TENDERNESS OF CONVENTIONALLY CHILLED OR ELECTRICALLY STIMULATED-HOT BONED BULL ADDUCTOR MUSCLE — ROASTED OR COOKED IN A MODEL SYSTEM

by

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INTRODUCTION

Tenderness, an attribute resulting from the total effect of muscle composition, aging before cooking, and changes in connective tissue and myofibrillar proteins during cooking, is the quality of meat most desired by consumers (Simmons and Rixson, 1975; Henrickson, 1978). Electrical stimulation and hot boning have been studied extensively as methods of improving tenderness of skeletal muscle and of reducing processing cost (Henrickson et al., 1974; Bendall et al., 1976; Davey et al., 1976; Gilbert et al., 1977; Shaw and Walker, 1977; Savell et al., 1978 a, b, c; Smith et al., 1978; Bouton et al., 1980 a, b; Elgasim et al., 1981; Ray et al., 1982). Electrical stimulation, followed by hot boning, reduced chilling space and aging time from 10 - 20 days to 2 days (Gilbert et al., 1977).

Generally, bull meat is coarser, less tender, and drier than steer meat (Henrickson, 1978). Hurst et al. (1975) reported that young bull meat was leaner and had higher Warner-Bratzler shear values than steer meat, but when other researchers (Klosterman et al., 1954; Bailey et al., 1966; Field et al., 1966) compared young bulls with steers for "overall acceptability," no differences were observed.

Sensory and objective measurements are used to evaluate effects of production and processing treatments on tenderness and texture of roasts and steaks. Differences in the temperature from one area to another in those cuts may affect sensory and objective measurements, depending on the sampling plan. Machlik and Draudt (1963) suggested using small pieces of muscle heated in a water bath (model

system) to obtain reproducible results in heat related studies. They heated semitendinosus muscle cores in a water bath (50^{o} - 90^{o}C) and obtained decreased shear values for cores heated at 58^{o} - 60^{o}C and at 71^{o} - 75^{o}C, which they attributed to the shrinkage (58^{o} - 60^{o}C) or breakdown (71^{o} - 75^{o}) of collagen. Similar observations were reported by Paul et al., (1973) and Penfield and Meyer (1975).

Brady and Penfield (1981) compared the effects of conventional roasting of beef semitendinosus (ST) roasts with those of heating small cores of ST muscle in a water bath on Instron textural characteristics and on solubilization of hyroxyproline for two rates of heating (93^{o} or 149^{o}C) and two end point temperature (60^{o} or 70^{o}C). The slower rate of heating (93^{o}C) in the water bath resulted in greater total cooking losses and a higher percentage of hydroxyproline solubilized than were obtained with conventional roasting; with the faster heating rate, no differences between cooking systems were found in those measurements. No differences between cooking systems were found with either heating rate for Instron measurements of penetration hardness, cohesiveness, or chewiness, or for shear cohesiveness, or firmness. They concluded that the cooking system had some influence on the quality of the cooked meat.

We compared conventionally chilled or electrically stimulated - hot boned bull adductor (AD) muscles, roasted to 70^{o}C, and small AD strips heated in a model system to 70^{o}C for cooking properties, sensory tenderness and texture, Instron texture characteristics, and percentage solubilized hydroxyproline. Relationships between sensory tenderness and texture attributes and Instron texture measurements and between those measurements and solubilized hydroxyproline were studied.

REVIEW OF LITERATURE

Model system as a tool for meat research

Roasts or steaks have been used in meat cookery research, but large variations in heat penetration rates and the poor reproducibility of sensory and objective measurements have been observed with large samples. According to Machlik and Draudt (1963) those shortcomings maybe overcome by using a model system to study the definitive thermal effect on meat. Most model systems for cooking meat use small pieces heated in a water bath. Details of the procedures of those systems vary to obtain the objectives of the experiment.

Winegarden et al. (1952) used a model system to study the effects of heating time (1, 2, 4, 16, or 64 min) and temperature (60^{o} - 95^{o}C at 5^{o}C intervals) on the microscopic appearance and softening of connective tissues. They used samples of bovine ligamentum nuchae (principally elastin), the deep flexor tendon (principally collagen), and the aponeurotic sheet (varying amounts of collagen and elastin). Samples were cut into strips of 2.1 cm with slightly varied thickness. Their model system was a "thermostated" stainless steel bath with a 600-ml beaker containing distilled water heated to and maintained at the desired temperature. After the water in the beaker reached the temperature for the test, connective tissues were heated in the beaker for a definite time. No apparent change was observed in either collagenous or elastic tissue heated at 60^{o} or 65^{o}C for short times. With heating at temperatures higher than 65^{o}C, rapid physical changes occurred in collagenous tissue, but not in elastic tissue.

Machlik and Draudt (1963) used a constant temperature bath to heat ST muscle cores (1.3 cm dia x 5.1 cm long) to study the effect of heating time and temperature on shear value. Muscle cores were heated from 50° - 70°C for 2 hrs, and from 70° - 90°C for 5 hrs. Marked decreases in shear values from those of the muscle heated to 50°C were obtained at 58° - 60°C and at 71° - 75°C, which they attributed to the shrinkage of the collagenous tissues at 58° - 60°C and to the breakdown of collagen at 71° - 75°C.

To study the relationship between sensory and objective measurements for tenderness of meat, Marsh et al. (1966) developed a model system for cooking small samples (80 - 200 g) of bovine sterno-mandibularis muscle. Samples were placed in polyethylene bags, which were vacuum shrunk on the samples: the bags were sealed and immersed in an 8-liter glass tank containing water, and the samples were equilibrated at 30°C for one hour. After equilibration the thermostat was set at 80°C and heating was continued for another hour or until samples reached an internal temperature of 80°C. Tenderness of the cooked samples was measured by a sensory panel and a tenderometer that recorded a force penetration curve of a blunt brass wedge used to cleave the samples. Sensory tenderness scores were correlated ($r = 0.64^{**}$ to 0.94^{***}) with the work required to cleave the samples.

To compare the length of the sarcomeres in the muscle fiber with other predictors of beef tenderness, Howard and Judge (1968) used LD muscle slices (5.1 cm thick) cut parallel to muscle fibers. Slices were cut into medial and lateral halves, and thermocouples were inserted into their centers. Slices were placed separately in Cryo-vac

bags, which were evacuated, sealed and heated in a constant temperature water bath to end point temperatures of 60°, 64°, 68°, or 72°C. After the samples reached an internal temperature of 1°C less than that of the water bath, they were held in the water bath for another 12 min, then they were removed and stored at 4°C for 24 hr before measurements for tenderness of the samples were made. Sarcomere length was correlated (r = o.54** to 0.56**) with tenderness in the medial muscle position for all end point temperature studied.

Laakkonen et al. (1970) developed a model system to study the relationship between tenderness of beef cooked at extremely low temperature and its water holding capacity (WHC), pH, or water soluble components. They used slices (2.5 cm thick, 100 - 130 g) of ST, LD, or rectus femoris (RF) beef muscles sealed in plastic bags and submerged in a 30°C water bath. The temperature of the water bath was increased at 0.1°C/min until the bath reached 60°C; that temperature was maintained for 10 hrs. Only minor changes in properties of the muscle occurred during the first three hours of heating. Major decreases in shear values and weight losses occurred in the next three hours of heating when meat was in the 50° - 60°C range. Gradual increase in pH with heating was observed. A rapid decrease in the amount of water solubles was observed during the fourth to sixth hours of heating. Dubé et al. (1972) used a constant temperature bath similar to that of Machlik and Draudt (1963) to study the relationship between the sulfhydryl content of beef and objective measurements for tenderness (shear value, fiber sarcomere length).

Paul et al. (1973) studied the heat induced changes in the extractability of collagen in beef ST and biceps femoris (BF) strips

(2 x 2 x 7 cm) placed in 22 mm test tubes and heated to 58°, 67°, 75°, or 82°C in a water bath. The water bath was programmed to follow the heating curve of a ST roast cooked at 163°C. Increased collagen solubilization occurred in both muscles with increased end point temperature. Correlation was significant ($r = -0.80$ ** for ST, $r = -0.55$ * for BF) between collagen solubilization and penetrometer readings, but between collagen solubilization and shear values, correlation was significant for BF (-0.45 *) only.

Penfield and Meyer (1975) studied the effect of heating rate and end point temperature on the shear value and the percentage solubilized hydroxyproline in ST strips cooked in model system. Muscle strips (2.5 x 5.7 cm) in 50-ml test tubes were cooked in a shaking water bath at a rate simulating the heating curve for a 2-kg round roast at 93°C (slow rate), or at 149°C(fast rate) to 40°, 50°, 60°, or 70°C. Results indicated that shear values decreased with increased end point temperature; percentage solubilized hydroxyproline increased with end point temperature for both slow and fast rates. Lower shear force values and greater solubilized hydroxyproline were obtained in strips heated at the slow rate than were obtained in those heated at the fast rate.

Hearne et al. (1978) used the same model system, strip dimensions, heating rates, and end point temperatures as those of Penfield and Meyer (1975) to study the effects of heating on the shear force, muscle fiber measurements, and cooking losses in bovine ST muscle. They obtained greater cooking losses with the slow rate of heating than they did with the fast rate. For both heating rates, Warner-

Bratzler shear force values of cooked strips decreased when end point temperature was increased from 40° to 60°C, but increased when end point temperature was increased from 60° to 70°C. With the fast heating rate, increased end point temperature increased muscle fiber disintegration. Because muscle fiber disintegration was identified as a predictor for tenderness, they suggested that there were other factors opposing the tenderizing effect of increased muscle fiber disintegration.

Brady and Penfield (1981) compared the effects of two heating rates (93° - slow, 149°C - fast), two heating systems (water bath, oven roasting) and two end point temperatures (60°, 70°C) on the Instron textural characteristics and on solubilized hydroxyproline. ST strips (2.5 x 5.7 cm) were heated at a rate simulating the heating curve of a roast. Their results indicated that more solubilized hydroxyproline occurred when strips or roasts were cooked at a slow rate to an end point of 70°C than when they were cooked to an end point of 60°C. Also, greater solubilized hydroxyproline was obtained in strips cooked in a model system than in roasts cooked by oven rasting. Instron texture measurements were neither affected by the heating rate nor by the heating system used.

McDowell et al. (1982) compared Instron and sensory measurements of top round roasts cooked by dry (oven roasting) or moist (oven film bag) heat and strips (2 x 2.3 x 7 cm) from top round heated at a rate simulating that of a 1.4 kg top round roast. They found that strips had lower Instron values than any of the roasts. With sensory measurements, strips were more like roasts cooked by dry heat than they were like roasts cooked by moist heat.

Meat tenderization by electrical stimulation (ES)

Meats have been preserved mainly be refrigeration and freezing, but the advent of fast freezing brought about serious complaints of cold shortening, an induced myofibrillar contraction occurring mainly with prerigor muscles (pH above 6.0) when subjected to near $0^{o}C$ (Locker and Hagyard, 1963). Consumers' demand for tender meat and the evidence that cold shortening is a major cause of meat toughness led processors and scientists to work jointly on methods to prevent cold shortening, including ES.

Carcass ES is a process of tenderizing meat by applying electric shocks immediately after animal is slaughtered or right after it is dressed. Despite the fact that numerous studies have been conducted on the effects of ES, its tenderization action still cannot be explained fully. Locker et al. (1975), Bendall et al. (1976), Chrystall and Hagyard (1976) attributed the tenderization of ES to the prevention of cold shortening. They postulated that when compared with unstimulated carcasses, ES caused an accelerated glycolytic rate, which resulted in an increased depletion rate of energy source (adenosine-triphosphate) and an increased rate of pH decline. The depletion of energy source for muscle contraction and the lowering of pH in the muscle before the ES muscles reached the temperature that induced cold shortening were believed to prevent cold shortening. Savell et al. (1978b) attributed tenderization by ES to the disruption of myofibrils, resulting from massive muscle contraction. They based their explanation on the histological appearance of both ES and unstimulated muscles. Contracture bands similar to those formed in muscles by extremely rapid post-mortem glycolysis or by physical disturbance such as pricking or

cutting of fibers at time of death were observed along the myofibrils of ES muscles, but they were not present in unstimulated muscles. Savell et al. (1977) and Moeller et al. (1976) suggested that tenderization was caused by the enhanced activity of the autolytic enzymes in stimulated muscles. They postulated that the rapid decline in pH in ES muscles coupled with the relatively high temperature of the muscle caused the disruption of the lysosomal membranes, which resulted in the release of hydrolytic enzymes, which subsequently promoted the aging process and tenderization.

Conditions for applying electrical stimulation. The conditions for applying ES have varied. Researchers in New Zealand used high voltage (1600 - 3600 volts; 30 cycles/sec) and continuous shocks for 2 min (Davey et al., 1976; Gilbert and Davey, 1976; Chrystall and Hagyard, 1976; Gilbert et al., 1977). Researchers in the United States used lower voltage (100 - 450 volts; 60 cycles/sec) with intermittent shocks over a 60 sec period (Savell et al., 1976, 1977, 1978a, b, c; Smith et al., 1979; Grusby et al., 1976; Ray et al., 1982). All of those authors reported an accelerated rate of pH decline with subsequent tenderization of meat in ES carcasses.

Bouton et al. (1978) pointed out that the use of high voltage ES presents a major safety problem, particularly in an abbatoir environment where strict safety precautions are essential. Shaw and Walker (1977) found that high voltage was not necessary to accelerate glycolysis; voltages in the range of 20 - 110 were as effective in accelerating glycolysis and rigor mortis as voltages of more than 1000.

Bouton et al. (1980b) reported substantial reduction of pH in carcasses stimulated at 1 hr post mortem with 1100 volts for 120 or 90 sec (10 msec pulse width, 14.3 pulses/sec) or with 110 volts for 90 sec (2 msec pulse width, 40 pulses/sec) within an hour after stimulation, but not with carcasses stimulated with 45 volts for 90 sec (10 msec pulse width, 14.3 pulses/sec). However, when ultimate pH values (after 22 hours) were compared, the pH of low voltage (45 volts) stimulated carcasses tended to be equal to the pH of the carcasses stimulated with higher voltages. High voltage was superior to low voltage in preventing cold shortening.

Time of applying electrical stimulation. Locker et al. (1975) stated that the most benefit could be attained from ES by stimulating the animal as soon as possible after slaughter. Generally, ES is administered after the dressing process and within 40 - 60 min post mortem (Davey et al., 1976; Gilbert and Davey, 1976; Gilbert et al., 1977; Savell et al., 1976, 1977, 1978a, b, c; Shaw and Walker, 1977; Cross et al., 1979; Bouton et al., 1978, 1980a, b; Elgasim et al., 1981; Taylor and Marshall, 1981; Ray et al., 1982).

Bendall et al. (1976) compared the effects of ES on undressed beef carcasses immediately after slaughter with the effects on dressed carcasses, 50 min post mortem. Similar rates of pH decline were obtained for cacasses stimulated immediately or 50 min after slaughter. They stated that the time at which carcasses should be stimulated is a matter of convenience. The effectiveness of ES in tenderizing meat remains as long as application is not delayed beyond 60 min; its effectiveness falls rapidly after 60 min post mortem.

Effect of electrical stimulation on bovine raw muscle "quality." Results of many studies conducted at Texas A & M University indicated that ES has no negative effects on raw muscle color, pH, or carcass shape (Smith et al., 1977). Grusby et al. (1976) reported that ES did not affect the USDA color scores for US Standard or US Good Grade beef carcasses. They also observed that ES did not produce heat rings. Heat rings are non uniform color formation caused by different rates of chilling within a carcass with an elevated pH (Savell et al., 1978c). Savell et al. (1978a, c) and Cross et al. (1979) found that ES brightened the red color and reduced the incidence of heat rings in beef. No change in color of lean in ES carcasses was observed by Smith et al. (1979).

Cooking and eating quality. The rate of pH fall or the ultimate pH in postmortem muscle can affect the quality of meat in several ways. Bouton et al. (1971) reported that pH affects the WHC of meat, which in turn affects the thawing and cooking losses from meat. Savell et al. (1978a) obtained greater cooking and thawing losses in stimulated muscle than in unstimulated muscle, which they attributed to the pH-temperature relationship, which caused a reduction in WHC of and physical disruption of myofibrils in stimulated muscle. That led to greater moisture loss (cooking and thawing loss) from stimulated muscle. Likewise, Bouton et al. (1980b) reported that cooking losses for muscles taken from carcasses stimulated with high voltage (1100 volts) were greater ($P < 0.05$) than those from unstimulated carcasses. With muscles obtained from carcasses stimulated with low voltages (110 and 45 volts), no differences for cooking losses between stimulated and unstimulated

muscles were obtained. Similar findings were reported by Savell et al. (1978a) and Smith et al. (1979).

According to Davey et al. (1976), the eating quality of meat that most likely would be affected by ES is tenderness. Higher tenderness scores and lower shear force values were obtained by Savell et al. (1977), Cross et al. (1979), Bouton et al. (1980a, b), Taylor and Marshall (1980) for ES muscles than for those obtained for unstimulated muscles.

Because ES may affect the WHC of the muscle, other sensory attributes likely to be affected are juiciness and firmness. Savell et al. (1978b), Bouton et al. (1980b) reported that steaks from stimulated carcass sides were less juicy than steaks from unstimulated sides; the rating of juiciness parallelled the cooking losses. In contrast, Cross et al. (1979) found that steaks from ES beef sides were juicier ($P < 0.05$) than those from unstimulated sides. Savell et al. (1976) found no differences in juiciness scores for meat from the stimulated and the unstimulated sides of beef carcasses. Firmness and texture of both aged and unaged muscles from stimulated sides were not different from those of unstimulated sides (Gilbert and Davey, 1976).

Hot boning (HB)

Hot boning, also known as pre-rigor excision, hot processing, high temperature processing, accelerated or rapid processing, or pre-chill processing is the process of cutting the carcass into muscle components soon after slaughter and normally before rigor mortis develops. Traditionally, primal cuts have been excised from carcass sides

after the muscles have entered and passed through rigor mortis during the chilling process. Carcasses are chilled normally at -4° to 0°C for 24 hr to dissipate excess heat and moisture of newly slaughtered animals. Thereafter, carcasses are chilled at 0° to 3°C until fabricated (Locker et al., 1975; Forrest et al., 1975). For conventional chilling, carcasses are fabricated or cold boned after carcasses passed through rigor mortis.

To save refrigerated space and energy consumption, hot boning of carcasses was introduced. Henrickson et al. (1974) found that by removing waste fat and bone before chilling, chilling space was reduced by 30 to 35 %. Furthermore, they stated that boneless meat had a faster cooling rate than that of intact carcasses. Gilbert and Davey (1976) suggested that boneless meat could be boxed and automatedly handled during the chilling and freezing processes. Nason (1979) estimated that 42 % of the energy requirements for cold processing is saved with HB of meat.

The major hazard in HB is the cold shortening of unrestrained muscles during the onset of rigor mortis, so beef should be kept in the temperature range of 14° - 19°C to minimize cold shortening, Locker and Hagyard, (1963). To prevent weight loss and contamination, packaging usually is included in the boning process. Schmidt and Gilbert (1970) reported that vacuum packing of HB muscles in Cryo-vac bags retarded microbial growth.

Schmidt and Gilbert (1970) evaluated the sensory qualities of pre-rigor excised beef. Primal cuts were excised at 2 hr post mortem, chilled for 22 hr at 9°C, and aged for 24 or 48 hr at 15°C. Mean

shear values for pre-rigor excised SM and ST muscles stored for either 24 or 48 hr were higher than those obtained for the cold boned control muscles. However, sensory tenderness scores indicated that pre-rigor excised muscles were as "acceptable" as the control muscles.

Schmidt and Keman (1974) compared the qualities of eight HB (1 hr post mortem) muscles with their cold boned (after 8 days storage at $1^{o}C$) counterparts. HB muscles were conditioned at $7^{o}C$ for 4 hr after boning, then chilled overnight at $1^{o}C$, vacuum packed, and aged for 7 days at $1^{o}C$. Larger ($P < 0.01$) fiber diameter was obtained for HB muscles, but no differences in shear value, flavor, juiciness, tenderness, or "overall acceptability" were noted between the hot and cold boned muscles.

Kastner et al. (1973) compared the qualities of muscle excised at 2, 5, or 8 hr post mortem (stored at $16^{o}C$) with CC ($2^{o}C$) beef muscles (boned 48 hrs post mortem). Less tender meat was obtained for HB musles removed at 2 ($P < 0.05$) or at 5 hr ($P < 0.10$) than for CC muscles, but no difference in tenderness was obtained for muscles HB after 8 hr holding. Flavor was not different for any holding period.

Kastner et al. (1976) compared measurements for tenderness of LD bovine muscle conditioned in intact half carcasses at $16^{o}C$ and excised at 6, 8, or 10 hr post mortem with bovine LD muscle chilled at $2^{o}C$ and excised at 48 hr post mortem. Hot and cold boned muscles did not differ in shear value, myofibrillar protein extractability, or sarcomere length. Higher mean diameter ($P < 0.10$) and mean fiber kinkiness ($P < 0.01$) were observed for muscles HB after 6 hr holding than for cold boned muscles. Conditioning intact half carcasses at

16°C and boning LD muscles after 8 hr of holding produced meat of "acceptable" tenderness.

