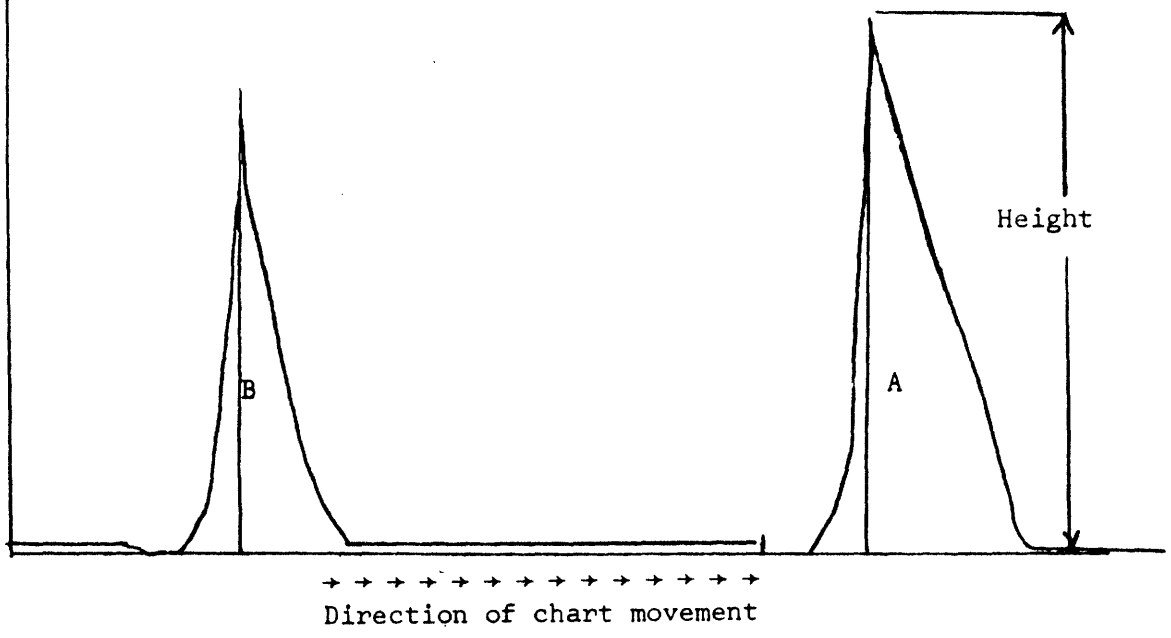

Figure 1--Typical work-force penetration curve. Parameters determined were "hardness" = height, expressed in kg; "cohesiveness" = area B/area A; "chewiness" = "hardness" X "cohesiveness."

the peak height of the curve (Bouton et al., 1971). "Cohesiveness" was defined as the ratio of the work done during the second penetration to that performed during the first. Work was determined by using a compensating polar planimeter to trace the area bounded by the baseline, the upward sweep of the curve, and the line drawn perpendicular to the baseline through the maximum point on the curve. "Chewiness" was defined as the product of "hardness" and "cohesiveness" and was expressed as kilograms of force.

Shear

Cores were sheared with a Warner-Bratzler shear attachment to the Instron. Load cell, crosshead speed, and chart speed were as described above. A range setting of 20 was used. The work-force curve for each of six shear operations per treatment was recorded. Evaluation of the curves produced the textural parameters of "firmness" and "cohesiveness" (Larmond and Petrasovits, 1972). "Firmness" was calculated as the slope of the line drawn from the curve's origin to its peak and was reported in kilograms per min. "Cohesiveness," expressed in kilograms, was measured as the peak force recorded on the curve.

Fiber Diameter

Two small sections, approximately 1 cm X 0.5 cm^2, of raw and cooked muscle from each treatment, were fixed in 10% formalin-physiological salt solution for at least 24 hr. A fiber suspension was prepared from each section according to Hearne (1976). The sections were homogenized with 15 ml distilled water in a mini cup of a Waring Blendor for 30 sec to separate intact muscle fibers. A drop of the fiber suspension was

placed in a hanging drop slide and viewed at 100X magnification. Fiber diameters were determined on 25 randomly selected fibers from each suspension with a phase contrast microscope equipped with an eyepiece micrometer.

Three cores from each treatment were reserved intact for sensory evaluation. The remaining core material was ground once in the manner described for the raw muscle. The ground meat was mixed well and apportioned for analysis.

Nonfat Dry Weight

Duplicate 3-5-g samples of ground muscle were weighed into preweighed Whatman extraction thimbles. Samples were dried in a vacuum oven at 60°C for 16 hr, weighed, and extracted with petroleum ether (b.p. 36.1-56.7°C) for 6 hr on a Goldfisch Fat Extraction Apparatus. Following extraction, samples were dried and weighed, and percent nonfat dry weight (NFDW) was calculated.

Expressible Moisture Index

Three-hundred-milligram portions of ground muscle were weighed onto three sheets of 15-cm square Whatman No. 1 filter paper. Each sheet then was placed on a piece of Plexiglass, and these were stacked with a fourth piece of Plexiglass on top. The stack was placed in a Harco-Hydraulic Press, and the pressure was increased to 2272 kg following a 5-min schedule (FSNFSA, 1976). The pressure was released, the stack removed from the press, and the meat and juice spread areas outlined in pencil. A compensating polar planimeter was used to measure the meat sample area and the meat plus juice area. Expressible moisture

index (EMI) was calculated as:

$$EMI = \frac{(\text{meat area})}{(\text{meat + juice area}) - (\text{meat area})}$$

Hydroxyproline Solubilization

Hydroxyproline solubilized during heating was determined by the method of Paul et al. (1973) as modified by Penfield and Meyer (1975). The term hydroxyproline solubilized rather than collagen solubilized is used since hydroxyproline values were not corrected for elastin content.

Water extracts of muscle tissue were prepared by homogenizing 10 g muscle tissue with 50 ml distilled water (40°C) in a Waring Blendor for 2 min. The homogenate was centrifuged at 4600 X G for 15 min. The supernatant was decanted through a single layer of cheesecloth and the volume recorded.

Five grams of meat or 5 ml of the water extract were placed in culture tubes having screw caps. Each sample was adjusted to 6 N by the addition of hydrochloric acid (10 ml 6 N HCl added to meat and 5 ml 12 N HCl to extract). The samples were hydrolyzed in an autoclave at 121-122°C for 16-17 hr. Following hydrolysis, decolorization was accomplished by adding a small amount of activated charcoal to the tubes, shaking 20 min on a mechanical shaker, and filtering through Whatman No. 42 filter paper into a volumetric container of appropriate size (250 ml for meat samples and 100 ml for extracts). The filtrate was neutralized with concentrated sodium hydroxide and brought to volume. Methyl red was used as an indicator.

Preliminary work revealed that hydrolysates from meat samples were too concentrated for accurate hydroxyproline analysis; therefore, 10 ml of the hydrolysate were diluted with distilled water to 100 ml. Aliquots for analysis were prepared by pipetting 0.5 ml diluted hydrolysate and 1.5 ml distilled water into test tubes.

The water extract hydrolysates were determined to be too dilute for the test procedure. These were concentrated by freeze-drying 20 ml of the hydrolysate and redissolving the resultant powder with 10 ml distilled water. Two milliliter portions of this concentrated hydrolysate were used for analysis.

Hydroxyproline analysis was performed using Method II described by Woessner (1961). This method is outlined in Appendix A. Percent hydroxyproline solubilized was calculated as:

$$\% \text{ hydroxyproline solubilized} = \frac{\text{hydroxyproline in water extract}}{\text{hydroxyproline in meat sample}} \times 100$$

Color

Color was measured with an IDL Color Eye, Model D-1. Five grams of the ground muscle were pressed into a 3.4-cm diameter sample holder, covered with glass (2.5 mm thick) and placed in the sample port of the instrument. X, Y, Z, and X' were determined. A daylight "C" white tile was used as a reference. These values were converted to L, x, and y values with a program for the Olivetti Programma 101 Calculator. The x and y values were used with a CIE System Chromaticity Diagram to determine the dominant wavelength of each sample.

Sensory Evaluation

Color, flavor, and texture of samples from intact roasts and cores were evaluated by a sensory panel. The panel consisted of graduate student volunteers from the Department of Food Science, Nutrition, and Food Systems Administration.

