THE EFFECT OF ELECTRICAL STIMULATION AND HOT BONING ON BOVINE MEAT PALATABILITY AND COLOR

by

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Chapter I

INTRODUCTION

Marsh and Leet (1966) found that prerigor lamb longissimus dorsi (LD) muscle subjected to a cold environment would undergo extensive shortening and result in toughness. Chrystall (1976) stated that cold shortening occurred when prerigor muscles were chilled to temperatures below 8 degrees C. before a pH of less than 6.0 has been reached. Cold shortening (CS) did not present a tenderness problem unless the degree of shortening exceeded about 20%.

Marsh and Leet (1966) have shown that shortening of muscle during the early postmortem period affected meat tenderness. They found that shortening up to 20% caused little or no toughening, shortening of 20% to 40% increased toughness several fold, shortening beyond 40% gradually improved tenderness, and shortening beyond 60% produced meat as tender as that which underwent no shortening at all.

Cold shortening and subsequent toughening can be avoided by physical restraint, delayed chilling or electrical stimulation. This review will discuss the use of electrical stimulation (ES), delayed chilling and hot boning (HB) in an accelerated beef processing system.

Chapter II

REVIEW OF LITERATURE

Effect of ES on Cold Shortening, Enzymatic Activity, and Structural Changes.

Three theories exist to explain the improvement in tenderness imparted to lamb and beef muscle by ES. New Zealand researchers were among the first to attribute the improvement in tenderness to prevention of CS (Chrystall and Hagyard, 1975[b]; Davey et al., 1976; Chrystall, 1976). On the other hand, Smith et al. (1977) proposed that ES enhanced the rate of autolytic proteolysis. Alternatively, Savell et al. (1978[b]) proposed that ES caused certain structural changes within the sarcomere.

A mechanism whereby ES leads to acceleration of glycolysis, rapid decline in pH, and the early initiation of rigor which prevents CS and resulting toughness has been proposed. For example, Bendall (1976) stated that the effect of ES was a result of long stimulation which in some way damaged the control mechanism in muscle, allowing a sufficient, sustained release of activated Ca^{++} ions. The Ca^{++} ions caused the observed increase in rate of ATP turnover. He further stated that the ATP level fell in step with the pH decline; at about pH 6.2, 50% of the ATP had disappeared, and at pH 5.7, more

than 90% had been depleted. In ES lamb carcasses, rigor was completed at least 4 hr earlier than in nonelectrically stimulated (NES) carcasses, making it possible to freeze stimulated lamb carcasses within 3 hr of slaughter.

Another theory concerning the increase in tenderness brought about by ES is that of increased enzymatic activity. Smith et al. (1977) attributed improved tenderness of ES meat to enhanced activity of autolytic enzymes. They further stated that ES produced a rapid decrease in muscle pH, which may hasten rupture of lysosomal membranes, and release of proteolytic enzymes at a time when muscle temperature is still quite high. The rate or duration of autolytic proteolysis is thereby enhanced.

Savell et al. (1978[b]) evaluated palatability, cooking parameters, and sarcomere length on carcasses after ES. They found that ES steaks were less juicy, more tender, more flavorful, and had lower shear force values than NES controls. Mean sarcomere lengths did not differ significantly between NES and ES samples. Electron micrographs showed definite structural differences between ES and NES sarcomeres. ES micrographs displayed contracture bands in certain areas and slightly stretched sarcomeres through the contracture bands, while sarcomeres on either side of the contracture bands seemed to be stretched or broken. The improvement in tenderness despite similarities in sarcomere length of NES and ES

samples may be explained by these structural differences.

Effect of ES on Muscle Physiology

Bowling et al. (1978) found that ES lowered the pH immediately after stimulation but the pH at 1 hr postmortem for LD and biceps femoris (BF) had risen (ammonia liberation by an AMP deaminase in conversion of AMP to IMP). Bowling et al. (1978) further stated that ES must increase ATP production as well as cause muscle contraction since ATP concentration was higher after stimulation than before. Thus they concluded that certain enzymes associated with muscle energetics may be stimulated to produce ATP at a faster rate than the contractile proteins can break it down.