Ray et al. (1982) obtained less ($P < 0.01$) tender meat from SM and ST muscles that were HB 1 hr post mortem than that from muscles that were cold boned 7 days after slaughter. Taylor et al. (1981) reported no difference between HB beef primal joints (conditioned 3 hr at 15°C before chilling) and cold boned (24 hr post mortem) beef primal joints for tenderness, juiciness, or Instron texture measurements.

Kastner et al. (1973) reported that cooking loss was not different between cold and hot boned meat conditioned at 16°C for 2, 5 or 8 hr before HB. Taylor et al. (1981) obtained less ($P < 0.01$) evaporative loss and slightly less drip loss from uncooked HB primal beef joints conditioned at 15°C and allowed to go into rigor mortis than from those that were cold boned. Ray et al. (1982) found that hot boned SM and ST muscles heated to 63°C cooked (72 min/kg) faster ($P < 0.01$) than cold boned muscles (95 min/kg).

Electrical stimulation-hot boning (ESHB)

Gilbert and Davey (1976), Davey et al. (1976), and Gilbert et al. (1977) found that with ES of beef carcasses, fast chilling rates sufficient to reduce deep tissue to below 8°C in 24 hr could be tolerated without cold shortening, because rigor developed within 5 hr. That finding led to the development of an ESHB process, which speeds up the processing time in addition to reducing the chilling space and operational cost (Gilbert and Davey, 1976).

Gillis and Henrickson (1969) showed that pre-rigor excised muscles allowed to freely contract were less ($P < 0.05$) tender than

muscles restrained during the development of rigor or excised post rigor; as muscle contraction increased, tenderness decreased. Gilbert and Davey (1976) compared the sensory qualities of ESHB bovine muscles with those of cold boned (24 hr after slaughter) muscles. Stimulated sides of the bovine carcass were boned 5 hr after slaughter. LD, BF, SM, and psoas major (PM) were divided into halves; each half was vacuum packed separately, and one-half of each muscle was aged at 10°C for 72 hr; the other half was frozen and stored at -18°C. Similar treatment was given to the 24 hr chilled, cold boned counterparts. Sensory evaluation indicated that tenderness, juiciness, and "general acceptability" of the ESHB cuts were as "acceptable" as the unstimulated cuts; ESHB cuts improved further with aging.

Gilbert et al. (1977) compared tenderometer and sensory measurements for LD, BF, SM, and PM muscles boned 24 hr post mortem with ESHB 2 hr post mortem muscles. ESHB muscles were divided into halves and each half was vacuum packed separately, then stored in two boxes, with lids. One box was aged at 5°C for 46 hr, the other box was frozen at -35°C. Unstimulated muscles were chilled, cut in half, vacuum packaged, and cartoned in two groups, with one group frozen at -35°C and the other group aged at 10°C for 65 hr. Unstimulated, unaged cuts all were tougher and less uniform in tenderness than their stimulated counterparts. Stimulation greatly reduced the vulnerability of cuts to cold shortening, despite early boning and rapid freezing. Aging the ESHB muscles before freezing produced a uniform degree of tenderness.

Taylor et al. (1981) compared cooking losses and eating quality assessments (objective and subjective) for meat subjected to the two

HB processes used to produce vacuum packed primal beef joints with the same measurements for meat given the cold boning process (24 hr post mortem). HB (1 to 2 hr post mortem) beef primal joints were conditioned for 3 hr at 15°C, then chilled at 10°C for 9 hr, then transferred to a chiller at 1°C for 18 hr before freezing or they were ES, chilled at 10°C for 24 hr, then frozen. Slightly more evaporative and drip losses were obtained from ESHB muscles than from unstimulated HB muscle, but losses were slightly less when compared with cold boned muscles. Tenderness, juiciness, Instron texture, color, pH, and sarcomere length measurements were similar for all three boning processes.

Ray et al. (1982) reported that ESHB bull or steer ST and SM muscles cooked pre-rigor were rated less ($P < 0.01$) tender and had higher ($P < 0.01$) Warner-Bratzler shear values than the unstimulated CC (7 days at 2°C) muscles. Furthermore, ESHB muscles produced greater ($P < 0.01$) cooking yield and required less time ($P < 0.01$) to reach an internal temperature of 63°C than did the unstimulated CC muscles.

Methods of evaluating tenderness

Consumers are the ultimate evaluators of cooked beef tenderness. All other measurements, chemical, physical, or histological, are assessed by how well they correlate with sensory evaluation. Campbell et al. (1979) stated that prerequisite to all quality attribute evaluation is the careful control of the sample preparation. They also pointed out that only when conditions of preparation are carefully controlled and defined can differences in quality be attributed to known variables.

Sensory evaluation. The choice of the method used for sensory evaluation depends on the purpose of the test. Larmond and Petrosavits (1972) used a paired comparison test as an alternative to correlation coefficients to study the relationship between objective and sensory measurements of tenderness. They found that a sensory panel's evaluation for beef tenderness was influenced more by Instron "shear cohesiveness" than by Instron "firmness" values. A disadvantage to the paired comparison test is that it can not give an absolute tenderness assessment of the sample; the value given to each sample is relative only to that of the other sample with which it is compared (Larmond, 1976).

A method commonly used for meat tenderness evaluation is numerical scoring, where a numerical score with a descriptive term is assigned to each sample. The score is based on the assumption that each score has the same meaning or sensation to each judge (Harries et al., 1972; Larmond, 1976).

To help the judge standardize his procedures for evaluating tenderness, Harrison et al. (1949) used the chew count method to help each panelist standardize his scoring from session-to-session. The number of "chews" necessary to thoroughly masticate a certain size piece of meat is counted. Szczesniak and Torgeson (1965) pointed out that people tend to chew with greater force when meat is tough than when it is tender. To check bias judgement, chew count should be used only as a guide in setting the panelist's chew range for a given score (Harrison et al., 1949).

Because tenderness is not a single property, but a composite of

several components, Cover et al. (1962a, b) subdivided tenderness of beef into six components: softness to tongue and cheek, softness to tooth pressure, ease of fragmentation of muscle fibers across the grain, mealiness, apparent adhesion between fibers, and the amount of firmness of connective tissue.

Collagen solubilization. Collagenous tissues significantly influence tenderness of meat. Collagen is the most abundant protein in the animal body, consituting about 20 - 25 % of the total protein. Reports indicated that collagen varies with muscles, but on the average, it comprises about 1.5 % of skeletal muscle. Variation in tenderness among muscles within an animal is affected by the nature of the collagen present and the distribution of collagenous tissue, which parallels physical activity of muscle. Limb muscles, which contain more collagen than the back muscles, consequently are less tender than back muscles. Because collagen has a relatively constant hydroxyproline content (about 13 - 14 % of the collagen protein), chemical assay for hydroxyproline is used commonly to determine the amount of collagen in tissue (Forrest et al., 1975). Elastin, which also contains hydroxyproline has 50 - 100 times less hydroxyproline than does collagen (Paul, 1972).

The amount of residual connective collagenous tissues in meat after cooking and the solubilization of collagen in gelatin during cooking have been associated with the tenderization of meat. However, research reports have varied as to the degree of correlation between the percentage of collagen solubilization and tenderness. Penfield and Meyer (1975) obtained a correlation coefficient of -0.704** for solubilized hydroxyproline and shear values. Paul et al. (1973) reported a

non significant relationship between collagen solubilization and shear values for ST muscle cores, but a significant relationship (r = - 0.45*) for BF muscle cores. Parrish et al. (1962) found a negative correlation (-0.843,***) between hydroxyproline values and sensory scores. However, McClain et al. (1965) found no relationship between the amount of alkali insoluble collagen in either raw or cooked beef and the shear values of cooked beef. That may be attributed, partially, to the methods and approaches used in determining the extent of collagen solubilization.

Early workers used collagen and elastin nitrogen (N) to measure the amount of connective tissues in muscles to determine the relationship between the residual collagenous tissues after cooking or the collagen solubilization and meat tenderness. The typical approach used in the older methods was to analyze the amount of N in the supposedly pure,extracted,collagenous autoclaved homogenate. The separation of collagenous connective tissues from the other muscle components was the common problem encountered by those researchers. Miller and Kastelic (1956) presented a comprehensive review of the early extraction procedures used to separate collagen from the other muscle proteins. In summary of Miller and Kastelic's (1956) early work, workers used an exhaustive dilute alkali treatment (24 hr or longer extraction time with 0.1 N NaOH) to separate the connective tissue proteins from the myofibrillar proteins. The procedure was based on the assumption that collagen and elastin are insoluble in dilute alkali. However, Miller and Kastelic (1956) cited some works contradicting that assumption. Cited were the works of Lloyd (1938) and Nageotte and Guyon's

(1930), who found that collagen solubilized in extremely dilute alkali or acid. To separate collagen and elastin, Miller and Kastelic (1956) autoclaved the myofibrillar salt (0.6 M KCl) extracted, protein-free residue with added water for several hours. They presumed that autoclaving would selectively hydrolyzed collagen to gelatin, so the N analyzed by microKjeldahl method from the autoclaved soluble fraction was from collagen and that analyzed in the residue was from elastin.

Extraction by blending with subsequent washings and centrifugation of alkali soluble myofibrillar proteins was used by Hartley and Hall (1949) to separate myofibrillar proteins from the connective tissue proteins. Works in which this method was used (Harrison et al., 1953; Skelton et al., 1963) showed reproducible results for raw meat samples, but not for cooked meat samples. They attributed that to possible entrapment of other nitrogenous, non-collagen materials in the collagen fiber complex during heating.

Adams et al. (1960) compared the blendor-centrifuge method of Hartley and Hall (1949) with a protease enzyme method of separating muscle fibers from connective tissue proteins. A protease enzyme (inactive to native collagen) was used to release the entrapped myofibrillar proteins in cooked meat. They found lower collagen values in myofibrillar protein-free, enzyme-extracted cooked meat than in blendor-centrifuged extracted samples.

Richey and Cover (1962) used the method of exhaustive dilute alkali extraction (40 hr) and autoclaving to separate connective tissue proteins from myofibrillar proteins. They determined the amount of alkali insoluble collagen N in raw and in cooked LD and BF steaks by

the microKjeldahl method and by hydroxyproline assay. They observed that muscle proteins in cooked meat were insoluble and more difficult to extract than those from raw meat. Furthermore, difficulty of extraction parallelled increased time of heating and cooking temperature. Because collagen N was analyzed on the alkali extracted residue, Harrison et al. (1953) and Skelton et al. (1963) using Hartley and Hall's (1949) method found greater collagen N in cooked meat than in raw meat. Ritchey and Cover (1962) found that collagen solubilization measured by hydroxyproline assay was 44 % in LD steaks and 41 % in BF steaks cooked to 61°C. With the microKjeldahl method, the percentage collagen solubilization was 33 % in LD and 35 % in BF steaks. Cooking steaks to 100°C resulted in 96 % collagen solubilization in both LD and BF steaks. They attributed the higher collagen solubilization values obtained in samples analyzed using the hydroxyproline assay than in those analyzed by microKjeldahl method to the use of an improper conversion factor for converting hydroxyproline to collagen.

Te determine the relationship between the tenderness and the percentage collagen solubilization and the amount of alkali insoluble collagen in cooked beef, Bayne et al. (1971) used the exhaustive dilute alkali extraction technique to assay for collagen hydroxyproline. They obtained collagen solubilization of 41 or 31 % for SM muscles cooked to 70°C at 93° or at 149°C, respectively. A correlation coefficient of 0.66** was obtained for collagen solubilization and tenderness scores, but no relationship was obtained between the amount of alkali insoluble collagen and shear values. Similarly, no correlation

between alkali insoluble collagen content and shear values of SM, LD, and tricep brachii steaks was reported by McClain et al. (1965).

Paul et al. (1973) extracted the hydroxyproline that solubilized during cooking by homogenizing a solid muscle sample with warm water ($40^{o}C$). The temperature of the water was selected to avoid further collagen solubilization, which occurs at temperatures above $40^{o}C$, or to prevent gelatinization at temperatures of $35^{o}C$ or less. They obtained a range of 1.3 - 13.4 % collagen solubilization in ST and BF muscle cores heated at $163^{o}C$ to 58^{o}, 67^{o}, 75^{o}, or $82^{o}C$. A correlation ($r = -0.80$ ** for ST, $r = -0.55$ ** for BF) occurred between collagen solubilization and shear values. Penfield and Meyer (1975) followed Paul's (1973) procedure to estimate solubilized hydroxyproline in ST muscle cores heated at 93^{o} or at $149^{o}C$ to 40^{o}, 50^{o}, 60^{o}, or $70^{o}C$. They reported a range of 4.2 - 13.6 % solubilized hydroxyproline and a correlation of -0.704** for solubilized hydroxyproline and shear force. Both groups of workers concluded that meat tenderization can not be explained entirely by the extent of collagen solubilization.

Williams and Harrison (1978) determined the amount of hydroxyproline in raw top round muscle samples, cooking drip losses, and in top round steaks cooked by moist heat in an oven film bag to calculate the percentage of solubilized hydroxyproline during cooking. They reported a range of 1.5 - 1.8 % solubilized hydroxyproline in steaks cooked to 70^{o} or $80^{o}C$ at 94^{o} or $149^{o}C$ respectively. Solubilized hydroxyrpoline was related to sensory tenderness scores ($r = -0.77$**) and to shear values ($r = 0.61$**) for steaks cooked at 94^{o} to $80^{o}C$. They suggested that the change in collagenous tissue is not the primary

factor influencing tenderness; denaturation of the myofibrillar proteins may have more effect on tenderness than does change in the collagenous tissue.

Variability of results for hydroxyproline determinations also may be attributed, partially, to the accuracy and the sensitivity of the method used. Samples with low hydroxyproline content require a more sensitive method than those with high content. To obtain accurate and reliable results for hydroxyproline assay, a working concentration for the standard and the sample must be established. Also, possible interferring substances in the sample must be removed or corrected, and the functions of each of the reagents used must be understood, and conditions for color development must be followed. Studies on different variables affecting the analysis for hydroxyproline such as the effects of the reagents and their concentrations, optimum time and temperature for color development, stability of the chromophore, and possible procedures to remove or correct for interferring substances have been undertaken by many investigators.

Neuman and Logan (1950) developed a spectrophotometric method for determining hydroxyproline based on the specific chromophore formation of p-dimethylamino benzaldehyde (p-dmab) with the oxidation products of hydroxyproline (2-carboxylic acid, pyrrole). In their assay, hydroxyproline is oxidized with hydrogen peroxide and stabilized with n-propanol before the oxidation products of hydroxyproline complexed with p-dmab.

Wierbicki and Deatherage (1954) found that in beef samples

analyzed by Neuman and Logan's (1950) method, tyrosine and tryptophan interferred with color development. Because, on the average, beef contains 1.02 % tyrosine and 0.33 % tryptophan, they suggested correction factors in the calculation of hydroxyproline to account for the presence of those interferring compounds in beef hydrolyzates.

To remove the compounds interferring with the chromphore formation, Prockop and Udenfriend (1960) proposed an extraction procedure using toluene as the extractant to separate pigments and other unspecified compounds in biological samples from the oxidation products of hydroxyproline. To remove humins (blackish substance containing tryptophan) from the acid hydrolyzate, a combination of activated charcoal and cationic resin was used. To increase the sensitivity of the method they recommended the reduction of sample and reagents volume.

Stegeman and Stalder (1967) found that increasing charcoal by 1000 fold did not influence the recovery of hydroxyproline. They also reevaluated the use of chloramine T as an oxidant, which they previously used to substitute for the highly unstable hydrogen peroxide oxidant used by Neuman and Logan (1950). They found that using chloramine T as an oxidant gave more reliable and highly reproducible results than did using hydrogen peroxide as the oxidant.

To obtain reliable and accurate absorbance readings for hydroxyproline, Woessner (1961) extracted from the developed chromophore the unreacted p-dmab (which gave a brownish cast) with benzene just before the absorbance reading was taken. They also reported that a concentration of 0.4 N NaCl and 0.1 - 0.2 ml of methyl red in the assay tube lowered the color intensity of the developed chromophore.

To improve the stability of the chromophore, Bergman and Loxley (1963) suggested the use of 2-propanol as a solvent for the chromophore. They showed that increasing the concentration of the 2-propanol kept p-dmab in a solution of low acidity more effectively than most of the solvents used by different investigators provided samples were protected from UV light. Because the color formed when 2-propanol was the solvent could stand without fading for a longer time, variation of color yield attributable to a delay in the absorbance reading was minimized.

Instrumental measurement of meat texture. The recognition that tenderness in cooked meat is related to changes in structural components (myofibrillar and connective tissues), which constitute the total impression of sensory tenderness, led to the definitions of basic textural characteristics of objective (mechanical) measurements. Friedman et al. (1963) used a General Food (GF) texturometer to measure texture in foods. They based their texture measurements on the descriptive evaluation of texture properties as classified by a highly trained texture *profile panel* (Szeczesniak et al., 1963). The GF texturometer has a flat faced cylinder that compresses a bite sized cube of food (approximately 1.2 cm along each side) to 25 % of its original height (75 % compression) two times in a reciprocating motion that imitates the chewing action ("chews"). A force-time curve, portraying the force for the simulated chewing action is plotted using a strain gauge and a strip chart recorder. Texture profiles derived from the force-distance compression curve are: hardness, cohesiveness, elasticity, *adhesivenes*, chewiness, brittleness, and gumminess (Appendix, p. 79 - 80).

Bourne (1978) used Friedman et al. (1963) GF texturometer definitions of texture characteristics for Instron texture measurements, except for elasticity, which was measured directly from the Instron penetration curve, and for work, which he defined as the force-distance integral under the compression portion of the curve. Bourne (1978) defined the whole area under the penetration force-distance curve as the summation of work done by the machine on the food sample (compression) and the work done by the food on the machine (decompression), Appendix, p. 81. In his brief review of the texture profile analysis, Bourne (1978) stated that the GF texturometer has an eccentric driving system, so the movement of the plunger follows a sinusoidal pattern. The crosshead speed of the GF texturometer decelerates as it approaches the end of the compression stroke, momentarily stops, then decelerates again as it makes the upward stroke while the strip chart speed remains constant. The curve generated is a force-time curve, thus the area under the curve does not represent a true work function. Also, as the load is applied in the GF texturometer, the supporting platform bends a little, which likely reduces the resolution between samples. In contrast, the Instron is rigid, hence there is no problem of bending. The crosshead speed and the chart speed of the Instron are driven synchronously, thus giving both a force-time and a force-distance curve, which allows for accurate calculation of true work. However, Bourne (1978) also pointed out that although the force in the first bite is linear with distance, the disadvantage of the Instron machine is that the speed of the Instron compression plate is rectilinear and does not imitate the sinusoidal speed pattern of the human jaw during mastication. Therefore, to

closely estimate the mastication pattern for different foods, different instrumental conditions are necessary.

Bouton et al. (1971) used the Instron to make penetration and shear deformation measurements in rectangular pieces of meat (0.66 x 1.5 x 1.3 cm). A Warner-Bratzler shear attachment was used to shear meat perpendicular to the muscle fibers. Penetration was done by driving a 0.63 cm diameter flat ended plunger perpendicular to the muscle fibers 80 % of the way through a 1.3 cm thick cooked sample. "Hardness" and "cohesiveness" were estimated from the compression (force-distance) curve (Friedman et al., 1963). "Chewiness" was estimated as the product of "cohesiveness" x "hardness." Both Warner-Bratzler shear values and Instron hardness values were correlated to sensory tenderness ($r = 0.80^{***}$ to 0.86^{***}).

Larmond and Petrosavits (1972) developed two measurements from a Warner-Bratzler deformation (shear force-time) curve. They observed that a Warner-Bratzler device deforms a meat sample before shearing begins, so they interpreted the first part of the Warner-Bratzler deformation curve as a compression phase that indicates the force required to produce a given deformation. From the sensory point of view, that part of the curve is considered as a measurement of firmness of the sample. Peak force indicates the force required to shear a sample and provides an index of cohesiveness. They studied the relationship between those measurements and sensory tenderness, and found that sensory tenderness was influenced more by "shear cohesiveness" than by "firmness" of the meat.

To assess the contribution of myofibrillar and connective tissue in a Warner-Bratzler shear force deformation curve, Bouton et al. (1975a) made five basic measurements: (1) initial yield force; (2) peak force; (3) initial yield distance;(4) final yield distance; and (5) slope at initial yield (Appendix, p. 81). They found that the initial yield force represented the force required to compress and initiate shear fracture planes through myofibrillar structure, and it was greatly dependent on myofibrillar strength. The difference between the initial yield force and the peak force was an indication of the strength of connective tissue and other structures remaining after the yield of the myofibrillar structure.

Bouton et al. (1975b) stated that initial yield force in a shear deformation curve could be an excellent indicator of myofibrillar toughness and be useful in assessing meat treatment effect. Furthermore, they reported that the poor correlation between sensory tenderness and shear force measurements pointed out by Szczesniak and Torgeson (1965) might be explained by the inadequacy of the Warner-Bratzler instrument to indicate the contribution of connective tissue. They concluded that detailed analysis of the shear deformation curves could yield comparative estimates of the myofibrillar and connective tissue contribution in the objective assessment of tenderness.