Panel orientation consisted of two sessions. In the first, panel members were given a copy of a proposed ballot format and asked to select parameters that they felt should be evaluated in order to give a complete sensory picture of the meat samples. They were told that each parameter would be evaluated on a 9-point scale anchored at each end with terms they selected to best represent opposite extremes of the parameter being evaluated. To aid panelists in the selection of the parameters, they were provided with samples of meat and a list of 25 terms compiled from literature reports of sensory evaluation of meat (Cover et al., 1962a; Harries et al., 1963; Sharrah et al., 1965; Harries et al., 1972; Civille and Liska, 1975; Randall and Larmond, 1977). The panelists selected 9 parameters and bipolar terms for each parameter. Guidelines also were established for each parameter's evaluation. Parameters selected were appearance (apparent doneness), visual moisture, softness to tooth pressure, moisture release, stringiness, chewiness, mealiness, flavor, and overall rating. The panelists felt that in addition to the bipolar terms of strong and very good the parameter flavor also needed a middle term of natural.

In the second session, panelists were presented with meat samples and asked to evaluate them using the ballot compiled during the first session. After sample evaluation, the adequacy of the ballot was

discussed. Suggested changes were incorporated into the final ballot (Appendix A).

Tape recordings of the previously described sessions were used to orient replacements for panelists who were forced to withdraw from panel participation prior to the beginning of actual testing.

In the testing sessions, panelists were presented with cylindrical samples 2.5 cm in diameter X 2 cm in length. Samples were presented singly, and one or two samples were evaluated per session. Responses of all panelists were averaged to give a single set of sensory scores for each sample.

Statistical Analysis

A factorial experimental design with three replications was used. Analysis of variance was performed with the SAS 76 computer program (Barr et al., 1976) to study the effects of the independent variables, heating system and endpoint temperature, and their interactions. All dependent variables were evaluated in this manner. When preliminary analysis of data showed no significant differences in a factor due to interactions of main effects, the interactions were pooled into the error term for final analysis. In such cases, interaction means are included in Appendix B, Table 16. Mean separation was accomplished with the Student-Newman-Keuls test (Sokal and Rohlf, 1969). Because of differences inherent in meat from different animals, heating rates were compared with a t-test and assuming unequal variances. Correlation coefficients were used to determine relationships among sensory parameters and between sensory parameters and related objective tests.

Summaries of analysis of variance and t-tests are presented in Appendix B (Tables 17 and 18).

CHAPTER IV

RESULTS AND DISCUSSION

I. HEATING OF MEAT

Characteristics of oven-heated beef roasts were compared with those of cylindrical cores from the same muscle heated in glass tubes in a water bath. Two endpoint temperatures, 60 and 70°C, were studied. Samples were heated at rates equivalent to oven roasting at 93 and 149°C. These are referred to as slow and fast rates, respectively.

Heating Times and Power Consumption

Mean heating times for oven roasting are shown in Table 1. When the meat was heated at the fast rate, approximately one-third more time was required to reach 70°C than was needed to reach 60°C. This difference was not significant. Slow heating of roasts required almost twice as long to reach 70°C as was required to reach 60°C ($P < 0.01$).

Heating times required to reach both endpoint temperatures were longer with the lower oven temperature than with the higher one. This corresponds with the work of Bengtsson et al. (1976) who reported that higher oven temperatures resulted in steeper temperature gradients and thus shorter heating periods than those at lower oven temperatures.

Power consumption required with the lower oven temperature-longer heating period of the slow heating rate was similar to that obtained with the higher oven temperature-shorter heating time of the fast rate. With both heating rates, more power was needed to reach the

Table 1--Mean heating times and power consumption for oven roasting of beef semitendinosus muscles to two endpoint temperatures at two rates[a]

Endpoint temperature (°C)	Heating time[b] (min/kg)	Power consumption (kwh/kg)
Fast heating rate		
60	131.2 ± 5.9	1.3 ± 0.2
70	173.0 ± 26.4	2.0 ± 0.3
Slow heating rate		
60	353.9a ± 6.4	1.4 ± 0.2
70	695.5b ± 28.8	2.0 ± 0.3

[a]Means and standard errors of three replications

[b]Means within a heating rate followed by different letters are significantly different ($P < 0.01$).

70°C endpoint than was needed to reach the 60°C endpoint; however, no statistical differences were found in power consumption values.

Cooking Losses

Analysis of variance showed that in roasts heated at the fast rate total and evaporative losses were not affected by endpoint temperature (Table 2). Heating to 70°C resulted in greater ($P < 0.05$) drip loss than heating to 60°C. Hamm (1966) explained that the coagulation of myofibrillar proteins by heat-denaturation and the subsequent decrease in water-holding capacity occurs primarily between 40 and 50°C. At 60°C coagulation and juice release are not complete and continue to a small extent with increasing temperature.

With the fast heating rate, drip and evaporative losses were both affected by heating system (Table 2). Oven roasting resulted in greater ($P < 0.001$) evaporative losses and lower ($P < 0.001$) drip losses than water bath heating. These results were probably due to the fact that in oven roasting the meat and the cooking pan were exposed to the hot air of the oven allowing losses to be dissipated as evaporation. In water bath heating the samples are enclosed. Therefore, most losses remain in the tube and are measured as drip.

Analysis of variance of loss data from slowly heated meat (Table 2) showed total, drip, and evaporative losses were affected by both endpoint temperature (total, $P < 0.001$; evaporative, $P < 0.05$; drip, $P < 0.01$) and heating system (total and drip, $P < 0.001$; evaporative, $P < 0.01$). At this rate of heating, drip ($P < 0.01$) and evaporative ($P < 0.05$) losses also were influenced by the endpoint

Table 2--Cooking losses of beef semitendinosus muscles heated as intact roasts in an oven and as cores in a water bath to two endpoint temperatures at two rates[a,b]

Source of variation	Loss (%)		
	Total	Evaporative	Drip
Fast heating rate			
Heating system			
Oven	20.05	18.08x	1.97x
Water bath	24.02	0.26y	23.76y
Endpoint temperature (°C)			
60	19.49	9.15	10.35a
70	24.58	9.19	15.39b
Slow heating rate			
Heating system			
Oven	22.87x	21.55p	1.32x
Water bath	33.14y	0.66q	32.47y
Endpoint temperature (°C)			
60	22.10x	8.00a	14.10p
70	33.91y	14.22b	19.69q
System X endpoint			
Oven 60	16.73	15.72a	1.01p
70	29.01	27.38b	1.63p
Water bath 60	27.47	0.27c	27.18q
70	38.80	1.05c	37.75r
Heating rate			
Fast	22.03a	12.87	9.17
Slow	28.00b	16.89	11.11

[a]Means of three replications

[b]Means in the same column within a variation grouping followed by different letters are different at $P < 0.05$ (a through c); $P < 0.01$ (p through r); or $P < 0.001$ (x and y).

temperature-heating system interaction (Table 2). Mean total loss values in Table 2 show that the effects of both endpoint temperature and heating system were greater with the slow heating rate than with the fast one. The patterns of greater drip and less evaporation with the water bath system and greater evaporation and less drip with oven roasting observed in the samples heated at the fast rate were observed also with the slow heating rate.

Mean total cooking losses of slowly heated samples were greater ($P < 0.05$) than those for the samples heated at the fast rate (Table 2). Mean drip and evaporative losses were similar for the two heating rates.

Hearne et al. (1978a) heated meat cores in a water bath at rates comparable to those in the present study and reported total cooking losses of 29.3 and 41.3% for endpoint temperatures of 60 and 70°C, respectively, for slow heating and 26.8 and 33.2% for the same endpoint temperatures for the fast heating rate. Somewhat lower losses were observed in the present study (Table 2). These differences in cooking losses might be due to variation in muscle pH. Hearne et al. (1978a) reported a mean muscle pH of 5.41 (5.25 to 5.48). Mean muscle pH in the current work was 5.69 (5.50 to 5.82). Higher muscle pH tends to increase the water-holding capacity of meat and thus results in lower cooking losses (Paul, 1972).

II. MUSCLE EVALUATION

Nonfat Dry Weight and Expressible Moisture Index

Increasing the endpoint temperature of samples heated at the fast rate from 60 to 70°C did not change the nonfat dry weight (NFDW), but in

the slowly heated samples increasing the endpoint temperature from 60 to 70°C resulted in an increase ($P < 0.001$) in NFDW of the cooked samples (Table 3). Hamm (1966) suggested that the increase in NFDW associated with an increase in the endpoint temperature can be related to decreased water-holding capacity of the meat due to greater heat-denaturation of the myofibrillar proteins.