Forrest and Briskey (1967) investigated the relationship between ES and glycolytic rate, initial lactic acid concentration, muscle fiber type, time responsiveness to ES, carcass weight and final lactic acid concentration. They found that muscles with a slow rate of glycolysis were significantly more responsive to electrical stimulation than those with an intermediate rate of glycolysis. Initial lactic acid concentration had little influence on the responsiveness of muscle to ES. ES response of red and white muscles was not significantly different. Previously these workers demonstrated that the period of time postmortem during which a

muscle remains responsive to ES as well as the strength of the electrical response are both directly related to the time course of rigor mortis. Heavy weight pork carcasses were more responsive to ES than light carcasses. Final lactic acid concentration of muscles increased significantly when the muscles were stimulated to exhaustion with a current consisting of 150 volts, .01 msec duration and a frequency of 2 Hz.

Effect of ES Parameters on Postmortem pH Decline

Muscle pH is a measure of onset of rigor, Marsh (1954). Once muscle is set in rigor, it is unlikely that shortening will occur. ES is capable of accelerating glycolysis and reducing the time to pH 6, the pH at which the onset of rigor usually occurs. The degree of glycolytic acceleration achieved by ES depends on voltage, frequency, duration of stimulation, time of stimulation and current path.

Bendall (1976) stated that very high stimulating voltages of 1000 V or more are necessary to obtain optimal rates and extents of pH fall on rabbit carcasses which have not been dressed. Bendall and Rhodes (1976) found that ES gave optimum pH decline on either intact dressed beef carcasses or sides when 700 V, 35 Hz, and a minimum of 3000 pulses were employed. Chrystall and Hagyard (1975a.) determined that the best ES current source was that which

delivered a high voltage (3.6 KV) and a low frequency (15 Hz).

The effect of ES on pH decline and subsequent development of rigor was measured by Davey et al. (1976). They found that ES induced an immediate and rapid pH fall. Furthermore, the extent of the fall was determined by the duration of stimulation. They also found that the time required for pH fall decreased after ES. The ES carcasses yielded muscle samples that were at a pH of 6 and approaching rigor onset within 5 hours while samples from NES carcasses did not approach rigor within 24 hours. These authors concluded that ES speeded glycolysis, and rigor was reached well before temperatures had fallen to levels which induced cold shortening. Grusby et al. (1976) found that LD muscle samples from ES sides had a more rapid postmortem decline in pH than did NES sides.

Shaw and Walker (1977) studied the effect of low voltage ES on the pH of beef muscle. In experiment #1, sides of beef were stimulated for varying times with voltages ranging from 20 to 110 V of direct current. In experiment #2, sides of beef were stimulated with 21 V for 4 min. Measurements of pH were taken at 1, 4, and 24 hr postmortem on the semimembranosus (SM), BF, LD, and triceps brachii (TB) muscles. These workers concluded that low voltage ES had a significant effect on 1, 4, and 24 hr pH. How-

ever, it does appear that low voltage ES is capable of lowering pH, but at a much slower rate than high voltage ES.

Low voltage ES (110 V) has also been studied by Bouton et al. (1978). Muscles from stimulated sides had significantly lower pH values at 1, 4, and 24 hr after slaughter than muscles from NES control sides.

Chrystall and Hagyard (1975[a]) recommended a 1 min ES period. Devine (1976) found that ES periods of 3 min gave more extensive pH declines than 2 min ES periods.

Chrystall and Hagyard (1975[a]) suggested that ES at 5 min versus 20 min postmortem can result in greater tenderness. Chrystall (1976) reported that if ES is delayed until after carcass dressing the effects appear to be reduced. He further stated that decreased effectiveness of ES may in part be due to decreasing muscle temperature postmortem. In order to attain maximum benefit from ES, it is essential that stimulation occur as soon as possible postmortem. This necessitates that current must pass through the lamb pelt barrier which Chrystall (1976) overcame to some extent through the use of high pressure water jets to wet the electrode contact area.

Conversly, Devine (1976) varied the time between slaughter and ES from 10 min to 3 hr and found that delays produced no change in the extent of pH decline, but he emphasized that

temperature remained constant over this period. In agreement with Chrystall (1976), Devine concluded that a reduction in carcass temperature postmortem may decrease effectiveness of ES. On the other hand, Devine (1976) found that ES for 2 min increased the muscle temperature 3 C through resistive heating and ultimately should allow for more rapid rigor development. Marsh (1954) had previously shown that the rate of rigor in beef muscle is faster at higher temperatures.