Moeller (1980) studied further the relationship of parts of the shear deformation curve to muscle fibers and connective tissues. The investigator found that Warner-Bratzler's initial yield force (WB-M), used to evaluate changes in myofibrillar tissues and the final yield force (WB-C), used to evaluate changes in connective tissues, were

better estimators of sensory tenderness and collagen solubility than was the WB peak force.

MATERIALS AND METHODS

Meat used

Forty AD muscles from 20 bull carcasses were purchased from the Kansas State University Department of Animal Science and Industry. The bulls were on grass until about 10 months old, then they were fed a ration of 56.1 % milo, 40.2 % forage sorghum silage, and 3.7 % vitamin and mineral supplement until slaughtered at an average weight of 510 kg (Group I, 10 bulls) or 450 kg (Group II, 10 bulls).

Carcass processing treatments, slaughter weights, and USDA quality grades are given in Table 1. Individual animal slaughter weights, carcass weights, processing treatments, and USDA quality are in table 9 (Appendix, p. 82). One side of each carcass was conventionally chilled (CC), the other side was electrically stimulated and hot boned with the excised adductor (AD) muscles being chilled slowly (ESHB-SI) or fast (ESHB-F).

Cooking

The AD muscles from the CC side of each carcass and the paired AD muscle from the ESHB side of the carcass were assigned randomly to one of two cooking methods, oven roasting (OR) or cooking muscle strips in a model system (S), Table 2. Either two roasts or two sets of strips were cooked at each of 20 evaluation periods.

Table 1 - Carcass processing treatments, slaughter weights, and USDA quality grades

Processing treatment	Treatment conditions	Approximate carcass weight, hot, kg		USDA quality grade 24 hr postmortem
		Average	Range	
Conventionally chilled (CC), one side of each carcass	3^{o} - 8^{o}C 48 hr, adductor muscles excised, vacuum packed, stored at 4^{o} - 5^{o}C until 7 days postmortem, and frozen at -26^{o}C	Group I		Group I
		324	307 - 340	High Standard to Low Choice
		Group II		Group II
		276	245 - 316	High Standard to Average Choice
Electrically stimulated-hot boned (ESHB), one side of each carcass	420 volts, A.C., 68 sec "on," 32 sec "off" for 2 min at 45 min postmortem, hot boned at 2 hr postmortem	Same as for CC		Not graded
ESHB-Sl (Slow chilling)	Adductor muscles loosely wrapped in vacuum bags, chilled (3^{o} - 8^{o}C) in a box until 48 hr postmortem, vacuum packed, stored at 4^{o} - 5^{o}C until 7 days postmortem, and frozen (-26^{o}C).			
ESHB-F (fast chilling)	Adductor muscles given the same treatments as those slow chilled except that they were chilled on a tray instead of in a box.			

Table 2 - Order and method of cooking adductor muscles

Cooking period	Animal number	Processing treatment 1	Processing treatment 2	Cooking method
		Group I		
1	14	CC	ESHB-Sl	OR
2	16	CC	ESHB-F	S
3	24	CC	ESHB-F	OR
4	45	CC	ESHB-F	S
5	37	CC	ESHB-F	S
6	70	CC	ESHB-Sl	OR
7	78	CC	ESHB-Sl	OR
8	74	CC	ESHB-F	OR
9	110	CC	ESHB-Sl	OR
10	206	CC	ESHB-Sl	S
		Group II		
11	27	CC	ESHB-Sl	S
12	103	CC	ESHB-F	OR
13	82	CC	ESHB-Sl	OR
14	91	CC	ESHB-F	OR
15	140	CC	ESHB-F	S
16	167	CC	ESHB-F	OR
17	175	CC	ESHB-Sl	S
18	238	CC	ESHB-Sl	S
19	184	CC	ESHB-Sl	OR
20	210	CC	ESHB-F	OR

CC, Conventionally chilled
ESHB-Sl, Electrically stimulated-hot boned, slow chilled
ESHB-F, Electrically stimulated-hot boned, fast chilled
OR, conventional oven roasting
S, strips cooked in a model system

Muscles assigned to OR were thawed four hours at approximately 25°C, then for 16 hr at approximately 4°C. Thawed muscles were trimmed to provide roasts of similar size and shape (avg, 700 g; 10 x 11 x 5 - 8 cm), Fig. 1. A short bulb thermometer was inserted into the geometric center of each trimmed roast, which was placed on a low rack in a shallow pan and roasted in a rotary hearth oven at 177°C to 70°C.

The rate heat penetrated the roast was observed by noting the temperature changes for the roasts from the initial temperature to 70°C at 5 min intervals. Total cooking time (min) was recorded; total, volatile, and drip cooking losses were calculated as percentage of the weight of the thawed raw roast. Roasts were sampled by a fixed position plan (Fig. 2).

One week before cooking, AD muscles assigned to S were thawed 4 hours at approximately 25°C, then cut into strips (2.3 x 2.3 x 8 cm) with the muscle fibers running parallel to the length of the strips (Fig. 1). Individual strips were wrapped tightly in house-hold plastic wrap to make them cylindrical in shape. The group of strips from each muscle was wrapped in aluminum foil, frozen, and stored at -22°C until used.

At the time of cooking, 16 strips (eight from each of the two muscles cooked at one evaluation period) were thawed for 25 min at approximately 25°C, unwrapped and then placed in 50-ml centrifuge tubes with thermometers inserted lengthwise into the centers of six strips. Because thermometer holes affect the thickness of the samples, and ultimately, the values obtained for Instron penetration and shear measurements, no thermometers were inserted in two strips of each of the muscles, which were used for Instron texture measurements. Strip

Fig. 1. Adductor muscles

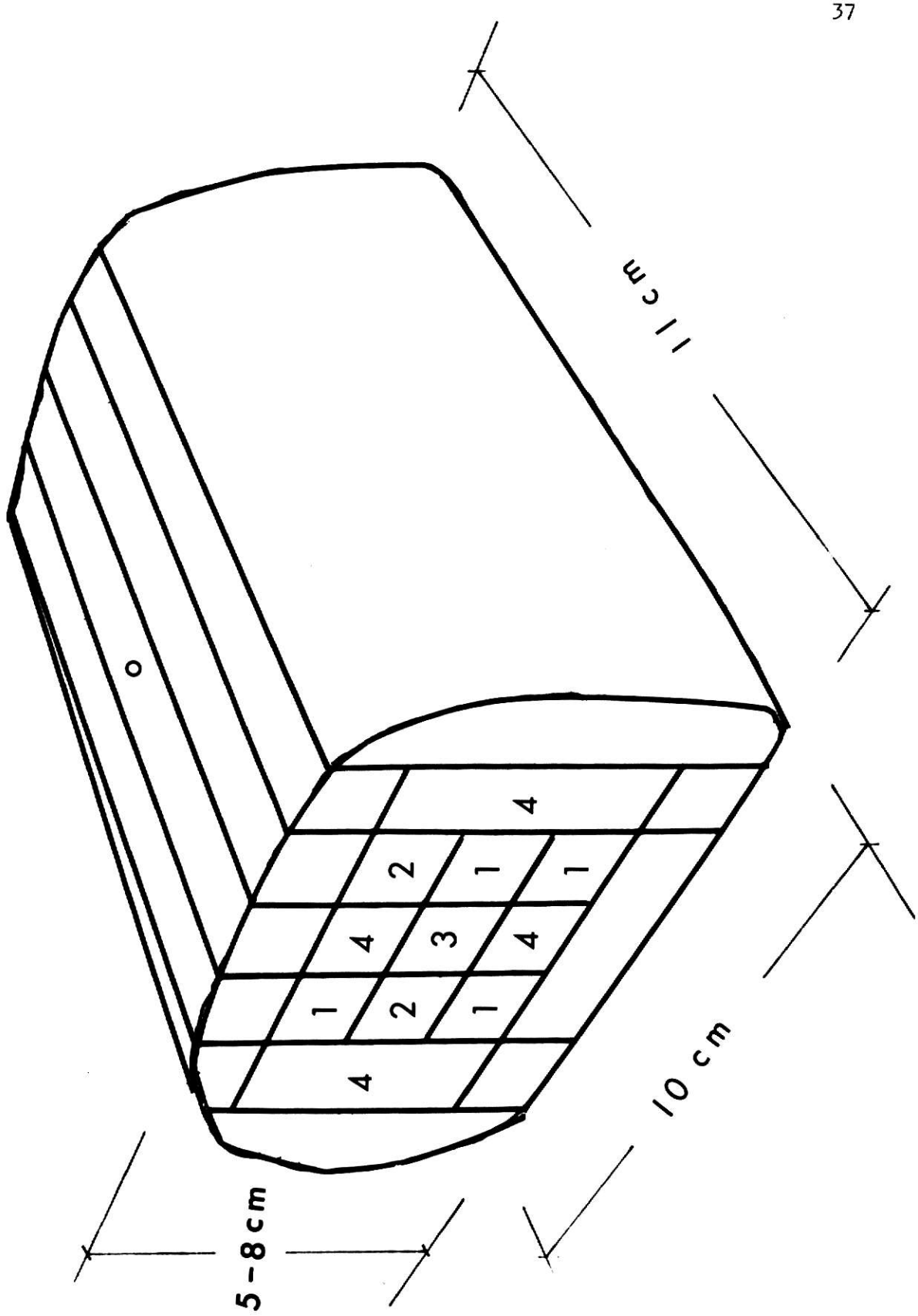
A. Adductor muscle to be cut into 2.3 x 2.3 x 8 cm strips, shown at left are sample strips

B. Muscle cut into 10 x 11 x 8 cm roast

B
A

Fig. 2. Sampling plan for cooked roast

1. Sensory evaluation samples
2. Instron texture samples
3. Water holding capacity measurements
4. Total moisture, ether extract, pH, and hydroxyproline samples

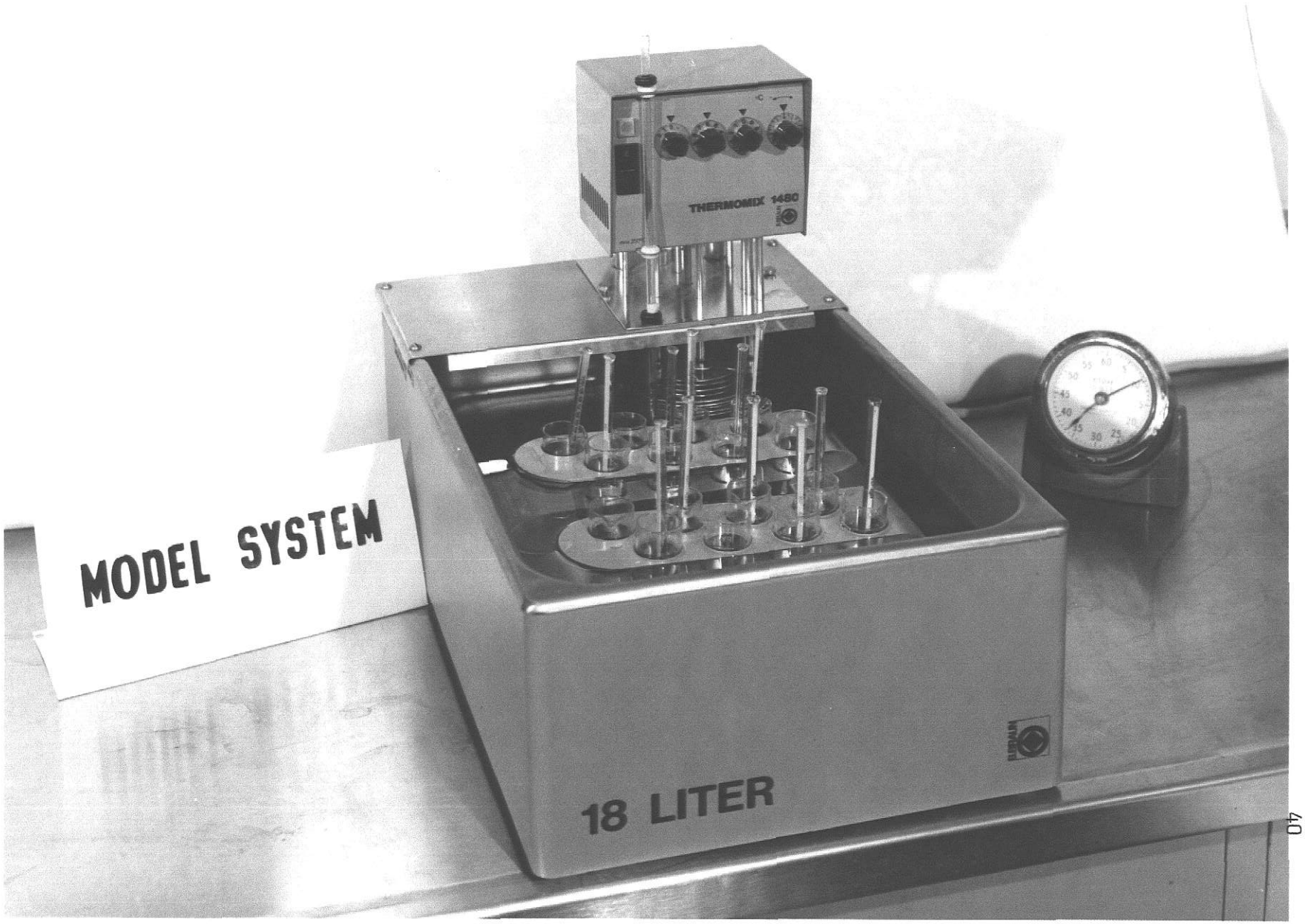

11 cm
o
4
2
1
1
4
3
4
1
2
1
4
10 cm
5-8 cm

portions with thermometer holes and the trimmings from samples for sensory and Instron texture measurements were ground and used for moisture, hydroxyproline, ether extract, and pH measurements. Test tubes were placed in an 18-liter circulating water bath (Fig. 3), in which strips were cooked to 70°C at a rate comparable to oven roasting an 890 g AD roast at 177°C. The temperature of the water bath rose approximately 1°C/min until the temperature of the strips was between 45° and 55°C, after that the water bath temperature rose about 0.6°C/min until the strips reached an end point of 70°C. The procedure for programming the water bath is given in the Appendix, p. 86.

Sensory evaluation

Tenderness, juiciness, mealiness,and softness of 1.3-cm cubes of cooked muscle were evaluated by an 8-member experienced laboratory panel using a 7 to 1-point intensity scale (Forms I and II, Appendix, p. 83-84). Instructions and training were given to the panel during the preliminary work. Each panel member standardized his tenderness scores by counting the number of chews necessary to masticate completely a cube of meat. Cubes were presented to panelists in the top of half-pint enamel double boilers set over hot water (approx 60°C) with the entire system on an electric hot tray set at low heat (approx 35°C). Immediately after samples were prepared for evaluation, each panelist selected randomly two cubes of muscle from samples representing each treatment (CC or ESHB). One sample was used to evaluate tenderness; the other cube was used to score juiciness and textural components.

Fig. 3. A model system; 18 l circulating water bath containing test tubes with strips, thermometers are inserted at the centers of each 12 strips, at left is a timer


MODEL SYSTEM
THERMOMIX 1480
18 LITER

Instron texture measurements

The Instron Universal Testing Machine, Model 1122, was used for penetration and shear measurements on rectangular strips of a cooked muscle (1.3 x 1.3 x 7 cm).

Penetration measurements. Hardness, cohesiveness, elasticity, and chewiness were derived from compression curves that were obtained when a flat ended cylindrical puncture probe (0.63 cm dia) was driven vertically about 80 % of the way through a rectangular strip (1.3 x 1.3 x 7 cm) that was positioned with the fibers perpendicular to the direction of penetration (Bouton et al., 1971). The probe was driven into the strip twice with two compression cycles at each of the three locations (center and about 1 cm from each end). A 50-kg load with a crosshead speed of 50 mm/min and a chart speed of 100 mm/min was used to record a force-distance curve.

"Hardness," the force (kg) necessary to achieve the first penetration, was recorded as the peak height of the first penetration. "Cohesiveness" was the ratio of the work done during the second penetration to that done during the first penetration. Work was estimated as the area (sq cm) of the first or the second penetration, measured with a compensating polar planimeter (Friedman et al., 1963). "Elasticity," the height (mm) that the muscle recovered during the time that elapsed between the end of the first penetration and the beginning of the second penetration, was measured as the horizontal distance (mm) from the origin of the second penetration to the perpendicular line dropped from the peak of the first penetration curve multiplied by (crosshead speed/chart speed). "Chewiness" was derived as the product

of "hardness" x "cohesiveness" x "elasticity" and was measured in kg-mm. (Friedman et al., 1963, Bourne, 1978).

Shear measurements. Muscle strips (1.3 x 1.3 x 7 cm) were sheared with a Warner-Bratzler shear attachment (D 372-26) for the Instron, using the same load, crosshead speed, and chart speed used for penetration measurements. Muscle strips were sheared in the center and approximately 1 cm from each end. The shear force-distance curve was recorded and used to evaluate shear cohesiveness and firmness. "Shear cohesiveness" was the peak force (kg) on the shear deformation curve. "Firmness" was measured as the slope of the line drawn from the origin of the curve to the peak, and expressed in kg/min (Larmond and Petrosavits, 1972).

Total moisture (TM), ether extract (EE),water holding capacity (WHC), and pH

Percentage TM in raw and cooked muscles was measured by drying duplicate 10-g samples of ground muscles for 120 min (raw muscle) or for 60 min (cooked muscle) at 121^{o}C in a C.W. Brabender Semi-Automatic Rapid Moisture Tester. Triplicate measurements of percentage dry matter and EE were determined (A.O.A.C., 1975) for samples of ground raw or cooked muscle by the Analytical Service Laboratory of the Department of Animal Sciences and Industry at Kansas State University. Percentage TM was calculated by subtracting the percentage dry matter from 100.

Triplicate measurements of WHC were made on samples (300 mg) of cooked meat, using the press method of Miller and Harrison (1965). The ratio of the pressed meat area to the juice area was designated as the expressible liquid index (ELI). WHC values were obtained by subtracting the ELI from 1.0, arbitrarily chosen as the maximum ELI. The ELI is inversely related to the amount of liquid expressed from the sample; the larger the WHC value, the more liquid expressed.

Duplicate pH readings were made on slurries of 5 g ground muscle and distilled, deionized water. The slurry was stirred 30 sec with a magnetic stirrer on an electric stirring table, the pH was measured, the beaker was turned 180^{o}, the slurry was stirred an additional 30 sec, and a second reading was taken. The pH meter was standardized against a buffer of pH 6.86 (Rogers et al., 1967).

Hydroxyproline measurement

Duplicate 2-g ground raw or cooked samples were used to determine hydroxyproline. The amount of hydroxyproline that solubilized during the cooking process was determined by calculating the difference between the total amount of hydroxyproline in the raw meat sample and the amount of hydroxyproline in the water washed ground cooked sample.

The raw sample was homogenized with 10 ml distilled, deionized water using a Brinkman Unitron homogenizer for one minute at speed 13. The meat homogenate and the washings from the homogenizer were combined and made up to 20 ml with distilled, deionized water and transferred to a 50-ml ampoule. Concentrated hydrochloric acid

(HCl, 20 ml) was added to make a final concentration of 6 N HCl. Likewise, cooked samples were washed with 20 ml of warm (40°C) distilled, deionized water, homogenized for 30 sec in the Brinkman Unitron homogenizer, centrifuged at 4,000 rpm for 10 min, and decanted to remove the water soluble proteins (Paul et al., 1973). The washing process was repeated to ensure complete removal of solubilized proteins and amino acids before a final homogenate of 20 ml was transferred to a 50-ml ampoule and acidified with 12 N HCl to provide a final concentration of 6 N HCl. The ampoules containing the acidified samples were sealed using a propane jet torch and incubated in an oven at a temperature of 107°C for 20 hrs (complete hydrolysis). Preliminary work showed that the amount of hydroxyproline reached a plateau after 18 to 30 hr of incubation. The resulting hydrolyzate was neutralized to a pH of 6.5 - 7.0 with 2.5 N NaOH and made up to 250 ml in a volumetric flask with distilled, deionized water before the final assay. The assay for hydroxyproline was done using one half the volume of the sample and reagents suggested by Bergman and Loxley (1963) to increase the sensitivity of their method, and to obtain a more accurate measurement of the low hydroxyproline concentration in the meat sample. The details of this method are given in the Appendix, p. 87-90. A standard curve for hydroxyproline with concentrations ranging from 0 - 10 μg was used to calculate the amount of hydroxyproline in the sample.

Statistical analyses of data

A split plot design with 5 replications was used to evaluate effects of the treatment combinations on the measurements made for bull AD muscle. The main plots were the cooking systems (OR, S) and chilling methods (F, S1); the subplots were the carcass treatments (CC, ESHB). The data obtained for each measurement were analyzed by the following analysis of variance:

Source of variation	D/F
Cooking system (A)	1
Chilling method (B)	1
A x B	1
Error (a)	16
Carcass treatment (C)	1
C x A	1
C x B	1
C x B x A	1
Error (b)	16
Total	39

Because measurements were not significantly different between chilling methods, data obtained for ESHB-F and ESHB-S1 were combined and reanalyzed according to a split plot design with 10 replications.