Mean NFDW of roasts heated at the fast rate was similar to that of water bath samples heated at the same rate (Table 3). However, NFDW of the slowly heated water bath samples was greater ($P < 0.01$) than that of the oven-roasted meat.

Samples heated at the fast rate had lower ($P < 0.05$) NFDW than samples heated at the slow rate (Table 3). These results are consistent with those reported by Laakkonen (1973).

The expressible moisture indices (EMI) of samples heated at the fast rate were not significantly altered by endpoint temperature or heating system. Although not significant, there was a general trend for oven roasting to result in lower EMI than water bath heating (Table 3).

Slowly heated samples had no significant differences in EMI due to endpoint temperature or heating system (Table 3). The trend toward higher EMI in water bath samples than in oven roasted samples observed in meat heated at the fast rate also was observed in meat heated at the slow rate (Table 3).

Differences in EMI due to heating rate approached significance at the $P < 0.05$ level (Table 3). Meat heated at the slow rate had higher EMI than meat heated at the fast rate.

Table 3--Percent nonfat dry weight, expressible moisture index, and fiber diameters of beef semitendinosus muscles heated as intact roasts in an oven and as cores in a water bath to two endpoint temperatures at two rates[a,b]

Source of variation	Nonfat dry weight (%)	Expressible moisture index	Fiber diameter (μm)
Fast heating rate			
Heating system			
Oven	27.44	0.236	48.5
Water bath	27.58	0.271	48.7
Endpoint temperature (°C)			
60	26.69	0.247	48.8
70	28.33	0.259	48.4
Slow heating rate			
Heating system			
Oven	28.80p	0.276	47.4
Water bath	30.28q	0.284	46.6
Endpoint temperature (°C)			
60	27.45x	0.267	48.6
70	31.62y	0.293	45.4
Heating rate			
Fast	27.51a	0.253	48.6
Slow	29.53b	0.280	46.6

[a]Means of three replications

[b]Means in the same column within a variation grouping followed by different letters are different at $P < 0.05$ (a,b); $P < 0.01$ (p,q); or $P < 0.001$ (x,y).

Although meat in both systems was heated to the same endpoint temperature, the greater difference in the water-holding capacity of water bath samples suggested that they received a more severe heat treatment. Heating system effects on water loss can be related to the physical differences of samples heated by the two systems. In oven roasting there was a relatively small surface area to sample mass ratio while the cores had a large area to mass ratio. This difference would be expected to contribute to greater moisture loss and subsequently higher cooking losses, nonfat dry weights, and EMI for the water bath samples.

Fiber Diameter

Muscle fiber diameters of the samples were not affected by endpoint temperature, heating system, or heating rate (Table 3). These findings are consistent with those of Hearne et al. (1978a) who reported that muscle fiber diameters of samples heated in a water bath decreased when endpoint temperature increased from 40 to 50 to 60°C but were virtually unaffected by heating from 60 to 70°C. Hearne et al. also reported no significant difference in fiber diameter measurements due to heating rate.

Penetration

In meat heated at the fast rate, neither endpoint temperature nor heating system had a significant effect on hardness, defined as the force required to achieve the first penetration (Table 4). In meat heated at the slow rate, however, hardness was affected ($P < 0.05$) by endpoint temperature in oven-roasted samples. Meat heated to 70°C had

Table 4--Penetration parameters of beef semitendinosus muscles heated as intact roasts in an oven and as cores in a water bath to two endpoint temperatures at two rates[a,b]

Source of variation	Hardness[c] (kg)	Cohesiveness[d]	Chewiness[e] (kg)
Fast heating rate			
Heating system			
Oven	3.271	0.538	1.698
Water bath	2.960	0.528	1.395
Endpoint temperature (°C)			
60	2.937	0.518	1.467p
70	3.294	0.549	1.626q
Slow heating rate			
Heating system			
Oven	2.647	0.540	1.276
Water bath	2.709	0.476	1.329
Endpoint temperature (°C)			
60	2.260a	0.581a	1.276
70	3.097b	0.435b	1.329
System X endpoint			
Oven 60	1.889a	0.700a	1.253
70	3.405b	0.379b	1.299
Water bath 60	2.630c	0.462b	1.299
70	2.788c	0.490b	1.358
Heating rate			
Fast	3.115	0.533	1.621x
Slow	2.678	0.508	1.276y

[a]Means of three replications

[b]Means in the same column within a variation grouping followed by a different letter are different at $P < 0.05$ (a through c); $P < 0.01$ (p,q); or $P < 0.001$ (x,y).

[c]Hardness defined as the force in kilograms required to achieve the first penetration.

[d]Cohesiveness defined as the ratio of the work done during the second penetration in a location to that done during the first.

[e]Chewiness defined as the product of hardness and cohesiveness.

higher hardness values and thus offered more resistance to penetration than samples heated to 60°C.

Paul et al. (1973) reported that increasing the endpoint temperature of semitendinosus cores heated in a water bath from 58 to 67°C increased the resistance of the meat to penetration.

Cohesiveness, defined as the work to produce the second penetration divided by the work to produce the first penetration, was not affected by endpoint temperature or heating system in meat heated at the fast rate. In slowly heated meat, there was an endpoint temperature-heating system interaction ($P < 0.05$) with respect to cohesiveness. In meat heated at the slow rate, cohesiveness of oven-roasted samples decreased with increased endpoint temperature, but cohesiveness was unaffected by endpoint temperature in meat heated in a water bath. Heating rate did not significantly affect cohesiveness.

Chewiness, which was determined as the product of hardness and cohesiveness, was altered ($P < 0.01$) by endpoint temperature but was not affected by heating system when samples were heated at the fast rate (Table 4). In meat heated at the slow rate, neither endpoint temperature nor heating system had an effect on chewiness. Chewiness was lower ($P < 0.001$) in samples heated at the slow rate than in samples heated at the fast rate.

Shear

Regardless of heating rate, neither endpoint temperature nor heating system had an effect on cohesiveness, measured as the maximum height of the shear force-deformation curves. Values presented in

Table 5 show that with both heating rates there was a slight but nonsignificant increase in cohesiveness with increasing endpoint temperature. Since cohesiveness was defined as the maximum height of the shear force-deformation curves (Larmond and Petrasovits, 1972), these findings are consistent with shear values reported by Laakkonen et al. (1970), Penfield and Meyer (1975), and Hearne et al. (1978a).

Firmness, defined as the slope of a line between the origin and the peak of the shear force-deformation curve, was not affected by endpoint temperature or heating system when meat was heated at the fast rate. Treatment means from this heating rate (Table 5), however, reveal a trend toward increased firmness with increasing endpoint temperature. With slowly heated samples firmness increased ($P < 0.05$) with increased endpoint temperature (Table 5). The firmness measurement was defined by Larmond and Petrasovits (1972) as an index of the force to produce deformation. Thus, increased endpoint temperature resulted in samples with greater resistance to deformation.

Mean shear values from the heating rates showed that, while the mean for cohesiveness was slightly greater for the fast heating rate than for the slow one (Table 5), this difference was not statistically significant. Firmness values, however, were higher ($P < 0.01$) with fast heating than with slow.

Hydroxyproline Solubilization

Hydroxyproline solubilization was not affected by endpoint temperature at either heating rate (Table 6). This is in contrast to the findings of Paul et al. (1973) and Penfield and Meyer (1975) who

Table 5--Shear parameters of beef semitendinosus muscles heated as intact roasts in an oven and as cores in a water bath to two endpoint temperatures at two rates[a,b]

Source of variation	Cohesiveness[c] (kg)	Firmness[d] (kg/min)
Fast heating rate		
Heating system		
Oven	7.42	75.81
Water bath	7.16	73.16
Endpoint temperature (°C)		
60	7.14	70.11
70	7.44	78.86
Slow heating rate		
Heating system		
Oven	7.35	71.80
Water bath	6.57	62.71
Endpoint temperature (°C)		
60	6.79	60.74a
70	7.13	73.76b
Heating rate		
Fast	7.30	75.33p
Slow	6.86	65.61q

[a]Means of three replications

[b]Means in the same column within a variation grouping followed by a different letter are different at $P < 0.05$ (a,b) or $P < 0.01$ (p,q).