Devine (1976) has presented further evidence of the importance muscle temperature has on the effectiveness of ES in accelerating the onset of rigor. He found that NES muscle at 43 C went into rigor twice as fast as ES muscle at 35 C. He also found that ES at 35 C took 1 hr longer to achieve rigor than ES muscle at 40 C.

Chrystall (1976) investigated the effect of probe placement on tenderness of ES lamb carcasses. He found that if only two probes were used with one placed in the neck and the other placed in the right leg that the right leg was tender after cooking while the left leg was not. Use of three electrodes, one in the neck and one in each leg produced consistently tender meat. Chrystall (1976) showed that current path is important to pH decline and prevention of cold shortening. But the exact path traveled

by current within a side has not yet been shown. This information could improve the response obtained from ES of beef carcasses.

It appears than an optimum voltage would be somewhere between 300 and 700 V for a dressed carcass or side. Furthermore, the ideal frequency seems to lie between 15 and 25 Hz.

A stimulation period of 1 to 3 min provides optimum pH decline. The rapid pH decline brought about during and after the stimulation period itself occurs in two parts. First, pH decline occurs most rapidly during the stimulation period. Secondly, pH decline after the stimulation period is significantly increased.

PH decline is hastened if the carcass is stimulated very shortly after exsanguination. Early stimulation takes advantage of high carcass temperature and results in a more rapid pH decline and early onset of rigor.

Tenderness Improvement in ES Muscle Attributed to Decreased Incidence of Cold Shortening

Bouton et al. (1978) reported that low voltage stimulation reduces the shear force values obtained from cooked samples of muscles removed from the back and hindquarter 24 hr after slaughter. Chrystall and Hagyard (1975[b]) con-

ducted an ES study in which lamb carcasses were frozen at -18 C 60 min postmortem. Legs and loins were roasted from the frozen state and stored overnight at 4 C prior to evaluation with the tenderometer of Macfarland and Marer (1966). ES caused a marked acceleration of glycolysis compared with that in NES carcasses. Furthermore, tenderness differences between ES and NES muscles were found to be highly significant, with the ES means being lower. Chrystall and Hagyard (1975[b]) concluded that ES lamb frozen 60 min postmortem does not suffer from cold and thaw shortening.

In a lamb ES study conducted by Carse (1973), five ES sides and five NES sides were held at 18 C for 5 hr postmortem (rapid chill) and subsequently frozen at -18 C. Five ES sides and 5 NES sides were held for 20 hr (delay chill) then frozen. After 3 days, all sides were removed from the freezer and sawed into cuts. Shear force evaluation showed that ES, rapidly chilled cuts were significantly more tender than the NES rapidly chilled cuts. Carse (1973) concluded that ES before early freezing caused a significant reduction in toughening. Conversely, no tenderness difference were found between the ES and NES delay chilled carcasses. He concluded that rapid occurrence of rigor through accelerated glycolysis did not significantly improve tenderness in delay chilled carcasses. Apparently some aging changes had occurred

in the delay chilled carcasses.

Davey et al. (1976) used right sides of beef for ES and used the left side as a NES control. After a 24 hr chill, cuts were boned, cut in half, and packaged. One group of halved ES and NES cuts was immediately frozen at -18 C while the second group received 48 hr of additional aging before freezing. Tenderness evaluation showed slow chilled NES cuts to be moderately tender but the fast chilled NES cuts were found to be tough and affected by cold shortening. On the other hand, the fast chilled ES cuts were found to be moderately and uniformly tender while the slow chilled ES cuts attained a highly acceptable level of tenderness. Taste panel data confirmed the objective tenderness conclusions. Davey et al. (1976) concluded that ES prevented toughening from rapid chilling and that tenderness of ES cuts can be further improved through aging.