The analysis of variance was:

Source of variation	D/F
Cooking system (A)	1
Error (a)	18
Carcass treatment (B)	1
A x B	1
Error (b)	18
Total	39

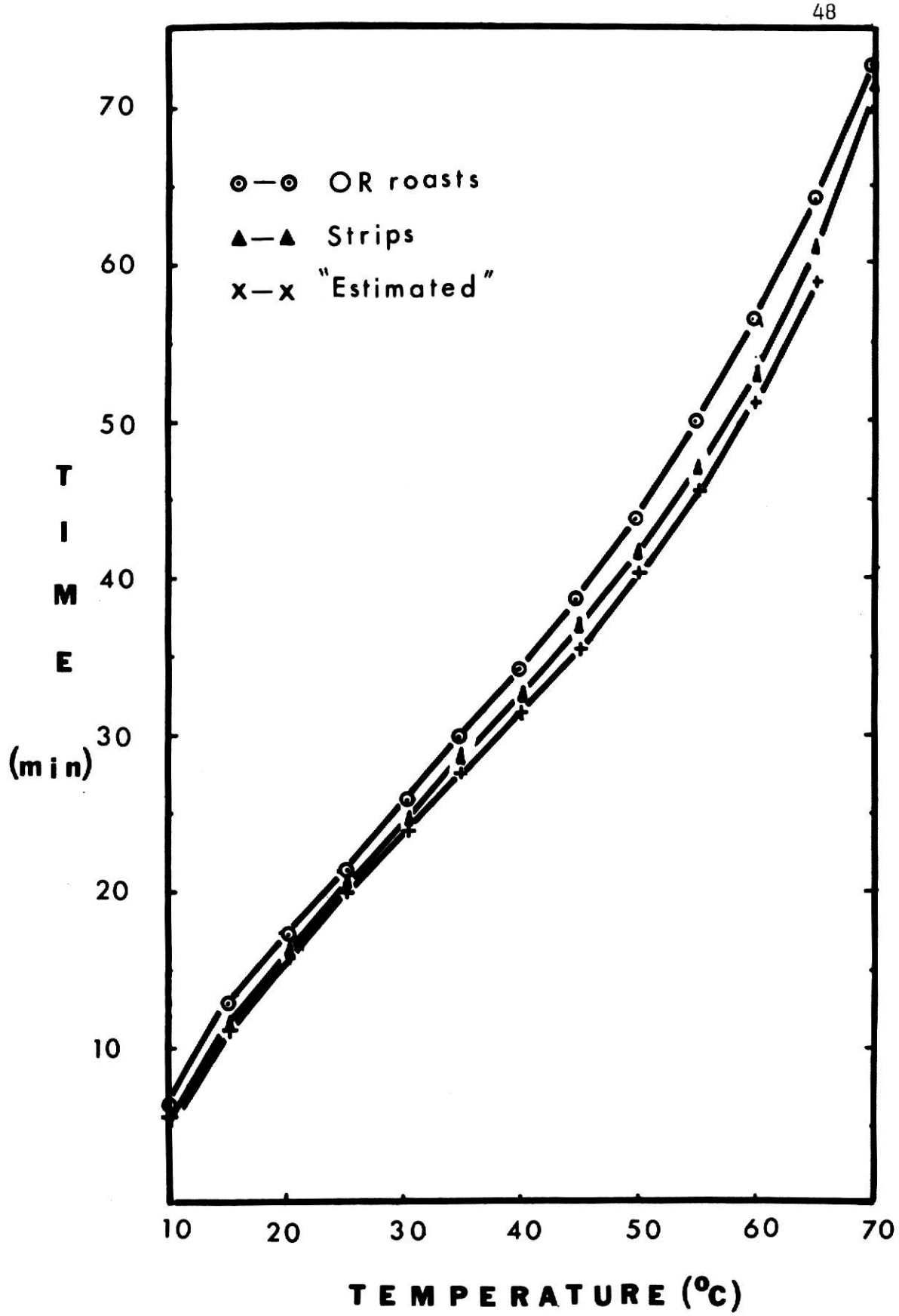
An F-test was used to compare sample variances to determine if precision in measurements differed between cooking systems. Correlation coefficients were calculated for selected paired variates on the basis of cooking systems, carcass treatments, and on data with all treatments combined.

RESULTS AND DISCUSSION

Effects of the cooking system

Heating time. Time that heat penetrated the roasts (OR) and strips (S) and the heating curve that OR and S were expected to follow ("estimated")are shown in Fig. 4. Heat penetration curves were plotted between 10^{o} and 70^{o}C, because below 10^{o}C, differences in heating time

Fig. 4. The time heat penetrated the AD muscle from 10^{o} to 70^{o}C for muscle strips, OR roasts, and (OR) roasts "estimated" (average heat penetration curve that strips and roasts were expected to follow).


70
60
50
40
30
20
10
TIME (min)
⊙—⊙ OR roasts
▲—▲ Strips
x—x "Estimated"
10
20
30
40
50
60
70
TEMPERATURE (°C)

among S, OR, and the "estimated"roasts were large, resulting from their initial temperature differences. The time required for the "estimated" roasts, S, or OR to increase from their initial temperatures of -1.0°, -1.2°, or 2.5°C to 10°C was 40.9, 24.6, or 15.9 min.

At any point from 10° to 65°C, the time heat penetrated S was not significantly different from that of "estimated" roasts. Also, S and OR did not differ significantly in the time required to increase in internal temperature from 10° to 50°C, but roasts required a longer ($P < 0.05$) time than did strips to increase from 50° to 55° - 65°C. From 65° to 70°C, no significant differences in heating time were observed between S and OR.

Measurements affected significantly by the cooking system. Measurements significantly affected by the cooking system (Table 3) were: cooking time, drip loss, volatile loss, percentage total moisture, and percentage ether extract. Cooking time given in Table 3 is the time between the initial temperature and 70°C. A longer ($P < 0.002$) cooking time was required for strips than for roasts to reach the end point temperature (70°C), which might be accounted for, partially, by the longer time required for heat to penetrate strips between the initial temperature and 10°C.

S and OR did not differ significantly in percentage total cooking losses (Table 10, Appendix, p. 91), but volatile loss was higher ($P < 0.0001$) and drip loss was lower ($P < 0.0001$) for OR than for S. Those results were expected, because with OR, most liquids that exuded from the meat during cooking were evaporated, which accounted for greater

Table 3 - Means, standard errors[a], F-values, and probability levels for measurements affected significantly by the cooking system

Measurement	Strips[b]	Roasts[b]	F-value	P
Cooking measurements				
Cooking time, min[c]	89.7 (±1.68)	81.4 (±1.68)	13.2	0.002
Drip loss, %	23.6 (±0.71)	3.7 (±0.71)	366.2	0.0001
Volatile loss, %	2.9 (±0.64)	21.1 (±0.64)	392.4	0.0001
Total moisture, %				
Cooked, Brabender	66.4 (±0.29	64.1 (±0.29)	30.7	0.0001
Cooked, AOAC	67.3 (±0.89)	63.5 (±0.89)	10.5	0.006
Ether extract, %	1.7 (±0.34)	3.8 (±0.34)	17.5	0.008

[a]Values in parentheses.

[b]Data for conventionally chilled (CC) and electrically stimulated-hot boned (ESHB), fast (F) or slow (Sl) chilled were combined.

[c]Includes time from initial temperature to 70°C.

volatile loss. In the water bath, strips were enclosed in glass centrifuge tubes and most of the liquid remained in the tubes as drip.

Total moisture, analyzed by using the Brabender Rapid Moisture Tester or by the AOAC method was greater ($P < 0.0001$, $P < 0.006$, Table 3) for cooked strips than for cooked OR roasts. The lower

moisture content of the OR roasts may be attributed, partially, to the moisture gradient in roasts, the central portion being moister than the portion near the edges. About 75 % of the ground muscle samples for total moisture, ether extract, pH, and hydroxyproline determinations were taken near the edges of the roast (Fig. 3) and about 25 % were from the central portion. Water holding capacity, which was measured in samples taken from the center of both the roasts (0.66) and strips (0.64), did not differ significantly between the two cooking systems. That also suggests that differences in total moisture between strips and roasts were attributable to sampling locations in roasts. Bengtsson et al. (1976) in their study of mass and heat transfer in roasted beef, found maximum moisture and minimum temperature near the center of an 800 to 900-g roast. Similarly, higher ($P < 0.05$) temperature and the appearance of doner and drier edges than centers of top round steaks cooked to 65°C at 177°C were observed by Moore et al. (1980). Funk et al. (1966) reported similar observations for beef loin roasts. In our experiment, cooked roasts yielded greater ($P < 0.008$) percentage ether extract than did cooked strips.

Despite the fact that roasts took longer ($P < 0.05$) heating time to reach an internal temperature of 55° to 65°C, differences between samples cooked by S or OR were not significant for sensory tenderness and texture, Instron texture, and solubilized hydroxyproline. McDowell et al. (1982) found no significant differences in sensory characteristics between oven roasts cooked by dry heat at 177°C and muscle strips heated in the model system at a rate similar to that of roasts, but they obtained significantly lower Instron hardness, chewiness,

firmness, and shear cohesiveness values for strips than for roasts, which they attributed to a significantly slower rate of heat penetration in strips at the 50° - 60°C range. Our results for texture characteristics and solubilized hydroxyproline were in agreement with those obtained by Brady and Penfield (1981), who reported no significant differences in those measurements between roasts cooked at 149°C to 60° or 70°C and strips heated at rates simulating those of the roasts.

Effects of the carcass processing treatments

CC vs. ESHB. Measurements for which significant differences occurred between CC and ESHB samples were only for: cooking time, sensory tenderness and mealiness, and percentage solubilized hydroxyproline (Table 4). ESHB samples required longer ($P < 0.01$) time to reach 70°C, were less tender ($P < 0.04$) and mealy ($P < 0.01$) and contained more ($P < 0.0007$) solubilized hydroxyproline than CC samples. Longer ($P < 0.01$) cooking time for ESHB samples may account, partially, for the significantly greater amount of solubilized hydroxyproline in those samples.

Although ESHB samples were scored significantly less tender and less mealy than the CC samples, the respective mean scores differed by only 0.3 or 0.4 points, and the standard errors were only 0.09 and 0.17 (Table 4). Instron texture values (Table 11, Appendix, p. 92) indicated that CC and ESHB samples were comparable in textural characteristics.

Table 4 - Means, standard errors[a], F-values, and probability levels for measurements affected significantly by the carcass treatment

Measurement	CC[b]	ESHB[b]	F-value	P
Cooking time, min	83.9 (±0.79)	87.2 (±0.79)	8.4	0.01
Sensory scores[c], 7-1				
Tenderness	5.6 (±0.09)	5.3 (±0.09)	4.8	0.04
Mealiness	4.7 (±0.17)	4.3 (±0.17)	7.9	0.01
Solubilized OHProline, %	17.6 (±1.10)	26.7 (±1.10)	17.7	0.0007

[a]Values in parenthesis.

[b]Data for oven roasts (OR) and strips cooked in the model system (S) were combined.

[c]Range, 7 (tender, mealy) to 1 (tough, chewy).

CC, conventionally chilled.

ESHB, electrically stimulated-hot boned.

Our solubilized hydroxyproline values ranged from 11.6 to 28.3 %, and were higher than values reported by other researchers, who also used water to extract hydroxyproline that solubilized during cooking. Paul et al. (1973) reported that ST and BF muscles cooked to 58°, 67°, 75°, or 82°C at 163°C yielded collagen solubilization of 4.3 to 13.4 %. Penfield and Meyer (1975) and Brady and Penfield (1981) showed that ST muscles cooked to 40°, 50°, 60°, or 70°C and to 60° or 70°C at 93° or 149°C had 1.3 to 13.6 % and 4.3 to 10.0 % solubilized hydroxyproline, respectively. Williams and Harrison (1978) reported a range

of 1.5 to 1.8 % solubilized hydroxyproline for top round steaks cooked to 70^{o} or 80^{o}C at 94^{o} or 149^{o}C. All the above authors analyzed the water extracts from cooked muscles and their drippings. In our study, drippings from the oven roasts formed a hard coagulum in the roasting pan, so we could not measure the solubilized hydroxyproline accurately using the approach of the previous workers. Our approach to estimating the amount of hydroxyproline that solubilized during cooking was based on the assumptions that: (1) water extractable hydroxyproline in cooked muscle came mainly from the solubilization of collagenous tissues, and (2) that the assay used was highly specific to hydroxyproline. The high values obtained in this study may be attributed, to the possibility that some partially solubilized collagen was extracted by warm water. Ideally, the amount of hydroxyproline in the hydrolyzed raw sample is equivalent to the summation of hydroxyproline in the hydrolyzed water extracted cooked sample, that of the water extract, and that of the drippings. Because percentage solubilized hydroxyproline was calculated using the equation:

$$\% \text{ Solubilized OHProline} = \frac{\text{mg OHProline in raw sample (dry wt)} - \text{mg OHProline in extracted cooked sample (dry wt)}}{\text{mg OHProline in raw sample (dry wt)}} \times 100$$

therefore, less hydroxyproline remaining in the water washed acid hydrolyzed cooked sample resulted in a higher percentage of solubilized hydroxyproline than when percentage solubilized hydroxyproline was calculated as the ratio of the sum of free hydroxyproline in the water

extract and in that of the drippings to the amount of hydroxyproline in the raw sample multiplied by 100.

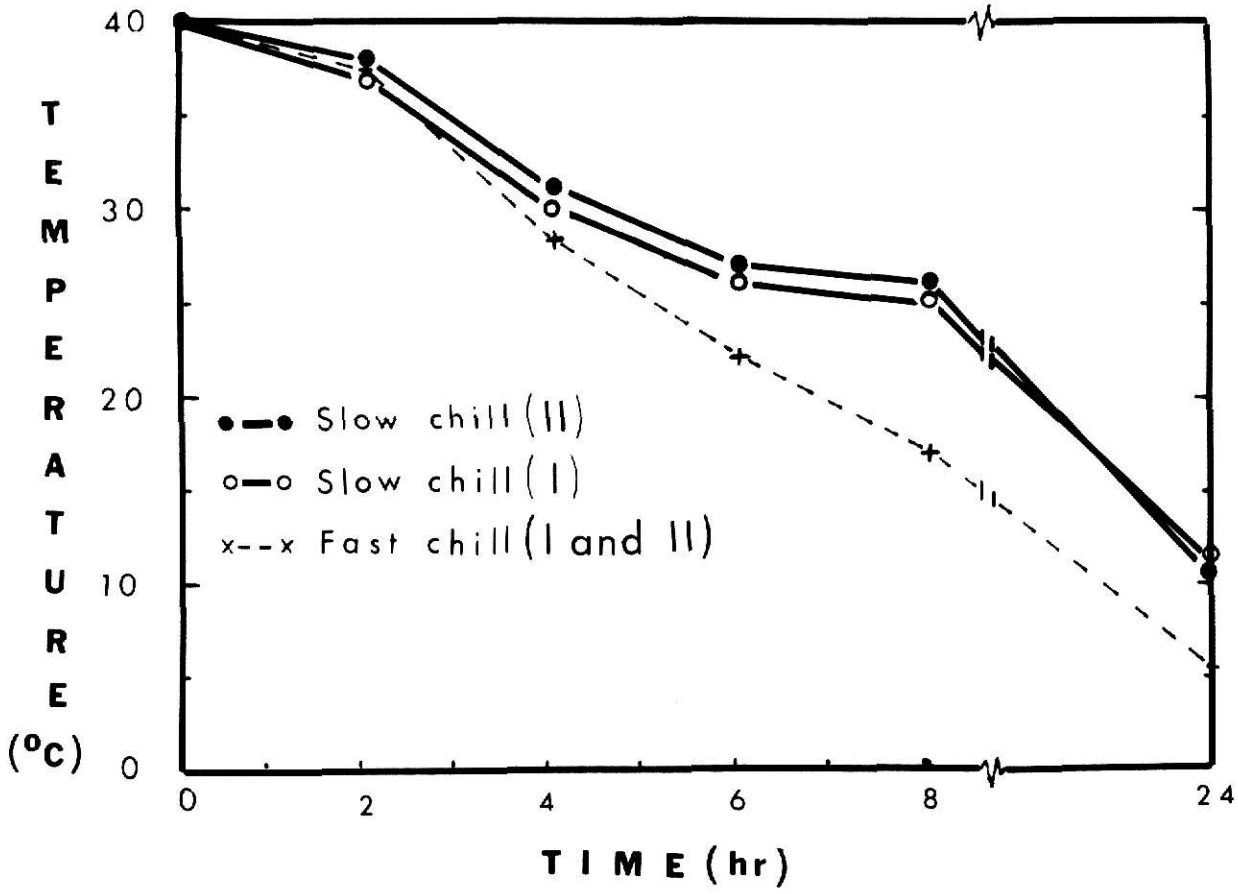
Fast vs. slow chilling. Because of the nature of the experimental design, the effects of the chilling rate for ESHB muscles (fast vs. slow) were confounded with the carcass treatments. The chilling effects referred to in this discussion were the effects of CC + ESHB - S1 or CC + ESHB - F. Means and F-values (Table 12, Appendix, p. 93) showed that no measurement was affected by the chilling rate. Time-temperature curves (Fig. 5a) indicated that ESHB muscles chilled in boxes (S1) and on trays (F) had practically the same rates of cooling during the first 3 hr of chilling. Differences in chilling rate were evident only between 4 and 24 hr of chilling. On the other hand, pH of ESHB muscles (Fig. 5b) declined to 6.0 or below between 2 and 3 hr post mortem, suggesting that, at that time, ESHB muscles chilled fast and slow become less vulnerable to cold shortening, thus no significant differences in tenderness measurements were observed between animals whose stimulated and hot boned sides were subjected to either rate of chilling. Bendall et al. (1976) and Locker et al. (1975) pointed out that cold shortening does not occur to any appreciable extent below pH 6.0.

Significant treatment combination interactions

Measurements significantly affected by the interaction between cooking system and carcass treatment were: cooking time, Instron hardness, and the percentage solubilized hydroxyproline (Table 5). The

Fig. 5a - Average rate of cooling from slaughter time to 24 hr post mortem for electrically stimulated-hot boned bovine SM muscles, slow or fast chilled (I - for animals slaughtered on April 14, 1981; II - for animals slaughtered on May 19, 1981).

Fig. 5b - Average rate of pH decline from slaughter to 24 hr post mortem for CC and ESHB bovine SM muscles (I - for animals slaughtered on April 14, 1981; II - for animals slaughtered on May 19, 1981).


TEMPERATURE (°C)
40
30
20
10
0
0
2
4
6
8
24
TIME (hr)
Slow chill (II)
Slow chill (I)
Fast chill (I and II)

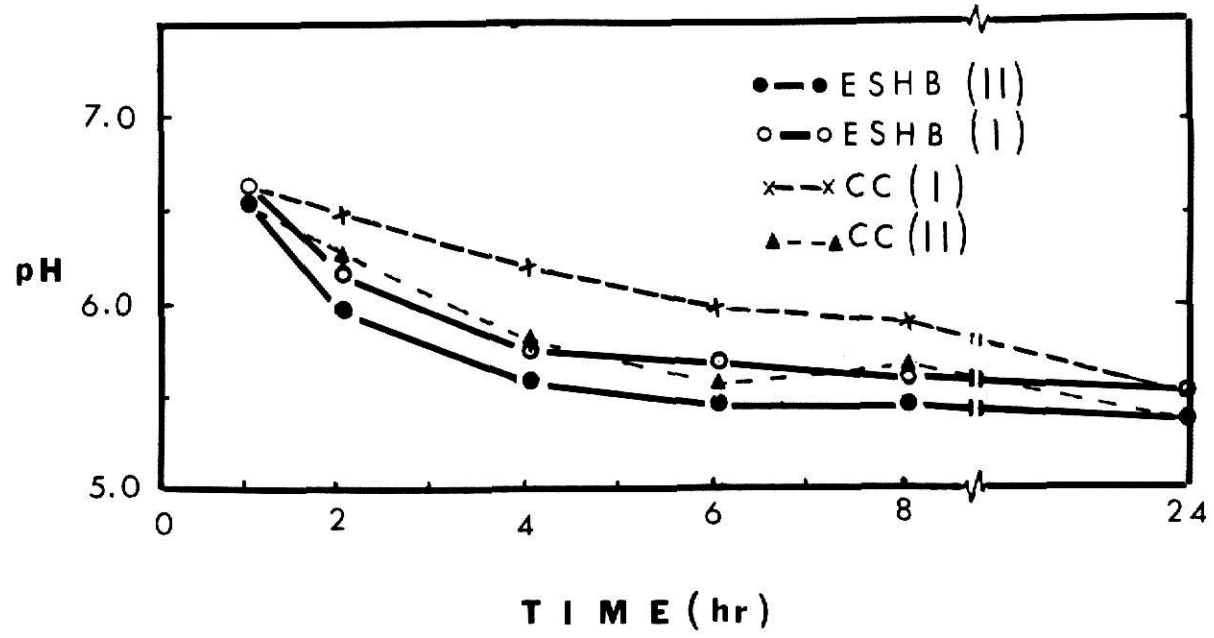

pH
7.0
6.0
5.0
0
2
4
6
8
24
TIME (hr)
ESHB (II)
ESHB (I)
CC (I)
CC (II)

Table 5 - Means, probability levels,and LSDs for significant cooking system x carcass treatment interactions

Measurement	Cooking system	Carcass treatment		P	LSD[a]	
		CC	ESHB		CC vs ESHB	S vs OR
Cooking time, min	Model system (S)	89.4	90.1	0.043	5.57	3.34
	Oven roasting (OR)	78.5	84.2			
Instron hardness,						
kg	Model system	7.6	8.6	0.045	1.29	0.90
	Oven roasting	8.6	7.9			
Solubilized						
OHProline, %	Model system	23.7	25.2	0.0002	7.40	4.67
	Oven roasting	11.6	28.3			

[a]Least significant difference ($P < 0.05$)

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

LSD for cooking system x carcass treatment indicated that significant differences in cooking time between cooking systems (Table 5) were attributable to the effects of both CC and ESHB, and the differences between carcass treatments (Table 5) were attributable to the effects of OR. Longer ($P < 0.05$) cooking time was required for the strips than for the roasts with a greater difference for CC than for ESHB samples.