[c]Cohesiveness defined as the maximum peak height of the force-deformation curve obtained during the shearing operation.

[d]Firmness defined as the slope of a line between the origin and the peak of the force-deformation curve from the shearing operation.

Table 6--Hydroxyproline solubilized during heating of beef semitendinosus muscles as intact roasts in an oven and as cores in a water bath to two endpoint temperatures at two rates[a,b]

Source of variation	Hydroxyproline solubilized (%)[c]
Fast heating rate	
Heating system	
Oven	5.65
Water bath	5.09
Endpoint temperature (°C)	
60	5.80
70	4.94
Slow heating rate	
Heating system	
Oven	6.71a
Water bath	9.16b
Endpoint temperature (°C)	
60	7.19
70	8.69
Heating rate	
Fast	5.37p
Slow	7.94q

[a]Means of three replications

[b]Means in the same column within a variation grouping followed by a different letter are different at $P < 0.05$ (a,b) or $P < 0.01$ (p,q).

[c]% hydroxyproline solubilized =

$$\frac{\text{hydroxyproline in water extract}}{\text{hydroxyproline in meat sample}} \times 100$$

reported increased hydroxyproline solubilization with increased endpoint temperature.

In meat heated at the fast rate, hydroxyproline solubilization was not affected by heating system. In slowly heated samples hydroxyproline solubilization was greater ($P < 0.05$) in water bath samples than in oven-roasted ones. Since hydroxyproline solubilization has been shown to increase with increased heat application (Paul et al., 1973; Penfield and Meyer, 1975), this increased solubilization suggests that, in slowly heated samples, water bath heating resulted in a more severe heat treatment than oven roasting.

Hydroxyproline solubilization was greater ($P < 0.01$) in samples heated at the slow rate than in samples heated at the fast rate (Table 6). These findings are in agreement with those of Penfield and Meyer (1975).

Color

Means in Table 7 reveal that as the endpoint temperature increased from 60 to 70°C, the dominant wavelength of samples heated at both rates decreased (fast, $P < 0.05$; slow, $P < 0.001$). This decrease was manifested in a shift away from the red section on the C.I.E. Chromaticity diagram and is suggested to be the result of myoglobin denaturation, reported by Hamm (1966) to take place at about 65°C.

Slowly heated water bath samples had lower ($P < 0.001$) dominant wavelengths (Table 7) and, therefore, were less red than oven-roasted samples heated to the same endpoint temperature. It is of interest to note that the mean dominant wavelength for water bath samples heated at the slow rate to 60°C was similar to that for oven-roasted samples

Table 7--Dominant wavelength and L-values of beef semitendinosus muscles heated as intact roasts in an oven and as cores in a water bath to two endpoint temperatures at two rates[a,b]

Source of variation	Dominant wavelength (nm)	L-value
Fast heating rate		
Heating system		
Oven	588.52	58.1
Water bath	587.29	58.6
Endpoint temperature (°C)		
60	589.33a	56.6a
70	586.48b	60.1b
Slow heating rate		
Heating system		
Oven	591.35x	58.5
Water bath	584.77y	60.5
Endpoint temperature (°C)		
60	591.12x	55.9x
70	585.00y	63.2y
Heating rate		
Fast	587.90	58.4
Slow	588.06	59.5

[a]Means of three replications

[b]Means in the same column within a variation grouping with different letters are different at $P < 0.05$ (a,b) or $P < 0.001$ (x,y).

heated at the same rate to 70°C. This suggests that myoglobin denaturation was similar with these two treatments.

With both heating rates, L-values were increased (fast, $P < 0.05$; slow, $P < 0.001$) by increasing endpoint temperature (Table 7). Heating rate means showed no significant differences in either dominant wavelength or L-values (Table 7).

Sensory Evaluation

Panel evaluation of sensory parameters was not greatly influenced by heating system effects. Discussions of these effects, when not significant, have been omitted.

Appearance. The sensory panel judged the appearance of the samples on a scale of 9 = well done to 1 = rare. Appearance scores were influenced by both endpoint temperature ($P < 0.001$) and heating system ($P < 0.01$) in meat heated at the fast rate (Table 8). Samples heated to the 60°C endpoint temperature were scored lower, that is judged less done, than samples heated to 70°C. Samples heated in the water bath system were assigned higher appearance scores, and thus judged more done, than samples heated to the same endpoint temperature in the oven system. Since the primary basis for the panel's assessment of appearance was sample color, these data suggest that greater myoglobin denaturation had occurred in the 70°C samples than in the 60°C samples and that more had occurred in the core-heated samples than in the intact roasts.

In meat heated at the slow rate, both endpoint temperature ($P < 0.001$) and heating system ($P < 0.001$) affected appearance scores (Table 8). The effects of these variables were similar to the effects

Table 8--Mean sensory panel scores of beef semitendinosus muscles heated as intact roasts in an oven and as cores in a water bath to two endpoint temperatures at two rates[a,b]

Source of	Appearance[c]	Visual moisture[c]	Softness to tooth pressure	Moisture release[c]	Stringiness[c]	Chewiness[c]	Mealiness[c]	Flavor[c]	Overall[c]
Fast heating rate									
Heating system									
Oven	3.87p	7.13x	4.80	6.31a	2.30	3.90	3.08	5.14	3.87
Water bath	5.80q	4.91y	4.91	4.89b	2.96	4.38	3.52	5.10	4.32
Endpoint temperature (°C)									
60	3.43x	7.52x	4.43	6.81p	2.60	3.57a	2.37p	5.14	3.59a
70	6.24y	4.52y	5.28	4.39q	2.67	4.71b	4.22q	5.10	4.60b
System X endpoint									
Oven 60	2.30	8.18p	4.55	7.07a	2.12	3.20	2.26	5.28	3.70
70	5.44	6.08q	5.04	5.55b	2.48	4.59	3.89	5.00	4.04
Water bath 60	4.55	6.85r	4.30	6.55c	3.07	3.93	2.48	5.00	3.48
70	7.04	2.96s	5.52	3.22d	2.85	4.82	4.55	5.19	5.15
Slow heating rate									
Heating system									
Oven	4.72x	5.21p	4.45	4.71p	2.67	4.16	3.95	4.60	4.46p
Water bath	6.87y	2.97q	5.06	2.80q	2.71	4.60	4.24	4.41	5.52q
Endpoint temperature (°C)									
60	4.19x	5.75x	4.45	5.06x	3.24a	3.89	2.58x	4.89	4.37p
70	7.41y	2.43y	5.06	2.45y	2.13b	4.87	5.61y	4.11	5.61q
System X endpoint									
Oven 60	2.70	7.36a	3.67	6.30	3.00	3.40	2.45	5.15	3.66
70	6.74	3.11b	5.22	3.11	2.33	4.92	5.44	4.04	5.26
Water bath 60	5.67	4.19c	5.22	3.81	3.48	4.37	2.70	4.63	5.07
70	8.07	1.79d	4.89	1.78	1.93	4.82	5.78	4.18	5.96
Heating rate									
Fast	4.85	6.02a	4.85	5.60a	2.63	4.13	3.30	5.12a	4.09a
Slow	5.80	4.08b	4.75	3.75b	2.69	4.38	4.09	4.50b	4.99b

[a]Means of three replications

[b]Scales: Appearance (9 = well done to 1 = rare); Visual moisture (9 = juicy to 1 = dry); Softness to tooth pressure (9 = very hard to 1 = very soft); Moisture release (9 = great to 1 = slight); Stringiness (9 = very stringy to 1 = none); Chewiness (9 = highly resistant to 1 = yields readily); Mealiness (9 = very mealy to 1 = none); Flavor (9 = strong to 5 = natural to 1 = very good); Overall (9 = very poor to 1 = very good)

[c]Means in the same column within a variation grouping followed by a different letter are different at $P < 0.05$ (a through d); $P < 0.01$ (p through s); or $P < 0.001$ (x,y).

observed with meat heated at the fast rate (Table 8).

There were no differences in appearance scores due to heating rate (Table 8).

Visual moisture. Moisture of the samples was rated visually by panelists prior to tasting. Samples were scored on a scale of 9 = juicy to 1 = dry. Scores of samples heated at both rates were related to endpoint temperature, heating system, and the interaction of these two variables (Table 8). With both heating rates, samples heated to 70°C in a water bath were drier ($P < 0.01$) than oven-roasted samples heated to 70°C or samples heated to 60°C in either system. Since heating to 70°C results in greater loss of water-holding capacity, and thus more moisture loss, than heating to 60°C (Hamm, 1966), the 70°C samples would be expected to appear drier than the 60°C ones.