Grusby et al. (1976) studied the effect of ES on two groups of cattle. Group 1 cattle ranged in carcass weight from 148 to 206 kg. Group 2 cattle were weanling calves which provided carcass weights from 52 to 107 kg. Paired sides were either ES or NES. Group 1 and group 2 ES LD muscles received significantly higher sensory panel tenderness scores and had lower Warner Bratzler (WB) shear values than group 1 and group 2 NES LD samples. Electrical stimu-

lation and control semitendinosus (ST) samples from group 2 had similar shear force values. These workers concluded that ES of beef carcasses prior to chilling resulted in a significant increase in tenderness for the muscles directly stimulated.

Bowling et al. (1978) studied the effects of prerigor conditioning treatments on quality characteristics using three muscles from each of 84 lamb carcasses. Carcasses were subjected 1 hr post exsanguination to one of six conditioning treatments and compared to normally chilled lambs. Treatments differed in conditioning period, conditioning chamber environment, (temperature, relative humidity, and air velocity) and in the use of ES. Among carcasses conditioned at 32 C, those which were ES had lower carcass temperatures at 3 and 4 hr postmortem, and faster rates of pH (LD and BF) and ATP (LD) decline but did not differ in tenderness from those which were NES. These researchers point out that the temperature, pH and ATP concentration of muscle in ES carcasses might have produced a brief period of heat induced shortening before the temperature decline.

Grusby et al. (1976) concluded that ES of beef carcasses prior to chilling significantly increased tenderness. Similarly, Chrystall and Hagyard (1975^{b}) found that ES significantly improved tenderness in lamb carcasses by preventing cold

shortening. Davey et al. (1976) concluded that ES prevents toughening resulting from rapid chilling and that tenderness of ES cuts can be further improved by aging. Conversely, Bowling et al. (1978) did not show a tenderness improvement and attributed the lack of improvement to heat induced shortening.

ES and Sub-Zero Conditioning

The data of Chrystall and Hagyard (1975[a]) led to a more clear understanding of how ES works with other treatments, specifically sub-zero conditioning. Chrystall and Hagyard (1975[a]) stimulated lamb carcasses and then utilized short delay periods (1 or 2 hr) before freezing. Legs and loins were cooked from the frozen state; dissected into LD, BF, gluteus medius (GM), SM, adductor (AD), and quadriceps femoris (QF); and evaluated with the tenderometer of Macfarlane and Marer (1966). Sub-zero conditioning (4 weeks at -12 C) did not significantly improve tenderness of ES legs and loins. However, it did have an appreciable tenderizing effect on the NES controls. They concluded that effects similar to conditioning effects had been achieved through ES and a brief delay before freezing. They also showed that by increasing the delay time before freezing from 4 hr to 8 or 12 hr, tenderness can be improved.

Tenderness Improvement in ES Muscle Attributed to Increased Enzymatic Activity.

Savell et al. (1978[a]) electrically stimulated carcasses 1 hr postmortem. The ES procedure was unique in that electrical impulses of .5 to 1 sec duration were administered between rest intervals. Warner-Bratzler shear force results showed that ES steaks from carcasses stimulated with 25, 50, or 75 electrical impulses had lower shear force values than steaks from NES controls. No evidence that use of 25 or 75 rather than 50 impulses would enhance the response in palatability achieved via ES. Taste panel results showed ES steaks to be more tender, have less detectable connective tissue, and superior in overall palatability. These workers attributed the improved tenderness to enhanced activity of the autolytic enzyme fraction of ES muscles as suggested by Smith et al. (1977).

ES and Drip Loss

Bendall and Rhodes (1976) report no excessive drip loss from ES meat. Similarly, Bowling et al. (1978) found that ES lamb carcasses held for 2 to 8 hr at -32 C had comparable shrinkage to that sustained by carcasses conventionally chilled at 0 C.

ES and Stressed Animals

Sorinmade et al. (1978) found that pH decline of non-stressed animals subsequently stimulated was rapid when compared with stressed ES or NES animals. Similarly, the non-stressed animals had lower ultimate pH values when compared with stressed animals. Tenderness evaluation showed that non-stressed stimulated animals were significantly more tender than non-stressed animals NES. Carcasses from stressed animals were borderline between tender and tough and were not significantly affected by ES.