Although neither the cooking system nor the carcass treatment per se significantly affected Instron hardness, interactions (Table 5) indicated that significant differences in Instron hardness occurred between cooking systems for CC samples. CC samples cooked in the model system were less ($P < 0.05$) hard than those cooked by OR.

The significant differences in solubilized hydroxyproline (Table 5) observed between carcass treatments were attributable to the effects of OR (Table 5). More ($P < 0.05$) solubilized hydroxyproline was found in CC samples cooked in the model system than with those cooked by OR. Similarly, Brady and Penfield (1981) reported greater ($P < 0.05$) solubilized hydroxyproline for strips cooked in a model system at a rate simulating that of roasts cooked at 93°C to either 60° or 70°C than for oven roasts.

Relationship between tenderness and texture measurements

Correlation coefficients were calculated to study the degree of relationship between selected tenderness and texture measurements (variates). Shindell (1964) cited Falkner (1962) who considered the relationship between variates low when the correlation coefficient,

regardless of sign, falls within the range of 0.00 to 0.39, moderate for 0.40 to 0.79, and high for 0.80 and above. For 18 degrees of freedom, a coefficient of at least 0.444 is required for a significant ($P \leq 0.05$) relationship between two measurements; a coefficient of 0.561 is required for the relationship to be significant at $P \leq 0.01$, or a coefficient of 0.679 for a significant relationship of $P \leq 0.001$ (Beyer, 1966).

Relationship between paired measurements were similar whether r-values were calculated on the basis of the cooking systems (D/F = 18, Table 6), on the basis of carcass treatments (D/F = 18, Table 7), or from data where all the treatment combinations were combined (D/F = 38, Table 21, Appendix, p. 104). Correlation coefficients calculated for paired tenderness and texture measurements using our data indicated that generally, sensory scores for tenderness, softness, and mealiness were related moderately to each other and to Instron values for shear cohesiveness and shear firmness. Correlations were low between Instron penetration measurements (hardness, chewiness) and sensory tenderness and texture scores. Penetration measurements were correlated moderately with shear cohesiveness and shear firmness (Tables 6 and 7). Correlation coefficients showed little relationship between the percentage solubilized hydroxyproline and any of the other tenderness or texture measurements.

Precision between cooking systems

To study differences in precision between OR and S, for each measurement on cooked muscle, we used the F-test to test sample

Table 6 - Correlation coefficients for paired tenderness and texture measurements on the basis of cooking systems

Paired variates D/F = 18	Cooking system: Strips r	Strips P	Roasts r	Roasts P
Tenderness scores vs.				
Softness scores	0.92	0.0001	0.74	0.0002
Mealiness scores	0.84	0.0001	0.58	0.007
Shear cohesiveness, kg	-0.60	0.005	-0.61	0.005
Shear firmness, kg/min	-0.61	0.005	-0.53	0.02
Hardness, kg	-0.35	0.13	-0.05	0.84
Chewiness, kg-mm	-0.15	0.51	-0.25	0.29
Solubilized OHProline, %	-0.17	0.49	-0.24	0.31
Softness scores vs.				
Mealiness scores	0.76	0.0001	0.24	0.30
Shear cohesiveness, kg	-0.57	0.009	-0.42	0.07
Shear firmness, kg/min	-0.63	0.003	-0.33	0.16
Solubilized OHProline, %	-0.13	0.59	-0.07	0.76
Mealiness scores vs.				
Shear cohesiveness, kg	-0.66	0.002	-0.20	0.39
Shear firmness, kg/min	-0.66	0.002	-0.37	0.09
Solubilized OHProline, %	-0.33	0.16	-0.50	0.02
Shear cohesiveness vs.				
Shear firmness, kg/min	0.88	0.0001	0.94	0.0001
Hardness, kg	0.68	0.001	0.43	0.06
Chewiness, kg-mm	0.71	0.0005	0.35	0.23
Solubilized OHProline, %	-0.11	0.64	0.26	0.28
Shear firmness vs.				
Hardness, kg	0.62	0.004	0.41	0.08
Chewiness, kg-mm	0.66	0.002	0.30	0.23
Solubilized OHProline, %	0.02	0.93	0.15	0.53

D/F = 18; r-value required for a significant relationship: $P \leq 0.05$; 0.444; $P \leq 0.01$, 0.561; $P \leq 0.001$, 0.679.

Table 7 - Correlation coefficients for paired tenderness and texture measurements on the basis of carcass treatments

Paired variates D/F = 18	Carcass treatment			
	CC		ESHB	
	r	P	r	P
Tenderness scores vs.				
Softness scores	0.82	0.0001	0.84	0.0001
Mealiness scores	0.60	0.004	0.70	0.0006
Shear cohesiveness, kg	-0.50	0.03	-0.66	0.002
Shear firmness, kg/min	-0.46	0.04	-0.65	0.002
Hardness, kg	-0.33	0.16	-0.07	0.78
Chewiness, kg-mm	-0.23	0.32	-0.12	0.31
Solubilized OHProline, %	0.01	0.98	-0.13	0.57
Softness scores vs.				
Mealiness scores	0.22	0.34	0.72	0.0003
Shear coheviness, kg	-0.43	0.06	-0.52	0.02
Shear firmness, kg/min	-0.44	0.05	-0.54	0.01
Solubilized OHProline, %	0.21	0.36	-0.13	0.56
Mealiness scores vs.				
Shear cohesiveness, kg	-0.30	0.19	-0.43	0.06
Shear firmness, kg/min	-0.17	0.49	-0.43	0.06
Solubilized OHProline, %	-0.19	0.43	-0.34	0.14
Shear cohesiveness vs.				
Shear firmness, kg/min	0.89	0.0001	0.91	0.0001
Hardness, kg	0.71	0.0005	0.31	0.110
Chewiness, kg-mm	0.63	0.003	0.40	0.08
Solubilized OHProline, %	-0.21	0.38	0.25	0.27
Shear firmness vs.				
Hardness, kg	0.63	0.003	0.38	0.10
Chewiness, kg-mm	0.51	0.02	0.38	0.10
Solubilized OHProline, %	-0.31	0.19	0.28	0.23

CC, conventionally chilled
ESHB, electrically stimulated-hot boned
D/F = 18; r-value required for a significant relationship: $P \leq 0.05$, 0.444; $P \leq 0.01$, 0.561; $P \leq 0.001$, 0.679

variances for equality between the cooking systems. Generally, sample variances for a given measurement were similar in size for OR and S. Variances for only four of the 21 measurements differed ($P \leq 0.05$) between cooking systems (Table 8). Measurements for which OR had significantly larger variances than those for S were cooking time, total moisture (AOAC), and Instron cohesiveness (calculated as defined by Friedman et al., 1963). For drip cooking losses, the variance for S was significantly larger than that for OR.

SUMMARY

Forty AD muscles from 20 bull carcasses were used in this experiment. One half of each of the bull carcasses was conventionally chilled (CC); the other half was electrically stimulated-hot boned (ESHB) two hours after slaughter. ESHB muscles were chilled either on trays or in boxes for 7 days, then frozen at -26°C, and stored at -22°C for about 45 days. CC and ESHB muscles were assigned randomly to either oven roasting (OR) or the model system (S) for cooking. Cooked samples were compared for sensory tenderness and texture, Instron texture characteristics, percentage solubilized hydroxyproline, and cooking time and losses. Muscles assigned to S were cut into strips (2.3 x 2.3 x 8 cm), placed in 50-ml centrifuge tubes, and heated in a water bath to 70°C at a rate simulating that of an average heating rate previously obtained by roasting seven adductor muscles at 177°C to 65°C, ("estimated" heat curve). Muscles assigned to OR were cut into roasts (avg.

Table 8 - Sample variances, F-values, and the probability that variance between cooking systems are equal

Measurement	Sample variance		F-value	P
	OR	S		
Cooking time	66.4500	6.6816	9.94	0.000
Cooking losses				
Volatile	5.0659	4.8308	1.05	0.458
Drip	0.6962	9.8863	14.20	0.000
Total	5.9341	4.5925	1.17	0.361
Total moisture				
Brabender	0.9298	1.0589	1.14	0.387
AOAC	31.5940	3.1950	9.89	0.000
Water holding capacity	0.0020	0.0012	1.71	0.121
pH	0.0042	0.0056	1.34	0.258
Ether extract	2.3884	1.3637	1.75	0.112
Sensory scores				
Tenderness	0.2602	0.3877	1.49	0.190
Softness	0.3867	0.4894	1.27	0.302
Mealiness	0.4973	0.2940	1.69	0.124
Juiciness	0.8037	0.4978	1.61	0.146
Instron texture measurements				
Hardness	2.3717	2.0015	1.18	0.354
Firmness	55.1665	56.5675	1.03	0.478
Chewiness (Friedman et al., 1963)	69.3514	66.5144	1.04	0.463
Chewiness (Bourne, 1978)	52.9116	67.8372	1.28	0.292
Elasticity	1.1012	1.8575	1.69	0.126
Cohesiveness (Friedman et al, 1963)	0.0048	0.0023	2.07	0.056
Cohesiveness (Bourne, 1978)	0.0023	0.0035	1.53	0.176
Shear cohesiveness	4.4791	4.0953	1.09	0.422
Solubilized hydroxyproline, %	126.9780	64.7494	1.96	0.070

OR, oven roasting; S, model system

700 g; 10 x 11 x 5 - 8 cm) and cooked in a rotary hearth gas oven at 177° to 70°C.

No significant differences in heating time at any point from 10° to 65°C were observed between strips and "estimated" roasts (roasts whose heating curve strips and OR roasts were supposed to follow). Differences in heating time between strips and OR roasts were observed only from 50° to 55° - 65°C, with roasts requiring longer ($P < 0.05$) time than strips. The longer time required for strips to increase from their initial temperature to 10°C accounted for the longer ($P < 0.002$) total time required for strips than for the roasts to reach 70°C.

Roasts, cooked by dry heat, exhibited greater ($P < 0.0001$) volatile losses and less ($P < 0.0001$) drip losses than did strips cooked by moist heat. Lower ($P < 0.0001$) moisture content and higher ($P < 0.006$) ether extract were obtained for roasts than for strips.

The longer ($P < 0.01$) cooking time required for ESHB samples may have accounted, partially, for the greater ($P < 0.0007$) percentage of solubilized hydroxyproline. ESHB samples were scored less ($P < 0.04$) tender and less ($P < 0.01$) mealy by the sensory panel, but mean sensory scores were not practically different. Interactions between cooking systems and carcass treatments affected the cooking time ($P < 0.04$), Instron hardness ($P < 0.045$), and the percentage solubilized hydroxyproline ($P < 0.0002$). Significant differences in cooking time between cooking systems were attributable to the effects of both CC and ESHB, and differences between carcass treatments were attributable to the effect of OR. Instron hardness was not affected significantly by the cooking system or

by the carcass treatment, but interactions indicated that CC samples cooked in the model system were less ($P < 0.05$) hard than those cooked by OR. Differences in solubilized hydroxyproline between carcass treatments were attributable to the effect of OR. More ($P < 0.05$) solubilized hydroxyproline was found in CC samples cooked in the model system than in those cooked by OR.

Generally, sensory scores for tenderness, softness, and mealiness were related moderately to each other and to Instron values for shear cohesiveness and shear firmness. Low correlations occurred between Instron penetration measurements and sensory tenderness and texture scores; moderate correlations occurred between Instron shear (cohesiveness, firmness) and penetration (hardness, chewiness) measurements. Relationships between paired measurements were similar whether r-values were calculated on the basis of cooking systems, carcass treatments, or from data where all treatment combinations were combined. Little correlation occurred between the percentage solubilized hydroxyproline and any of the tenderness or texture measurements.

Samples variances for most measurements were similar in size for OR and S, except for cooking time, drip losses, total moisture (AOAC), and Instron cohesiveness (calculated as defined by Friedman et al., 1963). Larger ($P \leq 0.05$) variances were exhibited by the roasts for cooking time, total moisture (AOAC), and Instron cohesiveness than by the strips, but strips exhibited larger ($P < 0.001$) variance for drip losses than did roasts.

CONCLUSIONS

Under the conditions of this study, we concluded;

1. The model system of cooking may be substituted for oven roasting when evaluating processing treatment effects on sensory tenderness and texture or Instron texture measurements.

2. The percentage solubilized hydroxyproline is not a major influence on sensory tenderness and texture, or on Instron texture attributes of bull adductor muscle cooked to 70°C.

3. Sensory tenderness and texture are related more to Instron shear cohesiveness and firmness than they are to Instron penetration measurements.

4. CC and ESHB bull AD muscles are comparable in sensory tenderness and texture and in Instron texture characteristics.

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APPENDIX

DEFINITIONS OF MEAT TEXTURE TERMS

General Terms:

Compression - The squeezing together of the test material, so that it still remains a single undivided unit, but may occupy less volume (Voisey, 1976).

Force deformation curve - A curve that portrays the entire force history of the simulated masticatory action and is plotted electronically during the objective (mechanical) test (Friedman et al., 1963). In the Instron instrument, the chart and the driving system are synchronized, so the instrument also yields a force-distance curve (Bourne, 1978).

Shear - The cutting or separation of sample material into two or more parts when stress is applied (Voisey, 1976).

GF texturometer profiles - An integral picture of the sensory texture characteristics of the product, which is translated to a force-time relationship (Friedman et al., 1963).

Work = Force x Distance

Compression measurements:

Cohesiveness - The strength of the internal bonds making up the body of the product, which is measured as the ratio of the work of the second "chew" to that of the first "chew" (Friedman et al. 1963).

Chewiness - The energy required to masticate a solid food product to a state ready for swallowing, which is mathematically expressed

as the product of "hardness" x "cohesiveness" x "elesticity" (Friedman et al., 1963). Organoleptically, it is the time required to masticate a sample at a rate of one chew/sec to reduce it to a consistency satisfactory for swallowing (Szczesniak, 1963).

Adhesiveness - The work necessary to overcome the attractive forces between the surface of the food and the surface of other materials with which the food comes in contact such as the tongue, teeth or palate, which is measured as the area under the negative curve between the first and the second chew (Friedman et al., 1963).

Hardness - The force necessary to attain a given deformation which is measured as the peak height of the first "chew" in the force-time curve of a GF texturometer (Friedman et al., 1963), or the force-distance curve of the Instron machine (Bourne, 1978). Organoleptically, it is the force required to penetrate a substance with the molar teeth (Szczesniak, 1963).

Elasticity - The rate at which a deformed material goes back to its original or initial condition after the deforming force is removed. It is measured as C - B, where C is the time constant for a standard inelastic material such as clay; B is the distance from the origin of the first "chew" to the origin of the second "chew" (Friedman et al., 1963). In the Instron compression curve, elasticity is the horizontal distance from the origin of the second curve to the perpendicular dropped from the peak of the first penetration curve, (Bourne, 1978).

Work - The area under the first "chew" or the second "chew" which is measured with a compensating polar planimeter or by an electronic

integrator (Friedman et al., 1963). Bourne (1978) defined work as the area under the compression portion of the first or the second "chew" defined by the upward sweep of the curve, the perpendicular line drawn from the peaks to the baseline and along the baseline of the origin.

Shear deformation measurements:

Firmness - The force required to produce a given deformation which is measured as the slope of the line from the origin to the peak of the curve and recorded as g/sec (Larmond and Petrosavits, 1972).

Shear cohesiveness - The peak force during the shearing that indicates the rupturing of the sample, which is measured as the peak height in the shear deformation curve (Larmond and Petrosavits, 1972).

Initial yield force - The force (kg) at which the sample first begins to yield, which is the first inflection in the shear deformation curve (Bouton et al., 1975a).

Peak force - The maximum force (kg) recorded in the shear deformation curve (Bouton et al., 1975a).

Initial yield, distance - The distance (cm) travelled by the Warner-Bratzler blade between initial contact with the sample and the first inflection, appearing on the force - deformation curve. (Bouton et al., 1975a).

Final yield distance - The distance (cm) travelled by the shear blade between initial contact with the sample and when the peak force had been reached (Bouton et al., 1975a).

Slope at initial yield - The rate of change of force with distance (slope) at the initial yield inflection point (kg/cm) (Bouton et al., 1975a).

Table 9 - Bull slaughter dates and weights, processing treatments, and USDA grades

Slaughter date	Animal number	Processing treatments		Approximate slaughter wt., kg	Approximate carcass wt., kg	USDA quality grade 24 hr postmortem
		1	2			
April 14, 1981	14	CC	ESHB-Sl	521	340	Low Good
	16	CC	ESHB-F	514	333	Low Choice
	24	CC	ESHB-F	510	323	High Good
	37	CC	ESHB-F	513	331	High Good
	45	CC	ESHB-F	519	324	High Good
	70	CC	ESHB-Sl	495	316	High Standard
	74	CC	ESHB-F	524	324	Low Good
	78	CC	ESHB-Sl	501	318	High Good
	110	CC	ESHB-Sl	522	319	High Good
	206	CC	ESHB-Sl	481	307	Average Good
May 19, 1981	27	CC	ESHB-Sl	428	256	Average Good
	82	CC	ESHB-Sl	479	296	Average Choice
	91	CC	ESHB-F	493	316	Low Good
	103	CC	ESHB-F	485	305	High Good
	140	CC	ESHB-F	451	283	Low Choice
	167	CC	ESHB-F	432	266	High Good
	175	CC	ESHB-Sl	421	248	High Standard
	184	CC	ESHB-Sl	406	245	Average Good
	210	CC	ESHB-F	441	264	Low Good
	238	CC	ESHB-Sl	464	284	Low Good

CC, conventionally chilled
ESHB, electrically stimulated-hot boned
Sl, slow chilling (in boxes)
F, fast chilling (on trays)

Form I Score Card for the Sensory Evaluation of Beef Adductor Muscle

Name _____ Date _____

Sample Number	Tenderness		Juiciness	Texture	
	Chews	Score		Mealiness	Softness

Descriptive Terms for Scoring:

Tenderness	Juiciness	Texture	
		Mealiness	Softness
7 Tender	7 Juicy	7 Mealy	7 Soft
6 Moderately tender	6 Moderately juicy	6 Moderatley mealy	6 Moderately soft
5 Slightly tender	5 Slightly juicy	5 Slightly mealy	5 Slightly soft
4 Neither tender nor tough	4 Neither juicy nor dry	4 Neither mealy nor chewy	4 Neither soft nor hard
3 Moderately tough	3 Moderately dry	3 Moderately chewy	3 Moderately hard
2 Slightly tough	2 Slightly dry	2 Slightly chewy	2 Slightly hard
1 Tough	1 Dry	1 Chewy	1 Hard

Comments:

Form II Instruction to Panel Members for Sensory Evaluation of Bovine Adductor Muscles. Naewbanij-Harrison, June-July, 1981.

For sensory evaluation, each panel member is to select two cubes of meat from each double boiler. Use one cube for counting the number of chews and assigning a tenderness score. Use the second cube to score juiciness and the texture components.

Scoring for Tenderness

Count the number of chews required to masticate a 1.3 cm cube of meat. Chew until the cube is masticated completely, then swallow. Record a score of 7 to 1 that describes your impression of the tenderness of the cube. Refer to the score card for descriptive terms of specific scores within the range 7 to 1.

Use the number of chews to help you standardize your tenderness scores from day to day. Set up for yourself a range of the number of chews for each score from 7 to 1. For example, if you chew from 15 to 25 times, you might record a score of 7; if you chew 25 to 30 times, a score of 6; 35 to 45, a score of 5; continuing to reduce the score by a given number of increased chews. Each panelist sets his own range of chews for a given score.

Scoring for Texture

Texture is broken down into two components; softness and mealiness. Softness to tongue and cheek, and softness to tooth pressure (the muscular force exerted in the meat cube) should be considered when scoring for softness. Record a score for each sample within a range of 7 to 1, as indicated on the score card. Mealiness can be thought of as fragmentation of the meat resulting in tiny, dry, and hard pieces of meat that cling to the cheek gums and tongue. Record a score for mealiness within the range of 7 to 1 that describes your impression of the sample. Refer to the score card for descriptive terms corresponding to each numerical score.