Samples heated at the fast rate were judged more moist ($P < 0.05$) than samples heated at the slow rate (Table 8).

Softness to tooth pressure. Softness to tooth pressure was evaluated as the amount of muscular force needed to bite into a sample across the muscle fibers. No differences were found in this parameter due to endpoint temperature, heating system, or heating rate (Table 8).

Moisture release. Samples were rated on the amount of moisture released after two or three chews. The scale for this evaluation was 9 = great (moisture release) to 1 = slight. Moisture release of samples heated at the fast rate was found to be affected by endpoint temperature ($P < 0.01$), heating system ($P < 0.05$), and their interaction ($P < 0.05$).

Samples heated to 60°C were found to release more moisture than samples heated to 70°C, and oven-roasted samples were more moist than water bath samples. Water bath heating amplified the drying effect of increasing endpoint temperature (Table 8). Differences in the moisture release of samples can be related to the same factors which caused similar differences in the visual moisture parameter.

With slowly heated samples, moisture release was greater ($P < 0.001$) in samples heated to 60°C than in samples heated to 70°C and lower ($P < 0.01$) in water bath samples than in oven-roasted ones (Table 8).

Samples heated at the fast rate released more ($P < 0.05$) moisture than samples heated at the slow rate (Table 8). Juiciness has been defined as the moisture squeezed out of meat by a few gentle chews (Ritchey and Hostetler, 1964); therefore, moisture release scores can be related to juiciness of the samples. Griswold (1955) and Bramblett and Vail (1964) also reported that slower heating resulted in less juicy meat. However, Bayne et al. (1969) found no differences in juiciness due to heating rate.

Stringiness. The panel detected no differences in the amount of stringy material encountered during chewing in samples heated at the fast rate (Table 8). Samples heated to 70°C at the slow rate were judged less stringy ($P < 0.05$) than samples heated to 60°C (Table 8). Hearne et al. (1978b) reported greater coagulation of myofibrillar proteins with slow heating than with fast heating and greater fiber disintegration at 70°C than at 60°C. It is possible that these two effects combine to produce a sensation of greater stringiness in the

samples heated to the 60°C endpoint at the slow rate.

Chewiness. The amount of work required to prepare a sample for swallowing was not found to be affected by endpoint temperature in samples heated at the slow rate or by heating system at either heating rate (Table 8). In samples heated at the fast rate, 60°C samples were judged to yield more readily ($P < 0.05$) to chewing than samples heated to 70°C (Table 8).

Mealiness. Mealiness was defined as the presence of tiny, dry, and hard fragments remaining in the mouth after swallowing (Cover et al., 1962a) and was scored on a scale of 9 = very mealy to 1 = none. With both heating rates, heating to an endpoint temperature of 70°C resulted in more mealiness (fast, $P < 0.01$; slow, $P < 0.001$) than heating to a 60°C endpoint temperature (Table 8). Cover et al. (1962c) proposed that mealiness was not present at endpoint temperatures of 60°C or below because any particles present were moist, not dry, and did not cling to the mouth after chewing.

Flavor. Flavor scores were unaffected by endpoint temperature or heating system (Table 8). However, the 5.1 mean flavor score for meat heated at the fast rate was significantly different ($P < 0.05$) from the 4.5 mean score for samples heated at the slow rate (Table 8). Because the flavor scale was anchored at 9 = strong, 5 = natural, and 1 = very good, mean rate scores suggest that both heating rates resulted in meat with acceptable flavor.

Overall. The panelists rated their general impression of a sample's quality on a scale of 9 = very poor to 1 = very good. With both heating rates, samples heated to the 70°C endpoint temperature were given higher scores (fast, $P < 0.05$; slow, $P < 0.01$), that is, judged of lower quality, than samples heated to 60°C (Table 8). With slow heating water bath samples were judged lower ($P < 0.01$) in quality than oven-roasted samples. Since rating of this parameter was dependent on the individual panelist's idea of meat quality, it is difficult to assess the reason for differences in this rating; however, comments by panelists suggested that moisture characteristics had a primary influence on rating of the samples.

III. RELATIONSHIPS AMONG VARIOUS TEST PARAMETERS

Tables 9, 10, and 11 list the correlation coefficients between sensory parameters for oven-roasted samples, water bath samples, and all samples, irrespective of heating system. Comparisons among these correlations show that there was a better relationship among sensory parameters in samples heated as roasts in an oven than among samples heated as cores in a water bath, and the relationships in the two-system sample closely resembled those of the oven-roasted samples. These results suggest that, in studies with the purpose of identifying relationships between sensory characteristics, the use of samples heated in an oven system or of a combined sample would be more appropriate than the use of samples heated in a water bath.

Sensory panel evaluations of softness to tooth pressure and stringiness were not well correlated with most of the other sensory

Table 9--Correlation coefficients among sensory parameters for beef semitendinosus muscles heated as intact roasts in an oven[a]

	Appearance	Visual moisture	Softness to tooth pressure	Moisture release	Stringiness	Chewiness	Mealiness	Flavor	Overall
Overall	0.643*	-0.866***	0.542	-0.810**	0.030	0.721**	0.856***	-0.727**	1.000
Flavor	-0.614*	0.823**	-0.477	0.720**	0.023	-0.656*	-0.678*	1.000	
Mealiness	0.890***	-0.916***	0.567	-0.922***	-0.112	0.731**	1.000		
Chewiness	0.630*	-0.695*	0.785**	-0.679*	0.437	1.000			
Stringiness	-0.224	0.083	0.138	0.041	1.000				
Moisture release	-0.837***	0.927***	-0.424	1.000					
Softness to tooth pressure	0.520	-0.527	1.000						
Visual moisture	-0.858***	1.000							
Appearance	1.000								

[a] $n = 12$

*$P < 0.05$

**$P < 0.01$

***$P < 0.001$

Table 10--Correlation coefficients among sensory parameters for beef semitendinosus muscles heated as cores in a water bath[a]

	Appearance	Visual moisture	Softness to tooth pressure	Moisture release	Stringiness	Chewiness	Mealiness	Flavor	Overall
Overall	0.821**	-0.733**	0.679*	-0.785**	-0.326	0.777**	0.789**	-0.428	1.000
Flavor	-0.295	0.298	-0.028	0.360	0.324	-0.151	-0.312	1.000	
Mealiness	0.869***	-0.692*	0.372	-0.712**	-0.691*	0.645*	1.000		
Chewiness	0.563	-0.270	0.900***	-0.290	-0.036	1.000			
Stringiness	-0.586	0.478	0.249	0.511	1.000				
Moisture release	-0.853***	0.966***	-0.191	1.000					
Softness to tooth pressure	0.391	-0.194	1.000						
Visual moisture	-0.894***	1.000							
Appearance	1.000								

[a] n = 12

*P < 0.05

**P < 0.01

***P < 0.001

Table 11--Correlation coefficients among sensory parameters for beef semitendinosus muscles--two-system sample[a]

	Appearance	Visual moisture	Softness to tooth pressure	Moisture release	Stringiness	Chewiness	Mealiness	Flavor	Overall
Overall	0.745***	-0.812***	0.647***	-0.824***	-0.075	0.748***	0.792	-0.535	1.000
Flavor	-0.453*	0.531	-0.224	0.510*	0.153	-0.429*	-0.490*	1.000	
Mealiness	0.797***	-0.749***	0.457*	-0.769***	-0.389	0.688***	1.000		
Chewiness	0.625**	-0.567**	0.831***	-0.534**	0.248	1.000			
Stringiness	-0.188	0.124	0.242	0.155	1.000				
Moisture release	-0.860***	0.956***	-0.328	1.000					
Softness to tooth pressure	0.459*	-0.370	1.000						
Visual moisture	-0.896***	1.000							
Appearance	1.000								

[a] n = 24

*P < 0.05

**P < 0.01

***P < 0.001

parameters. Since softness to tooth pressure and chewiness represented different approaches to assessing sample tenderness, the correlation between these two parameters observed within the combined sample and each heating system would be anticipated.