ES and the Pale, Soft and Exudative Condition

Carse (1973) reports no visual evidence of pale, soft, and exudative condition due to ES in lamb carcasses. Chrystall and Hagyard (1975[b]) also reported no evidence of pale, soft and exudative condition in lamb carcasses when ES was used. Furthermore, they reported no quality problems such as ruptured viscera or blood splashing when ES was applied to intact lamb carcasses.

Delayed Chilling and Hot Boning

Six prerigor conditioning treatments utilizing temperatures of 49, 32, 16, 0, -16, and -32 C were investigated by Bowling et al. (1978). All lamb carcasses were maintained

at 0 C after the 2 to 8 hr conditioning period until fabrication at 72 hr postmortem. Carcasses in the 16 C treatment reached temperatures critical to cold shortening 8 to 9 hr later than carcasses in the -16 C treatment. They had longer LD, BF, and SM sarcomeres, and had more tender BF, and SM muscles. Conversely, lamb carcasses held at 49 and 32 C had high rates of pH and ATP decline, the slowest rate of temperature decline, the shortest sarcomeres, and the toughest LD of any treatment. Bowling et al. (1978) attributed their toughness to heat induced shortening caused by high temperature denaturization of membrane-bound proteins, which increased the permeability of the sarcoplasmic reticulum and resulted in high intracellular Ca^{++} content, and more rapid pH fall, contraction, and ATP utilization.

Dutson et al. (1975) experimented with 53 bovine carcasses from animals ranging in age from 2 weeks to 26 months. One side of each carcass was held at an elevated temperature for 12 hr postmortem, then placed in a 1 C cooler. At 48 hr postmortem, LD samples were taken. Results showed a significant increase in sarcomere length, initial tenderness, muscle fiber tenderness, and overall tenderness when compared with conventionally chilled sides. They concluded that carcass temperature during the first 12 hr postmortem is critical in determining muscle tenderness. Furthermore, they con-

cluded that delay chilling increased tenderness because of a reduction in cold shortening and an increase in autolytic enzyme activity.

Both Bowling et al. (1978) and Dutson et al. (1975) concluded that delay-chill conditioning increased tenderness because of a reduction in cold shortening or an increase in autolytic enzyme activity. However, Bowling et al. (1978) warned that by high temperature and delay-chill conditioning, an increase in toughness may occur through heat induced muscle shortening.

Shear force data and taste panel results led Schmidt and Gilbert (1970) to conclude that muscles excised from beef carcasses prerigor and maintained at 15 C for 24 hr are usually as tender as muscles which are excised from carcasses after a 24 hr chill. Furthermore, these authors concluded that by extending the conditioning period an additional 24 hr, considerable aging can occur. Unfortunately, the 48 hr conditioning period had no effect on the SM muscle. Conversely, 48 hr conditioning data indicated the BF muscle was significantly more tender than the control. This muscle passively shortens when beef carcasses are vertically suspended. Prerigor excision may have produced a lengthening of muscles such as the BF, and tenderness improvement occurred. One overall exception was noted; the ST conditioned

either 24 or 48 hr had significantly higher shear force values. This may in part be explained by the fact that considerable shortening was observed upon prerigor excision of the ST.

In the hot boning study conducted by Schmidt and Keman (1974), taste panel results and shear force data indicated that no significant differences existed between hot boning and holding cuts at 7 C for 4 hr prior to placing them in the cold room. Similarly, any differences due to hot boning were negated by the 9 or 11 day aging period prior to taste panel evaluation. The results indicated that cold shortening did not occur or that cold shortening effects were alleviated by the aging periods. This was explained by the fact that boneless wholesale cuts were not exposed to cold temperatures of less than 3 C until after 5 hr postmortem.

Kastner et al. (1973) found significantly higher shear force values in 2 hr and 5 hr hot boned cuts (BF, ST, SM, and LD) than in cold boned cuts (chilled for 48 hr at 2 C before cutting) although these differences were probably not of economic significance. No significant differences were found for the 8 hr conditioning period compared with chilling 48 hr which appeared to alleviate the shear force differences which occurred at the 2 or 5 hr conditioning periods.