Scoring for Juiciness

Record a score for juiciness within the range of 7 to 1 that describes your impression of the sample at the beginning of the chewing process. Refer to the score card for descriptive terms for specific scores within the range of 7 to 1.

Comments

Comments about the sample and/or an explanation of why you gave a particular score to the sample are helpful.

Take your time to score each sample. Water is provided for rinsing your mouth between samples.

Procedure for programming the water bath

1. Adjust the temperature of the water bath to 10°C by adding ice.

2. Put the test tubes containing the muscle strips in the water bath, and maintain the water bath temperature at 10°C for 15 minutes.

3. Adjust the thermostat to 100°C; then, every five minutes record the changes in temperature of the muscle strips and of the water bath.

4. As the water bath temperature approaches 33°C (approximately 30 minutes after the thermostat was set at 100°C), replace about 2 liters of the water in the water bath with hot water (about 95°C) to increase the temperature by about 8° - 9°C. That will facilitate a faster rate of heat penetration, which will simulate closely the actual heating rate of an 890-g roast, particularly in the 50° - 70°C temperature range, where most of the critical changes take place.

Procedure for the determination of hydroxyproline in bovine muscle

A. Preparation of raw sample

1. Weigh 2 g of ground raw muscle and add 10 ml of distilled, deionized water. Homogenize the mixture using a Brinkman Unitron homogenizer at speed 13 for one minute.
2. Pour the homogenate in a 25-ml graduated cylinder and wash the homogenizer and the tube containing the homogenate with approximately 5 - 7 ml of distilled, deionized water.
3. Measure the total volume of the homogenate and washings.
4. Transfer the total homogenate to a 50-ml ampoule and wash the cylinder further with a measured amount of distilled deionized water to make a total volume of 20 - 25 ml total homogenate.
5. To the total volume of homogenate transfered to an ampoule, add the same amount of concentrated HCl (12 N), and with the use of a blow torch, seal ampoule. Allow ampoule to cool to approximately 25^{o}C, and shake mixture.
6. Hydrolyze the sample mixture in a 107^{o}C oven for 20 hrs.
7. Cool ampoules containing hydrolyzed samples to about 25^{o}C; break the top off each ampoule, and pour the content of each ampoule into a 250-ml beaker separately.
8. Neutralize the hydrolyzate to a pH of 6.5 - 7.0 with 2.5 N NaOH and transfer to a 250 ml volumetric flask. Fill to volume with distilled, deionized water.

9. Mix the neutralized hydrolyzate thoroughly and filter it through a fluted Whatman # 42 filter paper containing activated charcoal to remove the impurities (humins) and also, to decolorize the hydrolyzate.

B. Preparation of cooked sample

1. Weigh 2 g of ground cooked sample; transfer it to a 50-ml centrifuge tube.
2. Wash sample with 20 ml of warm (40^{o}C) distilled, deionized water; homogenize the mixture for 30 seconds at speed 13, using a Brinkman Unitron homogenizer.
3. Centrifuge the mixture at 4,000 rpm for 10 min using a bench top centrifuge.
4. Discard the supernatant; repeat the washing and centrifuging processes to ensure complete removal of the solubilized hydroxyproline in the cooked meat sample.
5. Make a 20 - 25 ml homogenate for acid hydrolysis by following the procedure given for the raw meat sample.

C. Procedure for the spectrophotometric assay of hydroxyproline

I. Preparation of reagents

Stock standard (0.1 mg/ml) - Dissolve 50 mg of standard L- (-) hydroxyproline (Eastman Kodak Co., Rochester, New York), in 500 ml of 0.001 N HCl. This can be stored indefinitely in a refrigerator (4^{o}C).

Working standard (20 μg/ml) - Dilute 10 ml of the stock standard to 50 ml with distilled, deionized water.

Acetate/citrate buffer, pH 6.0 - Dissolve 57 g of sodium acetate trihydrate, 37.5 g of sodium citrate dihydrate, and 5.5 g of citric acid monohydrate in 385 ml of isopropanol, and make up to a volume of 1 liter with distilled, deionized water.

Oxidant solution - Prepare a solution of 7 % chloramine T in acqueous solution (wt/vol). Just before the start of each series of analysis, mix chloramine T solution with the acetate/citrate buffer at a ratio of 1:4 (vol/vol).

Ehrlich's reagent solution - Dissolve 2 gm of p-dimethylamino benzaldehyde (p-dmab) in 3 ml of 60 % perchloric acid. Just before the start of each series of analysis, mix 3 volumes of the p-dmab solution to 13 volumes of isopropanol.

II. Assay for hydroxyproline

1. Prepare clean 10-ml test tubes for assay and label them according to the codes for the standard and samples.
2. Pipet the necessary volume of working standard to make standard concentrations of 2 μg, 4 μg, 6 μg, 8 μg, and 10 μg hydroxyproline in 0.5 ml. For the meat sample assay, pipet 0.5 ml of the neutralized meat hydrolyzate into the labelled tubes.

3. To each test tube, add 1 ml of isopropanol and mix.
4. To each test tube, add 0.5 ml of the oxidant solution mix, and allow to stand for 4 $\pm$ 1 minutes.
5. To each test tube, add 6.5 ml of the Erlich's reagent solution; mix well, and cover test tubes with para-film paper.
6. Heat tubes in a water bath at 60^{o}C for 25 minutes to allow color development.
7. Cool tubes for 2 or 3 minutes in running tap water, mix, and immediately measure absorbance at 558 nm wavelength using a spectrophotometer such as a Perkin Elmer dauble beam spectrophotometer.

Table 10 - Means[a], standard errors of the means, F-values, probability levels, and coefficients of variation for measurements of bull AD muscle not affected significantly by the cooking system

Measurements	Treatments[b]		F-value	P	Coefficient of variation[c]
	OR ± S.E.	S ± S.E.			
Sensory scores[d], 7 - 1					
Tenderness	5.39 ± 0.15	5.47 ± 0.15	0.14	0.72	7.69
Softness	4.54 ± 0.17	4.81 ± 0.17	1.28	0.27	11.31
Mealiness	4.36 ± 0.17	4.67 ± 0.17	1.62	0.22	9.46
Juiciness	4.76 ± 0.21	4.49 ± 0.21	0.83	0.38	15.31
Instron texture measurements					
Hardness, kg	8.24 ± 0.34	8.10 ± 0.34	0.09	0.77	14.68
Cohesiveness[e]	0.48 ± 0.02	0.48 ± 0.02	0.93	0.35	12.32
Cohesiveness[f]	0.45 ± 0.01	0.43 ± 0.01	0.81	0.38	13.15
Elasticity, mm	7.71 ± 0.27	8.26 ± 0.27	2.16	0.16	16.98
Chewiness, kg-mm	31.10 ± 2.00	32.25 ± 2.00	0.16	0.69	23.95
Chewiness[f], kg-mm	28.55 ± 1.85	29.16 ± 1.85	0.06	0.82	25.91
Shear cohesiveness, kg	8.22 ± 0.56	8.02 ± 0.56	0.06	0.81	18.92
Firmness. kg/min	30.55 ± 1.96	28.21 ± 1.96	0.74	0.40	20.33
Water holding capacity[g]	0.66 ± 0.01	0.64 ± 0.01	1.71	0.21	4.31
Solubilized hydroxyproline, %	19.92 ± 2.20	24.42 ± 2.20	2.10	0.17	22.22
Total loss, %	25.16 ± 0.58	26.38 ± 0.58	2.09	0.17	6.67
Total moisture, %					
Raw, Brabender	73.12 ± 0.29	73.32 ± 0.29	0.25	0.62	0.79
Raw, AOAC	74.48 ± 0.58	75.44 ± 0.58	1.37	0.26	3.09
pH, raw	5.44 ± 0.02	5.44 ± 0.02	0.07	0.80	0.50
pH, cooked	5.57 ± 0.02	5.54 ± 0.02	1.93	0.18	0.48
Ether extract, %, raw	2.11 ± 0.28	1.81 ± 0.28	1.74	0.21	60.38

[a] Data for CC and ESHB (fast or slow chilled) combined.
[b] Treatments: S- strips cooked in the model system, OR- roasts cooked by oven roasting.
[c] Based on 40 observations.
[d] Range, 7 (tender, soft, mealy, juicy), 1 (tough, hard, chewy, dry).
[e] Ratio of work, 2nd/1st penetration.
[f] Calculated using values of work as defined by Bourne (1978).
[g] 1.0 minus ELI; the greater the value, the more liquid expressed.

Table 11 - Means[a], standard errors of the means, F-values, and probability levels for measurements of bull AD muscle not affected significantly by the carcass treatment

Measurements	ESHB[b] ± S.E.	CC ± S.E.	F-value	P
Sensory scores[c], 7 - 1				
Softness	4.81 ± 0.10	4.55 ± 0.10	2.42	0.14
Juiciness	4.52 ± 0.16	4.73 ± 0.16	0.92	0.35
Instron texture measurements				
Hardness, kg	8.06 ± 0.27	8.28 ± 0.27	0.33	0.57
Cohesiveness	0.47 ± 0.01	0.47 ± 0.01	0.03	0.87
Cohesiveness[d]	0.45 ± 0.01	0.43 ± 0.01	1.09	0.31
Elasticity, mm	7.87 ± 0.30	8.10 ± 0.30	0.30	0.59
Chewiness, kg-mm	30.99 ± 1.70	32.36 ± 1.70	0.32	0.58
Chewiness[d], kg-mm	28.99 ± 1.67	28.72 ± 1.67	0.01	0.91
Shear cohesiveness, kg	7.79 ± 0.34	8.45 ± 0.34	1.88	0.17
Firmness, kg/min	28.19 ± 1.33	30.57 ± 1.33	1.58	0.23
Water holding capacity[f]	0.65 ± 0.01	0.64 ± 0.01	1.16	0.30
Total loss, %	25.41 ± 0.38	26.12 ± 0.38	1.72	0.21
Volatile loss, %	12.07 ± 0.30	11.90 ± 0.30	0.16	0.70
Drip loss, %	13.24 ± 0.30	14.02 ± 0.30	3.40	0.08
Total moisture, %				
Raw, Brabender	73.23 ± 0.13	73.21 ± 0.13	0.01	0.94
Raw, AOAC	75.08 ± 0.52	74.84 ± 0.52	0.11	0.75
Cooked, Brabender	65.19 ± 0.16	65.37 ± 0.16	0.57	0.46
Cooked, AOAC	64.50 ± 0.98	66.25 ± 0.98	1.50	0.24
pH, raw	5.45 ± 0.01	5.43 ± 0.01	2.68	0.12
pH, cooked	5.55 ± 0.01	5.56 ± 0.01	0.48	0.50
Ether extract, %				
Raw	2.02 ± 0.27	1.90 ± 0.27	0.10	0.76
Cooked	2.43 ± 0.30	3.01 ± 0.30	1.76	0.20

[a] Data for S and OR were combined.
[b] Data for ESHB-F and ESHB-S1 were combined.
[c] Range, 7 (soft, juicy), 1 (hard, soft).
[d] Ratio of work, 2nd/1st penetration.
[e] Calculated using values of work as defined by Bourne (1978).
[f] 1.0 minus ELI; the greater the value, the more liquid expressed.

Table 12 - Means, F-values, and probability levels for measurements of bull AD muscle not affected significantly by the chilling method

Measurements	Fast[a]	Slow[b]	F-value	P
Sensory scores[c], 7 - 1				
Tenderness	5.31	5.55	1.22	0.72
Softness	4.52	4.83	1.69	0.21
Mealiness	4.45	4.57	0.24	0.63
Juiciness	4.62	4.63	0.00	0.96
Instron texture measurements				
Hardness, kg	8.14	8.20	0.02	0.90
Cohesiveness[d]	0.47	0.47	0.02	0.89
Cohesiveness[e]	0.43	0.44	0.26	0.62
Elasticity, mm	8.29	7.68	2.64	0.12
Chewiness, kg-mm	32.99	30.36	0.87	0.37
Chewiness[e], kg-mm	29.28	28.44	0.10	0.75
Shear cohesiveness, kg	8.31	7.94	0.22	0.65
Firmness, kg/min	29.41	29.35	0.00	0.98
Solubilized hydroxyproline, %	19.71	24.63	0.55	0.47
Water holding capacity[f]	0.64	0.65	0.08	0.78
Total loss, %	26.51	25.03	3.09	0.10
Drip loss, %	13.65	13.61	0.00	0.97
Volatile loss, %	12.70	11.27	2.52	0.13
Total moisture, %				
Raw, Brabender	73.07	73.37	0.54	0.47
Raw, AOAC	75.04	74.88	0.04	0.85
Cooked, Brabender	65.13	65.42	0.50	0.49
Cooked, AOAC	65.70	65.06	0.31	0.59
pH, raw	5.43	5.45	0.59	0.45
pH, cooked	5.55	5.56	1.16	0.30
Ether extract, %				
Raw	1.97	1.95	0.00	0.96
Cooked	2.60	2.84	0.22	0.65

[a] Data for CC + ESHB-F.
[b] Data for CC + ESHB-S1.
[c] Range, 7 (tender, soft, mealy, juicy), 1 (tough, hard, chewy, dry).
[d] Ratio of work, 2nd/1st penetration.
[e] Calculated using values of work as defined by Bourne (1978).
[f] 1.0 minus ELI; the greater the value, the more liquid expressed.

Table 13 - Means, F-values, and probability levels for measurements of bull AD muscle not affected significantly by the cooking systems x carcass treatments interactions

Measurements	S x CC	S x ESHB[a]	OR x CC	OR x ESHB[a]	F-value	P
Sensory scores[b], 7 - 1						
Tenderness	5.67	5.26	5.47	5.30	0.83	0.38
Softness	5.02	4.60	4.59	4.49	0.92	0.35
Mealiness	4.72	4.61	4.68	4.03	4.01	0.06
Juiciness	4.52	4.46	4.51	5.00	1.51	0.24
Instron texture measurements						
Cohesiveness[c]	0.47	0.46	0.48	0.49	0.24	0.63
Cohesiveness[d]	0.44	0.42	0.46	0.44	0.00	1.00
Elasticity, mm	8.14	8.39	7.60	7.82	0.00	0.97
Chewiness[d], kg-mm	29.99	34.52	32.00	30.20	1.74	0.21
Chewiness[d], kg-mm	28.10	30.22	29.88	27.22	1.02	0.33
Shear cohesiveness, kg	7.65	8.39	7.93	8.51	0.03	0.88
Firmness, kg/min	26.60	29.81	29.78	31.33	0.19	0.67
WHC[e]	0.64	0.63	0.66	0.65	0.03	0.88
Total loss, %	26.14	26.63	24.69	25.62	0.17	0.69
Volatile loss, %	3.31	2.41	20.83	21.38	2.83	0.11
Drip loss, %	22.93	24.17	3.55	3.88	1.16	0.30
Total moisture, %						
Raw, Brabender	73.44	73.21	73.02	73.22	1.33	0.27
Raw, AOAC	75.50	75.39	74.66	74.29	0.03	0.86
Cooked, Brabender	66.42	66.41	63.96	64.33	0.67	0.43
Cooked, AOAC	67.19	67.32	61.81	65.19	1.29	0.27
pH, raw	5.44	5.43	5.45	5.44	0.12	0.73
pH, cooked	5.53	5.55	5.57	5.58	0.67	0.43
Ether extract, %						
Raw	1.81	1.81	2.23	1.99	0.11	0.75
Cooked	1.44	1.86	3.43	4.17	0.14	0.71

[a] Data for ESHB-F and ESHB-S1 were combined.
[b] Range, 7 (tender, soft, mealy, juicy), 1 (tough, hard, chewy, dry).
[c] Ratio of work, 2nd/1st penetration.
[d] Calculated using values of work as defined by Bourne (1978).
[e] 1.0 minus ELI; the greater the value, the more liquid expressed.

Table 14 - Means, F-values, and probability levels for measurements of bull AD muscle not affected by the cooking systems x chilling methods interactions

Measurements	S x F[a]	S x Sl[b]	OR x F[a]	OR x Sl[b]	F-value	P
Sensory scores[c], 7 -1						
Tenderness	5.36	5.57	5.25	5.52	0.02	0.89
Softness	4.72	4.90	4.32	4.76	0.30	0.59
Mealiness	4.68	4.65	4.22	4.49	0.38	0.55
Juiciness	4.68	4.30	4.55	4.97	7.84	0.19
Instron texture measurements						
Cohesiveness[d]	0.46	0.47	0.49	0.47	0.61	0.45
Cohesiveness[e]	0.42	0.44	0.45	0.45	0.32	0.58
Elasticity, mm	8.53	8.00	8.05	7.37	0.05	0.83
Chewiness, kg-mm	31.45	33.05	34.54	27.67	2.24	0.15
Chewiness[e], kg-mm	27.22	31.11	31.33	25.76	3.26	0.09
Shear cohesiveness, kg	7.67	8.38	8.94	7.50	1.84	0.19
Firmness, kg/min	26.46	29.96	32.36	28.75	1.70	0.21
Water holding capacity	0.62	0.65	0.67	0.65	2.91	0.11
Total loss, %	26.97	25.79	26.05	24.27	0.12	0.73
Drip loss, %	23.39	23.71	3.91	3.52	0.13	0.73
Volatile loss, %	3.54	2.18	21.86	20.36	0.01	0.94
Total moisture, %						
Raw, Brabender	72.97	72.68	73.18	73.06	1.03	0.33
Raw, AOAC	75.36	75.53	74.72	74.24	0.15	0.70
Cooked, Brabender	66.32	66.51	63.95	64.34	0.07	0.80
Cooked, AOAC	66.80	67.71	64.60	62.40	0.83	0.38
pH, raw	5.44	5.44	5.42	5.46	0.97	0.34
pH, cooked	5.55	5.53	5.55	5.60	0.10	0.76
Ether extract, %						
Raw	1.83	1.79	2.11	2.11	0.00	0.96
Cooked	1.59	1.71	3.62	3.97	0.01	0.93
Solubilized OHProline, %	20.84	28.00	18.58	21.26	1.00	0.33

[a] Data for CC + ESHB-F were combined.
[b] Data for CC + ESHB-Sl were combined.
[c] Range, 7 (tender, soft, mealy, juicy), 1 (tough, hard, chewy, dry).
[d] Ratio of work, 2nd/1st penetration.
[e] Calculated using values of work as defined by Bourne (1978).
[f] 1.0 minus ELI; the greater the value, the more liquid expressed.

Table 15 - Means, F-values, and probability levels for measurements of bull AD muscle not affected significantly by the carcass treatments x chilling methods interactions

Measurements	CC x F[a]	CC x S1[b]	ESHB x F[a]	ESHB x S1[b]	F-value	P
Sensory scores[d], 7 - 1						
Tenderness	5.35	5.79	5.26	5.30	2.30	0.15
Softness	4.49	5.12	4.55	4.54	3.67	0.07
Mealiness	4.67	4.73	4.23	4.41	0.20	0.66
Juiciness	4.44	4.59	4.79	4.67	0.36	0.56
Instron texture measurements						
Hardness, kg	8.21	7.92	8.08	8.48	0.81	0.38
Cohesiveness[e]	0.47	0.48	0.48	0.47	0.07	0.79
Cohesiveness[f]	0.44	0.46	0.43	0.43	0.08	0.79
Elasticity, mm	8.12	7.62	8.46	7.75	0.06	0.82
Chewiness, kg-mm	32.33	29.66	33.66	31.06	0.00	0.99
Chewiness[f], kg-mm	29.76	28.23	28.80	28.65	0.09	0.77
Shear cohesiveness, kg	8.18	7.39	8.43	8.47	0.74	0.40
Firmness, kg/min	29.65	26.73	29.17	31.97	2.28	0.15
WHC[g]	0.65	0.66	0.64	0.64	0.55	0.47
Solubilized OHProline, %	15.59	19.67	23.84	29.59	0.16	0.70
Total loss, %	26.17	24.66	26.85	25.40	0.00	0.96
Drip loss, %	13.26	13.23	14.04	14.00	0.00	0.99
Volatile loss, %	12.78	11.36	12.62	11.18	0.00	0.97
Cooking time, min	85.32	82.53	88.73	85.60	0.03	0.87
Total moisture, %						
Raw, Brabender	73.09	73.37	73.06	73.37	0.01	0.94
Raw, AOAC	75.02	75.14	75.06	74.62	0.15	0.71
Cooked, Brabender	64.92	65.46	65.35	65.39	1.16	0.30
Cooked, AOAC	65.13	63.88	66.27	66.23	0.18	0.68
pH, raw	5.44	5.46	5.43	5.44	0.12	0.73
pH, cooked	5.53	5.56	5.57	5.56	0.50	0.49
Ether extract, %						
Raw	1.98	2.06	1.97	1.84	0.08	0.78
Cooked	2.40	2.47	2.81	3.22	0.15	0.71

[a] Data for CC + ESHB-F were combined
[b] Data for CC + ESHB-S1 were combined
[c] Data for ESHB-F and ESHB-S1 were combined
[d] Range, 7 (tender, soft, mealy, juicy), 1 (tough, hard, chewy, dry).
[e] Ratio of work, 2nd/1st penetration
[f] Calculated using values of work as defined by Bourne (1978).
[g] 1.0 minus ELI; the greater the value, the more liquid expressed.