The basis for panel evaluation of overall sample quality was left to the discretion of the individual panelists. The high correlation between this parameter and the other sensory parameters suggests that the panelists based their rating for this parameter on their evaluation of several of the other sensory parameters.

Comparisons between sensory scores and objective measurements for oven roasting (Table 12), water bath heating (Table 13), and a combined sample (Table 14) suggest that the sensory parameters were most closely related to objective evaluations of moisture and color. Objective tests of tenderness--penetration and shear--did not correlate with sensory parameters of meat heated in a water bath. However, in oven-roasted samples, there were a number of correlations between the parameters of the objective tests and the sensory parameters. This suggests that changes in tenderness characteristics of samples were of a different nature in water bath samples than in oven-roasted ones.

Correlation coefficients between the objective tests of penetration and shear (Table 15), both measures of sample tenderness, indicate that in meat heated in a water bath all parameters were related except shear cohesiveness and penetration hardness. With oven roasting, shear cohesiveness was related only to the penetration parameter chewiness.

Table 12--Correlation coefficients between sensory parameters and objective measurements of beef semitendinosus muscles heated as intact roasts in an oven[a]

	Appearance	Visual moisture	Softness to tooth pressure	Moisture release	Stringiness	Chewiness	Mealiness	Flavor	Overall
Total cooking loss[a]	0.753**	-0.816**	0.520	-0.749**	-0.153	0.604*	0.797**	-0.774**	0.797**
Nonfat dry weight[a]	0.566	-0.820**	0.345	-0.825**	-0.173	0.486	0.752**	-0.682*	0.852***
EMI[a]	0.155	-0.389	0.214	-0.467	0.463	0.403	0.300	-0.448	0.362
Fiber diameter[a]	0.066	-0.092	0.159	-0.024	-0.190	0.089	0.225	-0.207	0.070
Penetration									
Hardness[a]	0.408	-0.395	0.626*	0.254	-0.287	0.243	0.512	-0.400	0.452
Cohesiveness[a]	-0.469	0.600*	-0.610*	0.422	0.343	-0.365	-0.577*	0.574	-0.625*
Chewiness[a]	0.107	0.120	0.347	0.193	-0.110	0.280	0.094	0.042	-0.010
Shear									
Cohesiveness[b]	0.532	-0.511	0.837**	-0.498	0.196	0.813**	0.702*	-0.357	0.701
Firmness[c]	0.779*	-0.560	0.797**	-0.515	-0.451	0.710*	0.748*	-0.478	0.522
Hydroxyproline solubilization[a]	0.441	-0.466	-0.127	-0.512	-0.278	-0.004	0.433	-0.338	0.275
Dominant wavelength[a]	-0.597*	0.365	-0.371	0.391	0.470	-0.250	0.499	0.158	-0.369
L-value[a]	0.689*	-0.728**	0.459	-0.766**	-0.197	0.635*	0.782**	-0.588*	0.838***

[a] $n = 12$ [b] $n = 10$ [c] $n = 9$

*$P < 0.05$

**$P < 0.01$

***$P < 0.001$

Table 13--Correlation coefficients between sensory parameters and objective measurements of beef semitendinosus muscles heated as cores in a water bath[a]

	Appearance	Visual moisture	Softness to tooth pressure	Moisture release	Stringiness	Chewiness	Mealiness	Flavor	Overall
Total cooking loss	0.919***	-0.892***	0.295	-0.908***	-0.565	0.439	0.760**	-0.494	0.834***
Nonfat dry weight	0.942***	-0.920***	0.162	-0.903***	-0.642*	0.380	0.837***	-0.377	0.763**
EMI	0.731**	-0.733**	0.053	-0.689*	-0.600*	0.094	0.475	-0.064	0.473
Fiber diameter	-0.425	0.472	0.320	0.370	0.339	0.180	-0.174	0.359	-0.102
Penetration									
Hardness	0.405	-0.277	0.145	-0.236	-0.386	0.277	0.455	0.163	0.224
Cohesiveness	-0.292	0.280	0.009	0.239	0.095	0.005	-0.002	-0.251	-0.140
Chewiness	0.117	-0.055	0.129	-0.047	-0.200	0.200	0.320	-0.093	0.104
Shear									
Cohesiveness	-0.421	0.276	-0.167	0.266	0.340	-0.243	-0.317	0.124	-0.299
Firmness	-0.024	0.025	-0.083	0.072	-0.041	-0.008	0.176	0.211	-0.154
Hydroxyproline solubilization	0.162	-0.288	-0.413	-0.405	-0.272	-0.238	0.138	-0.290	0.144
Dominant wavelength	-0.958***	0.873***	-0.250	0.846***	0.646*	-0.419	-0.802**	0.334	-0.747**
L-value	0.941***	-0.801**	0.156	-0.763**	-0.759**	0.433	0.888***	-0.264	0.678

[a] $n = 12$

*P < 0.05

**P < 0.01

***P < 0.001

Table 14--Correlation coefficients between sensory parameters and objective measurements of beef semitendinosus muscles--two-system sample

	Appearance	Visual moisture	Softness to tooth pressure	Moisture release	Stringiness	Chewiness	Mealiness	Flavor	Overall
Total cooking loss[a]	0.846***	-0.886***	0.411*	-0.877***	-0.218	0.543**	0.730***	-0.571**	0.848***
Nonfat dry weight[a]	0.698***	-0.830***	0.248	-0.849***	-0.396	0.437	0.802***	-0.496	0.790***
EMI[a]	0.436*	-0.577**	0.179	-0.593**	0.101	0.345	0.376	-0.307	0.456*
Fiber diameter[a]	-0.122	0.172	0.253	0.171	0.103	0.131	0.005	0.086	-0.029
Penetration									
Hardness[a]	0.284	-0.235	0.352	-0.148	-0.293	0.329	0.417*	-0.230	0.245
Cohesiveness[a]	-0.438*	0.482*	-0.346	0.359	0.188	-0.284	-0.367	0.329	-0.408*
Chewiness[a]	0.031	0.097	0.194	0.124	-0.175	0.208	0.178	-0.005	-0.003
Shear									
Cohesiveness[b]	-0.203	0.181	0.035	0.175	0.181	0.089	-0.040	-0.028	-0.136
Firmness[c]	0.189	-0.063	0.197	-0.034	-0.238	0.298	0.373	-0.128	-0.000
Hydroxyproline solubilization[a]	0.308	-0.381	-0.283	-0.462	-0.195	-0.084	0.236	-0.298	0.238
Dominant wavelength[a]	-0.796***	0.684***	-0.344	0.681***	0.323	-0.386	-0.599**	0.244	-0.620**
L-value[a]	0.750***	-0.739***	0.304	-0.747***	-0.416*	0.563**	0.834***	-0.441	0.732**

[a] n = 24 [b] n = 22 [c] n = 21

*P < 0.05

**P < 0.01

***P < 0.001

Table 15--Correlation coefficients among shear parameters and penetration parameters of beef semitendinosus muscles heated as intact roasts in an oven and as cores in a water bath

	Shear cohesiveness		Shear firmness	
	Intact[a]	Core[b]	Intact[a]	Core[c]
Penetration				
Hardness	0.542	0.198	0.828***	0.639*
Cohesiveness	-0.414	0.654*	0.665*	-0.674*
Chewiness	0.595*	0.578*	0.739**	0.873***

[a] n = 12

[b] n = 10

[c] n = 9

*P < 0.05

**P < 0.01

***P < 0.001

CHAPTER V

SUMMARY AND CONCLUSIONS

Physical and chemical characteristics of oven-roasted beef semitendinosus muscles were compared with those of muscles heated as cylindrical cores in glass tubes in a water bath. Two endpoint temperatures, 60 and 70°C, were studied. Samples were heated at rates equivalent to oven roasting at temperatures of 93 and 149°C. Cooking losses, nonfat dry weights, expressible moisture indices, fiber diameter measurements, hydroxyproline solubilization, and muscle color provided information regarding heat-related differences in muscle structure and composition. Penetration parameters of hardness, cohesiveness, and chewiness and shear parameters of cohesiveness and firmness were measures of tenderness. A sensory panel provided subjective evaluation of the meat samples.

With oven roasting less time and power were needed to reach the 60°C endpoint temperature than the 70°C endpoint temperature. Heating times were longer to both endpoint temperatures with the slow heating rate than with the fast. Despite the longer heating times, the slow heating rate did not use more power than the fast to reach an endpoint temperature.