Follett et al. (1974) evaluated prerigor excision of SM muscle coupled with holding temperatures ranging from -5

C to 15 C. The control treatment involved excision at 36 hr postmortem after chilling at 2 to 3 C. Shear force measurements were made with an Instron Universal Tester equipped with a Wolodkewitsch Jaw. In general, they found that prerigor excised muscles had lower shear values at 3 to 13 days than the postrigor excised muscles. However, in the -5 C prerigor treatment, tenderness was adversely affected. Therefore, the authors concluded that by cooling excised SM in air at 5 C and above that no detrimental effects occurred on tenderness. But they also suggested that muscles of small size and large surface area chilled at or below 2.5 C may undergo cold shortening which results in decreased tenderness.

Falk et al. (1975) used the following treatments:

#1. Delayed chilling of beef sides held at 16 C for 3, 5, or 7 hr, hot boning followed by storage at 1 C until 48 hr had elapsed.

#2. Removal of muscles after a 48 hr chilling period at 1 C.

WB shear analysis, taste panel testing, and histological evaluations were performed on both treatments. The WB shear and sarcomere length data demonstrated that slight changes in contraction state occurred if muscles were excised 3, 5, or 7 hr postmortem. These slight differences in contraction state translated into minor tenderness differences when evaluated by a taste panel (TP) but these may not have been of economic significance.

Dransfield et al. (1976) evaluated beef samples that were cut 0 to 3 hr after stunning followed by conditioning at 10 C for 24 hr and subsequent aging at 1 C for 6 to 10 days. This treatment was compared with conventional conditioning at ambient temperatures, excision at 24 hr postmortem, and subsequent aging at 1 C for 6 to 10 days. Taste panel results indicated that eating quality of hot boned, 10 C conditioned cuts was equal to that from meat cut 24 hr postmortem. However, the hot boned PM toughened. They attributed this increase in toughness to shortening of the PM when cut from its attachments prerigor. The authors also pointed out that a further small amount of muscle shortening occurred when muscles entered rigor. These data indicate that the eating quality of hot boned cuts can be improved by aging under cold conditions. These workers concluded that hot boning appears to be without any great effect on the eating quality of beef.

Taste panel results, shear force data, and penetration measurements, show only small differences in tenderness between the hot boned and cold boned treatments. Will and Henrickson (1976), through the use of these objective and subjective measurements, concluded that no major tenderness differences existed between beef muscles excised at 3, 5, or 7 hr postmortem and those allowed to remain on the suspended carcass for 48 hr at 2 C.

Kastner et al. (1973, 1975 and 1976) have been involved in three separate studies involving delay chill, and hot boning. Carcasses have been held at elevated temperatures for varying periods (2, 5, 6, 8, 10 hr postmortem) before hot boning. Kastner et al. (1973) found significant differences in tenderness when cuts held for 2 hr and 5 hr were compared with cold boned cuts. An additional 3 hr holding period (8 hr postmortem) eliminated the shear force differences between hot boned and cold boned cuts. Kastner and Russell (1975) concluded that tenderness appears to be similar between hot and cold boned treatments if muscles are excised no sooner than 8 hr postmortem. The former is supported by additional work done by Kastner et al. (1976).

The work of Schmidt and Gilbert (1970), Schmidt and Keman (1974), and Kastner et al. (1973, 1975 and 1976) lead to the conclusion that hot boning can produce meat as tender as that from conventionally chilled and cut carcasses. The work of Schmidt and Keman (1974) differs from Kastner et al. (1973, 1975 and 1976) in that cuts were excised as soon as possible postmortem and then held at an elevated temperature for a period of hours. Kastner et al. (1973, 1975 and 1976) allowed the entire carcass to remain at an elevated temperature for a period of hours, then test muscles were hot boned.

Combined Effects of ES and Hot Boning

Hot boning and ES of beef carcasses were studied concurrently by Gilbert and Davey (1976). The right side was ES 30 min postmortem and HB 5 hr postmortem. The NES side was cold boned at 24 hr postmortem. Both the ES and NES muscles were halved and divided into two groups. Group 1 was subjected to immediate freezing after hot boning while group 2 was aged for 72 hr before freezing. Taste panel tenderness results showed that tenderness of ES-HB muscles (frozen 5 hr after boning). Furthermore, the ES-HB LD was more tender than the NES-CB LD. Gilbert and Davey (1976) through the use of pH measurements found that the ES side was in rigor 5 hr after stimulation and hot boning could then take place without risk of cold shortening. Comparisons between ES aged cuts and NES aged cuts showed that all cuts aged to a highly acceptable degree of tenderness. Gilbert and Davey (1976) concluded that ES permitted additional tenderizing through aging.