Table 16 - Means, F-values, and probability levels for measurements of bull adductor muscle not affected significantly by cooking systems x carcass treatments x chilling methods interactions

Measurements	Strips				Roasts				F-value	P
	CC		ESHB		CC		ESHB			
	CC[a]	CC[b]	F	S1	CC[a]	CC[b]	F	S1		
Sensory scores[c], 7 - 1										
Tenderness	5.48	5.86	5.24	5.24	5.22	5.72	5.28	5.32	0.05	0.82
Softness	4.76	5.28	4.68	4.52	4.22	4.96	4.42	4.56	0.01	0.91
Mealiness	4.72	4.72	4.64	4.58	4.62	4.74	3.82	4.24	0.45	0.51
Juiciness	4.58	4.56	4.78	4.14	4.30	4.72	4.80	5.20	0.31	0.58
Instron texture measurements										
Hardness, kg	7.00	8.16	7.93	9.32	9.41	7.69	8.23	7.65	0.36	0.56
Cohesiveness[d]	0.46	0.47	0.45	0.46	0.48	0.48	0.50	0.47	0.14	0.71
Cohesiveness[e]	0.43	0.45	0.41	0.43	0.45	0.46	0.44	0.43	0.05	0.83
Elasticity, mm	8.36	7.91	8.69	8.08	7.88	7.32	8.22	7.42	0.00	0.96
Chewiness, kg-mm	28.64	31.33	34.26	34.77	36.02	27.98	33.06	27.35	0.22	0.65
Chewiness[e], kg-mm	26.09	30.13	28.34	32.12	33.42	26.33	29.25	25.19	0.12	0.73
Shear cohesiveness,kg	7.14	8.16	8.19	8.59	9.22	6.63	8.67	8.36	2.23	0.16
Firmness, kg/min	25.04	28.17	27.88	31.74	34.26	25.30	30.46	32.20	1.73	0.21
Solubilized OHProline,%	20.30	27.08	21.38	28.92	10.88	12.25	26.29	30.26	0.29	0.60
WHC[f]	0.62	0.66	0.62	0.64	0.67	0.65	0.66	0.64	0.26	0.62
Total loss, %	27.21	25.06	26.74	26.51	25.12	24.26	26.97	24.28	2.99	0.10
Drip loss, %	22.97	22.89	23.80	24.53	3.54	3.56	4.28	3.47	0.95	0.35
Volatile loss, %	4.24	2.38	2.84	1.99	21.32	20.34	22.40	20.37	1.45	0.25
Cooking time, min	89.83	88.87	90.87	89.40	80.80	76.20	86.60	81.80	0.01	0.94
Total moisture,%										
Raw, Brabender	73.01	73.86	72.92	73.50	73.16	72.88	73.19	73.24	0.68	0.42
Raw, AOAC	74.83	76.16	75.88	74.89	75.20	74.12	74.23	74.35	1.44	0.25
Cooked, Brabender	66.17	66.67	66.47	66.34	63.67	64.25	64.22	64.43	0.08	0.78
Cooked, AOAC	66.22	68.16	67.38	67.25	64.13	59.59	65.16	65.21	1.31	0.27
pH, raw	5.44	5.45	5.44	5.42	5.44	5.47	5.41	5.46	1.97	0.18
pH, cooked	5.52	5.53	5.57	5.53	5.54	5.60	5.56	5.60	0.76	0.40
Ether extract, % (raw)	1.97	1.65	1.69	1.93	1.98	2.48	2.24	1.75	1.05	0.32
Ether extract, % (cooked)	1.47	1.41	1.70	2.02	3.32	3.53	3.92	4.42	0.00	0.96

[a] Adductor muscle obtained from the CC side of carcass whose other half was subjected to ESHB-F.
[b] Adductor muscle obtained from the CC side of carcass whose other half was subjected to ESHB-S1.
[c] Range, 7 (tender, soft, mealy, juicy), 1 (tough, hard, chewy, dry).
[d] Ratio of work, 2nd/1st penetration.
[e] Calculated using values of work as defined by Bourne (1978).
[f] 1.0 minus ELI; the greater the value the more liquid expressed.

Table 17 - Time of heat penetration, in minutes, in individual roast to increase by increment of 5°C from the initial temperature to 70°C

Animal code	Initial temp.	5°C	10°C	15°C	20°C	25°C	30°C	35°C
24 CC	4.0	3.0	12.0	20.0	26.0	30.0	36.0	40.0
24 ESHB	-1.0	23.0	31.5	38.0	42.0	46.0	49.5	53.5
74 CC	4.0	5.5	15.0	18.0	21.5	26.5	31.0	35.0
74 ESHB	-1.0	22.0	26.5	30.0	35.0	38.5	42.5	47.0
14 CC	0.0	15.0	23.0	28.5	33.0	37.0	40.0	44.0
14 ESHB	0.0	23.0	31.5	38.0	42.0	46.0	49.5	53.5
70 CC	2.0	5.0	12.5	18.0	22.5	26.0	29.0	34.0
70 ESHB	4.0	8.5	18.0	23.5	28.5	35.0	39.0	44.0
110 CC	3.0	3.5	10.0	15.0	20.0	25.0	30.0	34.0
110 ESHB	4.0	1.0	5.5	10.0	15.0	20.0	26.0	31.0
91 CC	4.0	1.5	7.5	13.5	20.0	24.5	28.5	33.0
91 ESHB	-1.0	21.0	27.0	31.0	33.5	36.0	40.0	44.5
167 CC	3.0	1.5	7.5	13.5	20.0	24.5	28.5	32.5
167 ESHB	0.0	15.5	21.5	25.5	29.0	33.5	38.0	43.0
210 CC	-1.0	23.0	30.5	33.5	37.0	40.0	44.5	48.5
210 ESHB	1.0	8.0	15.5	20.0	24.0	30.0	33.5	37.0
82 CC	7.0	0.0	4.0	10.0	16.0	20.0	26.0	31.0
82 ESHB	5.0	0.0	8.0	13.5	19.0	25.0	30.0	34.0
184 CC	8.0	0.0	4.5	14.0	18.5	23.0	28.0	33.0
184 ESHB	7.0	0.0	5.0	13.5	18.0	22.5	26.5	31.5

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 17 (concluded)

Animal code	40°C	45°C	50°C	55°C	60°C	65°C	70°C
24 CC	46.0	52.0	59.0	66.5	75.0	83.0	90.0
24 ESHB	58.5	62.5	67.0	73.0	80.0	87.0	96.0
74 CC	41.0	46.5	51.0	57.0	65.0	73.5	82.0
74 ESHB	52.5	57.0	62.5	70.0	76.0	84.0	93.0
14 CC	48.5	52.5	58.0	63.0	68.0	75.0	83.0
14 ESHB	57.5	62.5	67.0	72.0	80.0.	87.0	97.0
70 CC	38.0	42.0	47.5	52.0	58.0	64.0	72.0
70 ESHB	49.0	54.0	59.5	65.0	70.0	78.0	83.0
110 CC	39.0	45.0	50.0	56.0	65.0	73.0	79.0
110 ESHB	35.0	41.0	46 .0	53.0	60 0	66.5	72.0
91 CC	38.0	43.0	48.5	55.0	63.0	71.0	81.0
91 ESHB	49.0	55.0	61.0	67.0	74.0	82.0	92.0
167 CC	38.5	43.0	49.0	55.0	63.0	71.0	79.0
167 ESHB	48.0	53.0	58.0	65.0	71.0	80.0	89.0
210 CC	52.0	56.5	61.0	66.0	71.0	79.0	87.0
210 ESHB	41.0	46.5	50.0	56.0	61.0	67.0	76.0
82 CC	37.0	42.0	47.0	50.0	59.0	68.0	76.0
82 ESHB	39.0	45.0	51.0	56.0	64.0	72.0	83.0
184 CC	38.0	41.5	46.0	51.0	57.0	64.0	71.0
184 ESHB	37.0	41.5	46.5	52.5	58.5	65.0	73.0

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 18- Average time of heat penetration in six strips per muscle to increase by increments of 5°C from the initial temperature to 70°C, in minutes.

Animal	code	Initial temp.	5°C	10°C	15°C	20°C	25°C	30°C	35°C
16	CC	-1.2	20.0	25.0	30.0	34.5	38.0	42.5	47.0
16	ESHB	-1.0	20.0	26.5	30.0	35.5	38.5	42.0	46.5
37	CC	0.5	20.0	29.0	33.0	36.0	39.0	43.0	47.0
37	ESHB	-1.3	20.0	27.0	32.0	35.5	39.5	42.5	46.5
45	CC	-0.8	22.0	26.5	30.5	35.5	40.5	44.5	48.5
45	ESHB	-1.5	20.5	26.0	31.0	35.5	40.0	45.5	49.5
78	CC	-1.2	20.5	26.0	30.0	34.5	39.0	43.5	46.5
78	ESHB	-1.9	21.0	26.0	30.5	34.5	39.5	44.0	47.0
206	CC	-1.2	18.0	24.0	30.0	34.0	38.5	42.0	45.5
206	ESHB	-1.3	19.0	24.0	30.0	34.5	39.5	43.0	46.0
103	CC	-1.2	14.0	22.0	29.0	33.0	38.0	43.0	47.0
103	ESHB	0.8	14.0	22.0	29.0	34.0	39.0	44.0	48.0
140	CC	0.2	18.0	23.0	27.0	32.0	37.0	41.5	45.5
140	ESHB	-1.7	18.0	23.0	27.0	32.0	37.0	41.5	45.5
27	CC	0.3	14.0	21.0	26.5	32.5	38.0	43.5	47.0
27	ESHB	0.7	16.0	21.0	26.0	32.0	38.0	42.0	47.0
175	CC	-1.7	20.0	25.0	30.0	35.0	39.0	42.5	46.5
175	ESHB	-1.3	17.0	24.0	30.0	35.0	39.0	42.0	45.0
238	CC	-1.3	19.0	26.0	31.0	34.0	38.0	42.0	45.5
238	ESHB	-1.3	16.0	22.0	27.0	33.0	37.0	40.0	44.0

CC, conventionally chilled
ESHB, electrically stimulated-hot boned

Table (concluded)

Animal code	40°C	45°C	50°C	55°C	60°C	65°C	70°C
16 CC	50.0	55.0	59.5	64.0	68.5	75.0	90.0
16 ESHB	50.5	55.5	59.5	64.5	72.0	80.0	91.0
37 CC	51.5	55.5	58.5	63.0	68.5	75.5	85.0
37 ESHB	50.5	54.5	59.0	64.5	70.0	78.0	87.0
45 CC	52.0	55.5	61.0	67.0	74.5	83.0	93.0
45 ESHB	53.5	57.0	62.0	68.0	76.0	85.0	96.0
78 CC	49.5	53.5	59.0	63.5	70.0	79.0	88.0
78 ESHB	50.5	55.0	60.0	65.0	71.5	80.0	89.0
206 CC	48.5	52.0	55.5	62.0	68.0	75.5	86.0
206 ESHB	48.0	51.0	55.0	62.0	68.0	75.0	87.0
103 CC	51.0	54.0	59.0	66.0	72.0	80.0	90.0
103 ESHB	52.0	58.0	62.0	67.0	73.0	81.0	90.0
140 CC	50.5	55.5	60.5	64.5	68.5	75.5	92.0
140 ESHB	50.5	55.5	61.0	65.5	69.0	77.0	91.0
27 CC	51.0	55.0	60.0	66.0	73.0	80.0	90.0
27 ESHB	51.0	55.0	60.0	66.5	73.0	80.0	90.0
175 CC	51.5	56.0	60.0	65.0	72.0	82.0	92.0
175 ESHB	49.0	54.0	60.0	66.0	73.5	82.0	91.0
238 CC	49.5	54.0	58.0	64.0	71.0	79.0	87.0
238 ESHB	48.0	53.0	58.0	64.0	71.0	79.0	88.0

CC, Conventionally chilled
ESHB, electrically stimulated-hot boned

Table 19 - Non-significant correlation coefficients for selected paired variates on the basis of cooking system

Paired variates, D/F = 18	Strips		Roasts	
	r	P	r	P
Tenderness scores vs.				
Juiciness scores	0.22	0.35	0.18	0.44
Hardness, kg	-0.35	0.13	-0.05	0.84
Cohesiveness	0.35	0.12	-0.18	0.45
Elasticity, mm	0.14	0.55	-0.28	0.24
Chewiness, kg-mm	-0.15	0.51	-0.25	0.29
Solubilized OHProline,%	-0.17	0.49	-0.24	0.31
Softness scores vs.				
Juiciness scores	0.22	0.35	Significant	
Mealiness scores	Significant		0.24	0.30
Hardness, kg	-0.36	0.12	-0.08	0.74
Cohesiveness	0.25	0.28	0.07	0.77
Elasticity, mm	0.03	0.89	-0.37	0.11
Chewiness, kg-mm	0.18	0.46	-0.18	0.46
Solubilized OHProline,%	-0.13	0.59	-0.07	0.76
Mealiness scores vs.				
Juiciness scores	0.04	0.88	-0.23	0.32
Hardness, kg	-0.35	0.13	0.19	0.42
Cohesiveness	0.36	0.12	-0.13	0.58
Elasticity, mm	0.04	0.88	Significant	
Chewiness, kg-mm	-0.20	0.40	-0.17	0.46
Solubilized OHProline, %	-0.33	0.16	Significant	
Elasticity vs.				
Shear cohesiveness , kg	-0.06	0.82	0.01	0.96
Firmness, kg/min	0.18	0.45	-0.17	0.47
Solubilized OHProline, %	-0.10	0.69	0.30	0.20
Solubilized OHProline vs.				
Chewiness, kg-mm	-0.33	0.15	0.11	0.64
Shear cohesiveness, kg	-0.11	0.66	0.26	0.28
Firmness, kg/min	0.02	0.93	0.15	0.53
Hardness vs.				
Cohesiveness	-0.12	0.62	0.01	0.97
Elasticity, mm	-0.28	0.23	0.37	0.11
Solubilized OHProline, %	-0.08	0.74	-0.03	0.90
Cohesiveness vs.				
Elasticity, mm	0.27	0.25	-0.33	0.16
Chewiness, kg-mm	0.41	0.07	0.34	0.14
Shear cohesiveness, kg	0.14	0.56	0.24	0.31
Firmness, kg/min	0.20	0.40	0.27	0.25
Solubilized OHProline,%	-0.36	0.12	0.01	0.98

D/F = 18; r-value required for a significant relationship: $P \leq 0.05$; 0.444; $P \leq 0.01$, 0.561; $P \leq 0.001$, 0.679

Table 20 - Non-significant correlation coefficients for selected paired variates on the basis of carcass treatment

Paired variates, D/F = 18	CC		ESHB	
	r	P	r	P
Tenderness scores vs.				
Juiciness scores	0.19	0.41	0.28	0.24
Hardness, kg	-0.33	0.16	-0.07	0.78
Cohesiveness	0.19	0.41	-0.08	0.73
Elasticity, mm	-0.11	0.65	0.09	0.70
Chewiness, kg-mm	-0.23	0.32	-0.12	0.31
Solubilized OHProline, %	0.01	0.98	-0.13	0.57
Softness scores vs.				
Mealiness scores	0.22	0.34	Significant	
Juiciness scores	0.24	0.31	0.39	0.08
Hardness, kg	-0.29	0.21	0.13	0.59
Cohesiveness	0.18	0.45	0.02	0.92
Elasticity, mm	-0.04	0.86	-0.07	0.75
Chewiness, kg-mm	-0.19	0.42	-0.09	0.70
Solubilized OHProline, %	0.21	0.36	-0.13	0.58
Mealiness scores vs.				
Juiciness scores	-0.24	0.30	0.004	0.98
Hardness, kg	-0.15	0.64	0.08	0.74
Cohesiveness	0.18	0.75	-0.10	0.68
Elasticity, mm	-0.27	0.24	-0.08	0.75
Chewiness, kg-mm	-0.20	0.40	-0.08	0.74
Shear cohesiveness, kg	-0.17	0.49	-0.43	0.06
Solubilized OHProline, %	-0.19	0.43	0.34	0.14
Solubilized OHProline vs.				
Hardness, kg	-0.19	0.43	0.33	0.99
Juiciness scores	-0.22	0.37	0.007	0.98
Cohesiveness	-0.36	0.12	0.06	0.80
Elasticity, mm	0.19	0.42	0.08	0.74
Chewiness, kg-mm	-0.20	0.40	0.01	0.97
Shear cohesiveness, kg	-0.21	0.38	0.26	0.27
Firmness, kg/min	-0.31	0.19	0.28	0.23

D/F = 18; r-value required for a significant relationship: $P \leq 0.05$; 0.444; $P \leq 0.01$, 0.561; $P \leq 0.001$, 0.679

Table 21 - Overall coefficients for selected significant paired tenderness and texture measurements

Paired variates, D/F = 38	r	P
Tenderness scores vs.		
Softness scores	0.84	0.0001
Mealiness scores	0.68	0.0001
Shear cohesiveness, kg	-0.60	0.0001
Firmness, kg/min	-0.57	0.0001
Softness scores vs.		
Mealiness scores	0.50	0.001
Shear cohesiveness, kg	-0.50	0.001
Firmness, kg/min	-0.50	0.0009
Mealiness scores vs.		
Shear cohesiveness, kg	-0.39	0.01
Firmness, kg/min	-0.33	0.04
Shear cohesiveness vs.		
Firmness, kg/min	0.90	0.0001
Hardness, kg	0.55	0.0005
Chewiness, kg-mm	0.52	0.0006
Firmness vs.		
Hardness, kg	0.51	0.0008
Chewiness, kg-mm	0.45	0.004

D/F = 35; r-value required for a significant relationship: $P \leq 0.05$, 0.325; $P \leq 0.01$; 0.418; $P \leq 0.001$, 0.519

D/F = 40; r-value required for a significant relationship: $P \leq 0.05$, 0.304; $P \leq 0.01$; 0.393; $P \leq 0.001$, 0.490

Table 22 - Non-significant correlation coefficients for selected paired variates on the basis of overall measurements

Paired variates, D/F = 38	r	P
Tenderness scores vs.		
Juiciness scores	0.18	0.26
Hardness, kg	-0.21	0.20
Cohesiveness	0.05	0.76
Elasticity, mm	-0.004	0.98
Chewiness, kg-mm	-0.19	0.24
Solubilized OHProline, %	-0.18	0.27
Mealiness scores vs.		
Juiciness scores	-0.17	0.31
Hardness, kg	-0.05	0.78
Cohesiveness	-0.007	0.96
Elasticity, mm	-0.17	0.30
Chewiness, kg-mm	-0.16	0.33
Softness scores		
Hardness, kg	-0.23	0.16
Cohesiveness	0.11	0.52
Elasticity, mm	-0.08	0.63
Chewiness, kg-mm	-0.16	0.33
Solubilized OHProline, %	-0.04	0.78
Hardness vs.		
Juiciness scores	-0.23	0.16
Cohesiveness	-0.03	0.85
Elasticity, mm	0.003	0.98
Solubilized OHProline, %	0.06	0.72
Chewiness vs.		
Solubilized OHProline, %	-0.05	0.75
Solubilized OHProline vs.		
Juiciness scores	-0.05	0.76
Cohesiveness	-0.15	0.35
Elasticity, mm	-0.15	0.35
Shear cohesiveness, kg	0.09	0.57
Firmness, kg/min	0.06	0.73

D/F = 35; r-value required for a significant relationship: $P \leq 0.05$, 0.325; $P \leq 0.01$, 0.418; $P \leq 0.001$, 0.519

D/F = 40: r-value required for a significant relationship: $P \leq 0.05$ 0.304; $P \leq 0.01$, 0.393; $P \leq 0.001$, 0.490

Table 23 - Sensory evaluation scores[a] for strips

Animal Code	Tenderness	Softness	Mealiness	Juiciness
16 CC	4.7	3.7	4.5	4.5
16 ESHB	4.5	3.7	4.0	4.3
37 CC	6.0	5.5	4.8	4.8
37 ESHB	5.6	4.6	5.0	4.9
45 CC	5.9	5.5	5.1	5.1
45 ESHB	6.1	5.8	5.4	5.0
78 CC	5.1	4.5	4.1	3.0
78 ESHB	5.4	4.6	4.4	3.6
206 CC	6.3	6.0	5.5	4.0
206 ESHB	5.8	5.2	5.3	3.8
103 CC	5.9	5.1	4.9	4.9
103 ESHB	5.1	4.5	4.4	5.6
140 CC	4.9	4.0	4.3	3.6
140 ESHB	4.9	4.8	4.4	4.1
27 CC	5.4	4.9	3.9	5.9
27 ESHB	4.3	3.9	4.0	4.1
175 CC	6.1	5.6	4.8	4.8
175 ESHB	5.0	4.1	3.9	4.9
238 CC	6.4	5.4	5.3	4.6
238 ESHB	5.9	4.8	5.3	4.3

[a] Range, 7 (tender, soft, mealy, or juicy), 1 (tough, hard, chewy, or dry).