Although total cooking losses were not affected by heating system in meat heated at the fast rate, total losses of slowly heated meat were greater ($P < 0.001$) in water bath samples than in oven-roasted ones. Oven roasting resulted in greater ($P < 0.01$) evaporative loss and less

($P < 0.001$) drip loss than water bath heating with both heating rates. Regardless of heating rate, increasing endpoint temperature tended to increase total cooking losses.

With fast heating there was no system difference in nonfat dry weight; however, with slow heating nonfat dry weight was greater ($P < 0.01$) in samples heated in a water bath than in oven-roasted samples. Samples heated at the fast rate had lower ($P < 0.05$) nonfat dry weights than samples heated at the slow rate. Endpoint temperature did not affect nonfat dry weight with the fast heating rate, but with the slow heating increasing endpoint temperature increased ($P < 0.001$) the percent nonfat dry weight of the samples.

Neither heating system, endpoint temperature, or heating rate affected EMI or muscle fiber diameters. With both heating rates, however, there was a trend toward greater EMI with oven roasting than in water bath heating.

While the penetration parameters of hardness and cohesiveness were not affected by endpoint temperature or heating system with fast heating, with slow heating firmness increased ($P < 0.05$), and cohesiveness decreased ($P < 0.05$) with increasing endpoint temperature. Chewiness was not altered by endpoint temperature with either heating rate, but with the fast rate chewiness was affected ($P < 0.01$) by heating system. Chewiness was lower ($P < 0.01$) in samples heated at the fast rate than in samples heated at the slow rate.

Shear parameters of cohesiveness and firmness were not affected by endpoint temperature or heating system with the fast heating rate. With slow heating cohesiveness was not affected by endpoint temperature

or heating system, but firmness was increased ($P < 0.05$) by increasing the endpoint temperature from 60 to 70°C. Firmness was higher ($P < 0.01$) in samples heated at the fast rate than in slowly heated ones.

Dominant wavelength of samples heated at both rates decreased (fast, $P < 0.05$; slow, $P < 0.001$) with increasing endpoint temperature. With slow heating water bath samples had lower ($P < 0.001$) dominant wavelengths than oven-roasted samples. L-values were increased ($P < 0.05$) by increasing endpoint temperature with both heating rates. There were no significant differences in either dominant wavelength or L-values due to heating rate.

A sensory panel found samples heated in a water bath were more done than samples heated to the same endpoint temperature in an oven. Samples heated to the 70°C endpoint temperature were judged more done than samples heated to 60°C. Panel evaluations of sample moisture, both visually and as moisture released during chewing, found that water bath samples were drier than oven-roasted ones. Meat heated to 70°C was drier than meat heated to 60°C. Samples heated at the fast rate were judged more moist than samples heated at the slow rate. For samples heated at the slow rate, the 70°C samples were judged less ($P < 0.05$) stringy than the 60°C samples. When samples were heated at the fast rate, the 60°C samples were found to yield more readily to chewing than samples heated to the 70°C endpoint temperature. Flavor was not affected by heating system or endpoint temperature. Panelists found overall sample quality of meat heated at both rates was decreased (fast, $P < 0.05$; slow, $P < 0.01$) by increasing endpoint temperature. With slow heating overall quality of water bath samples was rated lower than that of oven-roasted samples.

In conclusion, characteristics of meat heated as cores in a water bath system are affected by both endpoint temperature and heating rate. These same factors serve to alter the characteristics of meat heated as intact roasts in an oven. However, the extent of the heat-related changes and of their effects on final meat quality is, at least in part, determined by the heating system. If conclusions from research studies using water bath heating are to be applied to meat heated as intact roasts in an oven, it will be necessary to further define the similarities and differences of the two systems.

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APPENDIXES

APPENDIX A

SUPPLEMENTAL MATERIAL FOR METHODS OF EVALUATION

I. HYDROXYPROLINE SOLUBILIZATION[a]

1. To tubes containing 2.0-ml samples prepared as previously described, add 1 ml of 0.05 M chloramine T, mix thoroughly, and allow to stand 20 min at room temperature.

2. Add 1 ml of 3.15 M perchloric acid, mix, and allow tubes to stand for 5 min.

3. Add 1 ml of 20% p-dimethylaminobenzaldehyde (20 g PDAB to 100 ml in ethylene glycol monomethyl ether) to each tube and mix contents.

4. Cap tubes and place in a 60°C water bath for 20 min.

5. Cool in tap water for 5 min.

6. Add 10 ml benzene to each tube, stopper tubes, and shake vigorously.

7. After the layers separate, use an aspirator to rapidly remove the benzene layer.

8. Add a second 10-ml portion of benzene, stopper tubes, and shake vigorously.

9. Centrifuge tubes at low speed to separate phases sharply.

10. Carefully introduce a pipet into the water layer, withdraw 3.5 ml and place in a cuvette.

11. Read absorbancy at 557 nm. (Steps 6-11 should be completed in 10 min.)

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[a]Method II described by Woessner, J. F. 1961. The determination of hydroxyproline in tissue and protein samples containing small proportions of this imino acid. Arch. Biochem. Biophys. 93: 440.

12. Immediately after reading, add 0.2 ml of 30% H_2O_2 to the cuvette and mix thoroughly.

13. Read absorbancy exactly 5 min after the addition of peroxide.

14. Correct reading for chromagen fading by:

$$(A - B) - 0.12(B - C)$$

A = absorbancy of sample after benzene extraction

B = absorbancy of sample after peroxide treatment

C = absorbancy of water blank after peroxide treatment

0.12 = empirical correction factor

Standard Curve

A series of standards is prepared containing 0.5 µg hydroxyproline in a 2-ml total volume. Standards are treated in the manner described for samples. Plot absorbancy vs. amount of hydroxyproline.

Calculations[b]

Calculate the collagen content from hydroxyproline values as:

$$\frac{\text{mg collagen}}{\text{g sample}} = \frac{\text{µg hydroxyproline} \times \text{hydrolysate volume (ml)} \times 10^{-3}}{\text{aliquot volume (ml)} \times \text{sample weight (g)} \times 0.13^{c}}$$

[b]Penfield, M. P. 1973. Changes in tenderness and collagen of beef semitendinosus muscle heated at two rates. Ph.D. dissertation, The University of Tennessee, Knoxville.

[c]Conversion factor. Collagen is 13% hydroxyproline.

NAME _____ PANEL SESSION # ____ DATE _____

Roast Beef Tenderness

Evaluate criteria in order given. Place score in box on right.

Scoring criteria	Sample Score
A. Appearance Before tasting visually judge apparent doneness 9 8 7 6 5 4 3 2 1 Well done ... Rare	
B. Moisture Before tasting visually judge moisture of sample 9 8 7 6 5 4 3 2 1 Juicy ... Dry	
C. Softness to tooth pressure Rate on amount of muscular force needed to bite sample across fibers (perpendicular to longitudinal fibers) 9 8 7 6 5 4 3 2 1 Very hard ... Very soft	
D. Moisture After 2 or 3 chews judge rate of moisture release 9 8 7 6 5 4 3 2 1 Great ... Slight	
E. Stringiness Evaluate amount of stringy material encountered during chewing 9 8 7 6 5 4 3 2 1 Very stringy ... None	
F. Chewiness Judge amount of work required to prepare sample for swallowing 9 8 7 6 5 4 3 2 1 Highly resistant ... Yields readily	
G. Mealiness Presence of tiny, dry, and hard fragments remaining in mouth after swallowing 9 8 7 6 5 4 3 2 1 Very mealy ... None	
H. Flavor After swallowing, rate your impression of the sample's flavor 9 8 7 6 5 4 3 2 1 Strong ... Natural ... Very good	
I. Overall Rate your overall impression of the sample's quality 9 8 7 6 5 4 3 2 1 Very poor ... Very good	

Comments: Note presence of fat and connective tissues. Also comment on any other factors affecting your rating of the sample.