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 24 - Sensory evaluation scores[a] for roasts

Animal code	Tenderness	Softness	Mealiness	Juiciness
24 CC	4.9	3.9	4.1	4.6
24 ESHB	5.4	5.3	4.0	5.9
74 CC	5.0	3.7	4.7	4.0
74 ESHB	5.1	3.9	3.0	4.4
14 CC	5.5	4.8	3.6	4.4
14 ESHB	4.9	4.1	3.8	5.4
70 CC	6.0	4.4	6.0	3.7
70 ESHB	6.4	5.3	5.1	5.4
110 CC	5.8	5.4	4.8	5.9
110 ESHB	5.9	5.4	4.4	5.5
91 CC	5.1	4.3	5.1	2.6
91 ESHB	5.0	4.4	4.0	5.1
167 CC	5.7	4.2	5.3	5.0
167 ESHB	5.0	3.8	4.0	3.7
210 CC	5.4	5.0	3.9	5.3
210 ESHB	5.9	4.7	4.1	4.9
82 CC	5.3	5.1	4.3	5.9
82 ESHB	5.1	4.6	4.3	5.4
184 CC	6.0	5.1	5.0	3.7
184 ESHB	4.3	3.4	3.6	4.3

[a] Range, 7 (tender, soft, mealy, or juicy), 1 (tough, hard, chewy, or dry.

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 25 - Instron texture measurements for ESHB oven roasts

Animal number	Hardness (kg)	Cohesiveness[a]	Elasticity (mm)	Chewiness (kg-mm)	Shear Cohesiveness (kg)	Firmness (kg/min)
24	8.00	0.50	7.38	28.99	8.90	33.60
74	8.55	0.47	9.88	39.77	7.92	27.27
14	5.17	0.53	6.31	18.51	6.57	24.70
70	9.17	0.43	7.25	28.70	5.97	24.87
110	8.10	0.48	8.35	34.56	5.97	24.60
91	7.97	0.69	6.44	36.43	11.10	40.90
167	8.93	0.44	9.13	35.26	7.18	27.97
210	7.70	0.41	8.29	24.85	8.23	22.60
82	6.57	0.47	6.42	19.55	9.43	35.98
184	9.23	0.44	8.75	35.42	13.87	47.83

[a]Ratio of work, 2nd/1st penetration

ESHB, electrically stimulated-hot boned

Table 26 - Instron texture measurements for CC oven roasts

Animal Number	Hardness (kg)	Cohesiveness[a]	Elasticity (mm)	Chewiness (kg-mm)	Shear Cohesiveness (kg)	Firmness (kg/min)
24	7.07	0.39	8.25	22.73	8.17	30.53
74	9.78	0.48	8.65	41.89	7.88	28.77
14	6.18	0.52	8.36	28.83	5.41	17.90
70	7.18	0.37	6.69	17.68	6.10	25.03
110	6.60	0.48	5.98	18.90	7.18	31.77
91	11.80	0.52	7.27	43.96	11.32	41.40
167	8.28	0.57	7.08	33.24	8.80	34.02
210	10.10	0.46	8.17	38.26	9.93	36.57
82	9.07	0.51	8.21	39.18	6.72	22.97
184	9.41	0.50	7.35	35.33	7.74	28.83

[a]Ratio of work, 2nd/1st penetration

CC, conventionally chilled

Table 27 - Instron texture measurements for ESHB strips cooked in a model system

Animal Number	Hardness (kg)	Cohesiveness[a]	Elasticity (mm)	Chewiness (kg-mm)	Shear Cohesiveness (kg)	Firmness (kg/min)
16	7.22	0.43	7.13	21.84	7.22	25.73
37	7.22	0.50	10.38	36.56	8.23	30.23
45	6.30	0.47	10.27	31.59	5.47	17.83
78	8.25	0.42	7.63	26.33	6.80	24.07
206	8.68	0.48	6.75	28.15	7.53	22.87
103	9.80	0.41	8.54	34.10	9.85	35.93
140	9.12	0.43	7.13	47.22	10.20	29.67
27	10.28	0.47	7.27	35.29	10.40	39.60
175	8.50	0.48	11.54	47.22	10.23	41.27
238	10.87	0.47	7.21	36.86	8.00	30.90

[a]Ratio of work, 2nd/1st penetration

ESHB, electrically stimulated-hot boned

Table 28 - Instron texture measurements for CC strips cooked in the model system

Animal Number	Hardness (kg)	Cohesiveness[a]	Elasticity (mm)	Chewiness (kg-mm)	Shear Cohesiveness (kg)	Firmness (kg/min)
16	8.23	0.41	8.71	31.66	8.58	27.83
37	6.18	0.38	8.92	20.96	5.13	13.70
45	6.50	0.49	6.54	21.13	5.57	18.73
78	8.43	0.36	6.21	18.82	7.62	28.07
206	6.40	0.51	8.50	26.49	5.87	22.47
103	7.68	0.50	9.04	35.47	6.60	27.60
140	6.43	0.53	8.59	33.98	9.83	37.33
27	10.10	0.50	8.27	42.52	12.87	38.23
175	7.73	0.47	8.42	32.26	6.63	28.77
238	8.13	0.53	8.17	36.56	7.80	23.30

[a]Ratio of work, 2nd/1st penetration

CC, conventionally chilled

Table 29 - Percentage solubilized hydroxyproline and hydroxyproline contents[a] of raw and cooked strip samples

Animal code	OHProline in raw	OHProline in cooked	% Solubilized OHProline	Animal code	OHProline in raw	OHProline in cooked	% Solubilized OHProline
16 CC	2.784	2.260	18.86	16 ESHB	2.551	1.869	26.75
45 CC	1.537	1.228	20.10	45 ESHB	1.714	1.423	17.01
37 CC	2.927	2.093	28.51	37 ESHB	2.875	2.014	30.07
78 CC	3.040	1.855	39.00	78 ESHB	3.175	1.938	38.98
206 CC	2.576	1.904	26.09	206 ESHB	2.878	2.098	27.10
103 CC	1.704	1.490	12.56	103 ESHB	1.842	1.592	13.57
140 CC	2.685	2.109	21.47	140 ESHB	2.706	2.178	19.52
27 CC	2.914	2.279	21.79	27 ESHB	3.210	2.309	28.08
175 CC	3.035	1.964	35.29	175 ESHB	3.266	2.234	31.60
238 CC	2.742	2.379	13.24	238 ESHB	2.918	2.368	18.85

[a]Expressed in mg/gm, moisture free basis

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 30 - Percentage solubilized hydroxyproline and hydroxyproline contents[a] of raw and cooked roasts

Animal code	OHProline in raw	OHProline in cooked	% Solubilized OHProline	Animal code	OHProline in raw	OHProline in cooked	% Solubilized OHProline
24 CC	1.726	1.475	14.57	24 ESHB	2.054	1.312	36.16
74 CC	2.695	2.232	17.18	74 ESHB	3.058	1.953	36.17
14 CC	2.629	2.226	14.04	14 ESHB	2.848	2.230	21.70
70 CC	2.565	2.323	9.44	70 ESHB	2.869	2.029	29.27
110 CC	2.870	2.775	3.33	110 ESHB	3.230	2.183	32.41
91 CC	2.598	2.368	8.85	91 ESHB	2.194	1.625	25.92
167 CC	2.678	2.509	6.31	167 ESHB	2.694	2.428	9.88
210 CC	2.381	2.203	7.50	210 ESHB	2.474	1.898	23.34
82 CC	3.002	2.507	16.35	82 ESHB	3.122	2.342	24.98
184 CC	2.042	1.714	16.08	184 ESHB	2.228	1.271	42.95

[a] Expressed in mg/gm, moisture free basis

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 31 - Initial weights and cooking time for roasts

Animal code	Initial weight, kg	Cooking time, min	Animal code	Initial weight, kg	Cooking time, min
24 CC	653	90	24 ESHB	695	96
74 CC	717	82	74 ESHB	720	94
14 CC	616	83	14 ESHB	833	97
70 CC	578	72	70 ESHB	785	83
110 CC	613	79	110 ESHB	590	73
91 CC	601	81	91 ESHB	852	78
167 CC	602	79	167 ESHB	703	89
210 CC	584	72	210 ESHB	631	76
82 CC	712	76	82 ESHB	595	83
184 CC	598	71	184 ESHB	585	73
Avg.	627.4	78.5		698.9	84.2

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 32- Average initial weights and cooking times for strips

Animal code	Avg. initial weights, g	Cooking time, min	Animal Code	Avg. initial weights, g	Cooking time, min
16 CC	32.33	89.83	16 ESHB	31.00	90.83
45 CC	33.83	93.50	45 ESHB	36.00	96.00
37 CC	34.83	85.00	37 ESHB	39.83	87.00
78 CC	32.17	87.83	78 ESHB	35.00	89.33
206 CC	32.33	86.17	206 ESHB	35.00	86.00
103 CC	36.50	89.83	103 ESHB	34.17	90.00
140 CC	35.50	91.50	140 ESHB	35.50	90.50
27 CC	36.17	90.50	27 ESHB	36.67	90.00
175 CC	34.17	91.33	175 ESHB	34.50	91.50
238 CC	34.33	88.50	238 ESHB	35.33	90.17
Avg.	33.92	89.40		35.35	90.13

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 33 - Volatile, drip, and total cooking losses [a] for strips cooked in a model system

Animal code	Volatile loss,%	Drip loss, %	Total loss,%	Animal Code	Volatile loss, %	Drip loss,%	Total loss,%
16 CC	2.56	28.89	31.44	16 ESHB	1.62	28.52	30.14
45 CC	2.97	22.56	25.53	45 ESHB	1.76	27.34	28.67
37 CC	10.05	16.19	26.24	37 ESHB	7.53	17.58	25.11
78 CC	3.12	23.35	26.46	78 ESHB	1.43	23.82	25.26
206 CC	1.62	21.17	22.79	206 ESHB	1.89	24.51	26.39
103 CC	1.83	22.82	24.65	103 ESHB	0.51	25.39	25.89
140 CC	3.77	24.41	28.18	140 ESHB	2.78	20.19	22.97
27 CC	2.78	22.73	25.50	27 ESHB	1.39	24.21	25.60
175 CC	2.44	24.38	25.82	175 ESHB	2.40	25.11	27.51
238 CC	1.93	22.81	24.74	238 ESHB	2.83	24.98	27.81

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

[a]Average of six strips

Table 34- Volatile, drip, and total cooking losses for roasts

Animal code	Volatile loss, %	Drip loss,%	Total loss, %	Animal Code	Volatile loss,%	Drip loss,%	Total loss, %
24 CC	17.00	5.51	22.82	24 ESHB	20.58	4.75	25.76
74 CC	21.76	2.79	25.10	74 ESHB	25.83	4.17	30.28
14 CC	23.21	3.73	27.27	14 ESHB	23.05	4.32	27.85
70 CC	21.28	3.63	25.43	70 ESHB	20.00	3.69	24.20
110 CC	19.74	3.43	23.65	110 ESHB	17.46	3.22	21.02
91 CC	22.80	3.00	26.29	91 ESHB	23.47	3.76	27.35
167 CC	22.43	3.99	26.58	167 ESHB	22.48	4.13	27.03
210 CC	22.60	2.40	24.83	210 ESHB	19.65	4.60	24.41
82 CC	17.42	2.67	20.37	82 ESHB	21.01	2.18	23.53
184 CC	20.07	4.35	24.58	184 ESHB	20.51	3.93	24.79

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 35 - Total moisture, Brabender and AOAC (%) for roasts

Animal code	Raw		Cooked	
	Brabender	AOAC	Brabender	AOAC
24 CC	72.20	75.52	63.80	64.43
24 ESHB	72.90	73.79	63.95	61.52
74 CC	72.90	74.45	64.10	62.33
74 ESHB	73.10	72.91	63.45	68.83
14 CC	73.50	73.18	62.00	60.82
14 ESHB	74.05	75.12	64.60	63.68
70 CC	74.05	75.39	64.55	41.10
70 ESHB	74,25	75.70	64.05	66.30
110 CC	72.25	77.00	64.55	63.71
110 ESHB	71.85	72.98	64.45	65.24
91 CC	74.20	75.97	64.65	64.57
91 ESHB	74.25	73.35	64.95	66.88
167 CC	73.50	74.80	61.75	63.77
167 ESHB	73.25	75.98	63.40	62.34
210 CC	73.00	75.26	64.05	65.06
210 ESHB	72.45	73.12	65.35	66.25
82 CC	71.85	71.95	65.55	65.81
82 ESHB	73.65	72.91	65.10	65.27
184 CC	72.75	73.08	64.60	66.53
184 ESHB	72.40	75.04	63.95	65.55

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 36- Total moisture, Brabender, AOAC, (%) for strips

Animal code	Raw		Cooked	
	Brabender	AOAC	Brabender	AOAC
16 CC	72.05	73.91	64.65	64.68
16 ESHB	73.75	84.04	64.80	67.39
45 CC	72.15	72.54	65.80	66.34
45 ESHB	70.75	73.17	66.95	66.82
37 CC	74.05	75.80	66.55	65.65
37 ESHB	73.65	73.89	67.60	67.32
78 CC	71.70	70.91	65.70	67.64
78 ESHB	72.35	72.55	65.20	66.21
206 CC	73.85	79.27	65.25	63.90
206 ESHB	73.20	77.24	66.45	65.72
103 CC	74.00	76.66	67.20	66.51
103 ESHB	73.70	75.33	66.65	68.95
140 CC	72.80	75.24	66.65	67.91
140 ESHB	72.75	72.99	66.35	66.40
27 CC	74.50	77.64	66.90	70.97
27 ESHB	73.65	72.26	66.40	66.41
175 CC	73.50	76.43	68.40	69.20
175 ESHB	74.70	77.66	68.10	69.73
238 CC	73.95	76.44	67.10	69.11
238 ESHB	73.60	74.74	65.55	-

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 37 - pH and ether extract (%) for roasts

Animal code	pH		Ether extract	
	Raw	Cooked	Raw	Cooked
16 CC	5.46	5.46	3.86	0.97
16 ESHB	5.49	5.59	2.83	3.81
45 CC	5.49	5.67	1.93	1.01
45 ESHB	5.47	5.71	1.79	0.56
37 CC	5.47	5.51	0.22	1.94
37 ESHB	5.44	5.57	1.26	0.57
78 CC	5.43	5.51	3.15	3.14
78 ESHB	5.38	5.50	3.45	3.14
206 CC	5.41	5.44	1.55	0.70
206 ESHB	5.36	5.46	0.17	1.89
103 CC	5.33	5.49	1.84	0.69
103 ESHB	5.36	5.52	1.87	2.30
140 CC	5.44	5.49	1.98	2.76
140 ESHB	5.45	5.48	0.72	1.24
27 CC	5.50	5.62	2.19	2.27
27 ESHB	5.53	5.66	3.02	3.57
175 CC	5.42	5.53	0.57	0.46
175 ESHB	5.42	5.53	0.71	0.40
238 CC	5.48	5.53	0.79	0.47
238 ESHB	5.43	5.50	2.31	-

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 38 - pH and ether extract (%) for roasts

Animal code	pH		Ether extract	
	Raw	Cooked	Raw	Cooked
24 CC	5.45	5.50	1.78	1.77
24 ESHB	5.35	5.55	3.23	5.33
74 CC	5.41	5.56	2.38	3.19
74 ESHB	5.46	5.53	2.34	3.79
14 CC	5.51	5.62	2.64	5.25
14 ESHB	5.46	5.57	0.72	5.45
70 CC	5.42	5.57	0.47	1.20
70 ESHB	5.43	5.59	2.04	5.23
110 CC	5.41	5.51	1.06	5.04
110 ESHB	5.40	5.51	2.81	3.48
91 CC	5.40	5.51	1.61	0.54
91 ESHB	5.39	5.55	0.37	2.48
167 CC	5.44	5.52	3.10	6.20
167 ESHB	5.38	5.51	1.60	4.89
210 CC	5.48	5.61	1.06	4.91
210 ESHB	5.47	5.64	3.64	3.11
82 CC	5.56	5.73	3.68	2.58
82 ESHB	5.58	5.71	2.80	3.67
184 CC	5.44	5.56	4.53	3.69
184 ESHB	5.43	5.60	0.37	4.25

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

Table 39 - Water-holding capacity for cooked roasts or strips

Animal code	Cooking system	WHC	Animal code	Cooking system	WHC
24 CC	OR	0.69	24 ESHB	OR	0.71
74 CC	OR	0.61	74 ESHB	OR	0.67
14 CC	OR	0.56	14 ESHB	OR	0.58
70 CC	OR	0.61	70 ESHB	OR	0.61
110 CC	OR	0.72	110 ESHB	OR	0.67
91 CC	OR	0.72	91 ESHB	OR	0.64
167 CC	OR	0.64	167 ESHB	OR	0.64
210 CC	OR	0.69	210 ESHB	OR	0.66
82 CC	OR	0.68	82 ESHB	OR	0.66
184 CC	OR	0.68	184 ESHB	OR	0.68
16 CC	S	0.60	16 ESHB	S	0.61
45 CC	S	0.59	45 ESHB	S	0.66
37 CC	S	0.63	37 ESHB	S	0.63
78 CC	S	0.66	78 ESHB	S	0.65
206 CC	S	0.64	206 ESHB	S	0.63
103 CC	S	0.65	103 ESHB	S	0.59
140 CC	S	0.63	140 ESHB	S	0.61
27 CC	S	0.64	27 ESHB	S	0.63
175 CC	S	0.72	175 ESHB	S	0.70
238 CC	S	0.65	238 ESHB	S	0.59

CC, conventionally chilled

ESHB, electrically stimulated-hot boned

OR, oven roasting

S, strips cooked in a model system

TENDERNESS OF CONVENTIONALLY CHILLED OR ELECTRICALLY STIMULATED-HOT BONED BULL ADDUCTOR MUSCLE ROASTED OR COOKED IN A MODEL SYSTEM

by

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AN ABSTRACT OF A MASTER'S THESIS

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Tenderness and texture, attributes of meat resulting from the total effect of muscle composition, carcass treatment, and cooking affect the acceptability of meat and meat products, and often, they are used to evaluate the effects of processing or cooking treatments on eating quality. Conventionally chilled (CC) or electrically stimulated-hot boned (ESHB) bull adductor (AD) muscles, roasted (OR) or the muscle strips cooked in a model system (S) were compared for cooking time and losses, sensory tenderness and texture, Instron texture properties, and percentage solubilized hydroxyproline.

No significant differences in heating time at any point from 10^{o} to 65^{o}C were observed between strips and "estimated" roasts (roasts whose heating curve strips and OR roasts were supposed to follow). Differences in heating time between strips and OR roasts were observed only from 50^{o} to 55^{o} - 65^{o}C, with roasts requiring longer ($P < 0.05$) time than strips. The longer time required for strips to increase from their initial temperature to 10^{o}C accounted for the longer ($P < 0.002$) total time required for strips than for the roasts to reach 70^{o}C.

Roasts, cooked by dry heat, exhibited greater ($P < 0.0001$) volatile losses and less ($P < 0.0001$) drip losses than did strips cooked by moist heat. Lower ($P < 0.0001$) moisture content and higher ($P < 0.006$) ether extract were obtained for roasts than for strips.

The longer ($P < 0.01$) cooking time required for ESHB samples may have accounted, partially, for the greater ($P < 0.0007$) percentage of solubilized hydroxyproline. ESHB samples were scored less ($P < 0.04$) tender and less ($P < 0.01$) mealy by the sensory panel,

but mean sensory scores were not practically different. Interactions between cooking systems and carcass treatments affected the cooking time ($P < 0.04$), Instron hardness ($P < 0.045$), and the percentage solubilized hydroxyproline ($P < 0.0002$). Significant differences in cooking time between cooking systems were attributable to the effects of both CC and ESHB, and differences between carcass treatments were attributable to the effect of OR. Instron hardness was not affected significantly by the cooking system or by the carcass treatment, but interactions indicated that CC samples cooked in the model system were less ($P < 0.05$) hard than those cooked by OR. Differences in solubilized hydroxyproline between carcass treatments were attributable to the effect of OR. More ($P < 0.05$) solubilized hydroxyproline was found in CC samples cooked in the model system than in those cooked by OR.

Generally, sensory scores for tenderness, softness, and mealiness were related moderately to each other and to Instron values for shear cohesiveness and shear firmness. Low correlations occurred between Instron penetration measurements and sensory tenderness and texture scores; moderate correlations occurred between Instron shear (cohesiveness, firmness) and penetration (hardness, chewiness) measurements. Relationships between paired measurements were similar whether r-values were calculated on the basis of cooking systems, carcass treatments, or from data where all treatment combinations were combined. Little correlations occurred between the percentage solubilized hydroxyproline and any of the tenderness or texture measurements.

Sample variances for most measurements were similar in size for

OR and S, except for cooking time, drip losses, total moisture (AOAC), and Instron cohesiveness (calculated as defined by Friedman et al., 1963). Larger ($P < 0.05$) variances were exhibited by the roasts for cooking time, total moisture (AOAC), and Instron cohesiveness than by the strips, but strips exhibited larger ($P < 0.001$) variance for drip losses than did roasts.