APPENDIX B

TABLES

Table 16--Interaction means for testing of beef semitendinosus muscles heated as intact roasts in an oven and as cores in a water bath to two endpoint temperatures at two rates[a]

Test parameter	Fast heating rate				Slow heating rate			
	Intact		Core		Intact		Core	
	60°C	70°C	60°C	70°C	60°C	70°C	60°C	70°C
Cooking losses (%)								
Total	19.54	20.56	19.44	28.59	16.73	29.01	27.47	38.80
Evaporative	18.09	18.07	0.20	0.31	15.72a	27.38b	0.27c	1.05c
Drip	1.45	2.49	19.24	28.28	1.01p	1.63p	27.18q	37.75r
Nonfat dry weight (%)	27.53	27.35	25.85	29.30	26.97	30.62	27.93	32.62
Expressible moisture index	0.242	0.229	0.252	0.289	0.261	0.290	0.273	0.295
Fiber diameter (μm)	48.5	48.5	49.0	48.3	47.0	47.8	50.2	43.0
Penetration								
Hardness (kg)	3.208	3.333	2.665	3.255	1.889a	3.405b	2.630c	2.788c
Cohesiveness	0.499	0.577	0.536	0.520	0.700a	0.379b	0.462b	0.490b
Chewiness (kg)	1.537	1.859	1.396	1.393	1.253	1.299	1.299	1.358
Shear								
Cohesiveness (kg)	7.19	7.64	7.09	7.23	6.84	7.86	6.74	6.40
Firmness (kg/min)	71.18	80.44	69.04	77.27	61.34	82.25	60.14	65.27
Hydroxyproline solubilized (%)	5.72	5.58	5.88	4.29	6.01	7.41	8.36	9.96
Color								
Dominant wavelength (nm)	589.33	587.70	589.32	585.25	595.03	587.67	587.20	582.33
L-value	5.698	5.927	5.625	6.091	5.458	6.249	5.713	6.391

[a]Means of three replications

[b]Means in a row within a heating rate with a different letter are different at $P < 0.05$ (a through c) or $P < 0.01$ (p through r).

Table 17--Analysis of variance summaries for evaluation of beef semitendinosus muscles heated as intact roasts in an oven and as cores in a water bath to two endpoint temperatures at two rates

Fast heating rate			Slow heating rate		
Source	df	ms	Source	df	ms
		Total loss			
Endpoint	1	77.572	Endpoint	1	418.074***
System	1	47.084	System	1	316.111***
Error	7	18.855	Error	7	2.812
		Evaporative loss			
Endpoint	1	0.005	Endpoint	1	116.065*
System	1	953.548***	System	1	1309.176**
Error	7	7.823	Endpt X Sys	1	88.781*
			Error	2	1.633
		Drip loss			
Endpoint	1	76.306*	Endpoint	1	93.800**
System	1	1424.412***	System	1	2910.656***
Error	7	11.626	Endpt X Sys	1	74.152**
			Error	2	0.409
		Nonfat dry weight			
Endpoint	1	8.003	Endpoint	1	52.083***
System	1	0.053	System	1	6.601**
Error	7	2.080	Error	7	0.371
		Expressible moisture index			
Endpoint	1	0.000	Endpoint	1	0.002
System	1	0.004	System	1	0.000
Error	7	0.001	Error	7	0.001
		Fiber diameter			
Endpoint	1	0.333	Endpoint	1	16.333
System	1	0.083	System	1	0.000
Error	7	12.744	Error	7	21.131
		Penetration-hardness			
Endpoint	1	0.384	Endpoint	1	2.103*
System	1	0.289	System	1	0.012
Error	7	0.258	Endpt X Sys	1	1.383*
			Error	2	0.036
		Penetration-cohesiveness			
Endpoint	1	0.003	Endpoint	1	0.065*
System	1	0.000	System	1	0.012
Error	7	0.009	Endpt X Sys	1	0.091*
			Error	2	0.003

Table 17, continued

Fast heating rate			Slow heating rate		
Source	df	ms	Source	df	ms
		Penetration-chewiness			
Endpoint	1	0.280**	Endpoint	1	0.033
System	1	0.074	System	1	0.003
Error	7	0.015	Error	7	0.027
		Shear-firmness			
Endpoint	1	108.646	Endpoint	1	323.077*
System	1	39.275	System	1	134.681
Error	5	25.995	Error	6	32.294
		Shear-cohesiveness			
Endpoint	1	0.448	Endpoint	1	0.058
System	1	0.051	System	1	0.919
Error	6	0.438	Error	6	0.301
		Hydroxyproline solubilization			
Endpoint	1	2.253	Endpoint	1	6.675
System	1	0.963	System	1	18.130*
Error	7	2.561	Error	7	2.375
		Dominant wavelength			
Endpoint	1	24.368*	Endpoint	1	112.241***
System	1	4.563	System	1	130.021***
Error	7	4.386	Error	7	3.613
		L-value			
Endpoint	1	0.362*	Endpoint	1	1.619***
System	1	0.006	System	1	0.118
Error	7	0.031	Error	7	0.031
		Appearance			
Endpoint	1	23.773***	Endpoint	1	31.105***
System	1	11.117**	System	1	13.868***
Error	7	0.570	Error	7	0.428
		Visual moisture			
Endpoint	1	26.940***	Endpoint	1	33.001***
System	1	14.874***	System	1	15.053**
Endpt X Sys	1	2.376**	Endpt X Sys	1	2.271*
Error	2	0.012	Error	2	0.027
		Softness to tooth pressure			
Endpoint	1	2.210	Endpoint	1	1.116
System	1	0.040	System	1	1.116
Error	7	0.719	Error	7	1.257

Table 17, continued

Fast heating rate			Slow heating rate		
Source	df	ms	Source	df	ms
		Moisture release			
Endpoint	1	17.642**	Endpoint	1	20.462***
System	1	6.092*	System	1	10.925**
Endpt X Sys	1	2.457*	Error	7	0.395
Error	2	0.099			
		Stringiness			
Endpoint	1	0.015	Endpoint	1	3.696*
System	1	1.313	System	1	0.004
Error	7	0.341	Error	7	0.353
		Chewiness			
Endpoint	1	3.910*	Endpoint	1	2.901
System	1	0.677	System	1	0.555
Error	7	0.421	Error	7	0.907
		Mealiness			
Endpoint	1	10.268**	Endpoint	1	27.664***
System	1	0.581	System	1	0.264
Error	7	0.369	Error	7	0.358
		Flavor			
Endpoint	1	0.006	Endpoint	1	1.825
System	1	0.006	System	1	0.105
Error	7	0.137	Error	7	0.369
		Overall			
Endpoint	1	3.000*	Endpoint	1	4.625**
System	1	0.590	System	1	3.360**
Error	7	0.487	Error	7	0.270

*P < 0.05

**P < 0.01

***P < 0.001

Table 18--Summary of t-tests between mean values for fast and slow heating rates[a]

Source of variation	Heating rate		t
	Fast	Slow	
Total loss	22.034	28.000	-2.118*
Drip loss	12.867	16.890	-0.675
Evaporative loss	9.168	11.105	-0.441
Nonfat dry weight	27.508	29.533	-2.505*
Expressible moisture index	0.253	0.280	-2.038
Fiber diameter	48.583	46.583	1.037
Penetration			
Hardness	3.115	2.678	1.773
Cohesiveness	0.533	0.508	0.532
Chewiness	1.621	1.276	4.205***
Shear			
Firmness	75.334	65.606	2.928**
Cohesiveness	7.295	6.855	1.577
Hydroxyproline solubilization	5.368	7.941	-3.367**
Dominant wavelength	587.900	588.058	-0.097
L-value	5.835	5.952	-0.807
Appearance	4.851	5.797	-1.167
Visual moisture	6.017	4.083	2.218*
Softness to tooth pressure	4.851	4.748	0.250
Moisture release	5.600	3.749	2.698*
Stringiness	2.633	2.685	-0.175
Chewiness	4.134	4.378	-0.616

Table 18, continued

Source of variation	Heating rate		t
	Fast	Slow	
Mealiness	3.297	4.093	-1.357
Flavor	5.116	4.500	2.576*
Overall	4.092	4.989	-2.384*

[a]t-tests assuming unequal variance

*P < 0.05

**P < 0.01

***P < 0.001

VITA

Pamela Louise Brady was born in Aberdeen, Maryland, on February 29, 1952. She attended public schools in Kansas, Missouri, Pennsylvania, Texas, and Louisiana and was graduated from Bolton High School, Alexandria, Louisiana, in 1970.

She attended the University of Arkansas, Fayetteville, from September, 1970, through December, 1975, and received the Bachelor of Science and Master of Science degrees in Horticultural Food Science. She worked as a graduate research assistant from June, 1974, through December, 1975.

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