Two unique experiments were carried out by McCollum and Henrickson (1977). In experiment #1, one side from each of six beef carcasses was stimulated 1 hr postmortem for 30 min and hot boned 4 hr postmortem. In experiment #2, one side from each of 7 cattle was stimulated 30 min postmortem for 15 min and hot boned 2 hr postmortem. Data for pH shows

that the LD and SM responded to ES but the PM did not. These authors concluded that ES is an excellent way of increasing postmortem metabolism and quickly initiating the rigor process.

Gilbert et al. (1976) electrically stimulated beef sides 60 min postmortem. At 2 hr postmortem the ES side was hot boned. One group of cuts was held at 5 C and aged for 46 hr before frozen. The other group of ES cuts was placed directly in the freezer. The right side was chilled to 8 C in 24 hrs, cuts were excised and divided into two groups. One group was aged for 65 hr at 10 C then frozen. A second group was directly frozen.

Aged, ES cuts were uniformly tender. However, aging did not produce an acceptable level of tenderness in NES striploins. NES rump, topside, and filet aged acceptably. Except for filet, NES unaged cuts were all tougher and less uniform than ES counterparts. Cuts produced in the accelerated processing scheme were at least as tender as those produced from conventionally processed carcasses. Furthermore, Gilbert et al. (1976) concluded that the advantages of ES were particularly evident when aging was part of processing.

Gilbert et al. (1976) stated the advantages of ES as follows:

1. Hasten rigor, reduce the possibility of cold shortening and permit hot boning.
2. Cuts produced in the accelerated system are at least as tender as those produced in a conventional system.
3. ES permitted additional tenderizing through aging.

Color Improvement

Smith et al. (1977) found that the exposed rib eye of ES beef carcasses ribbed at 24 hr had a more desirable muscle color and condition than NES carcasses. Furthermore, they also found that ES sides were brighter colored, firmer and did not exhibit heat rings. Similarly, Savell et al. (1978[a]) stated that ES sides had brighter colored muscle, more youthful USDA lean maturity scores and less severe development of heat ring than did control sides. On the other hand, Grusby et al. (1976) found no influence of ES on muscle color.

Ashmore et al. (1972) explained that the improved color of ES meat is due to pH dependence of color by means of mitochondrial respiration. At higher pH values oxygen consumption by surface mitochondria inhibits the penetration of O_2 into the tissue and subsequently reduces the conversion of myoglobin to oxymyoglobin. Lower ultimate pH values obtained more rapidly by ES inhibit mitochondrial activity and allow more oxygen to penetrate the meat surface and form oxymyoglobin.

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Chapter III

Introduction

The goal of an accelerated meat processing system is to reduce processing costs while maintaining acceptable meat quality. An important component of an accelerated beef processing system is hot boning. Hot boning refers to the removal of primal cuts from a carcass 1 to 2 hr postmortem. Energy savings are realized through chilling only the edible portion of the carcass. However, a serious problem that is often associated with hot boning is a meat toughening phenomenon known as cold shortening. Cold shortening occurs when prerigor muscles are chilled to temperatures below 8 C before a pH of 6 has been reached. Schmidt and Gilbert (1970) and Schmidt and Keman (1974) have reduced the effects of cold shortening by delay chilling hot-boned primals. Kastner et al. (1973) and Kastner and Russell (1975) decreased the incidence of cold shortening by conditioning entire carcasses for periods up to 8 hr at 10 C prior to hot boning. Cold shortening can also be avoided through electrical stimulation of the dressed beef carcass. Gilbert and Davey (1976) and Gilbert et al. (1976) concluded that electrically stimulated hot boned beef is of comparable tenderness with conventionally processed beef. Furthermore,

Savell et al. (1977), and Grusby et al. (1976) concluded that electrical stimulation can actually improve the tenderness of conventionally processed carcasses.

In our study, pH and temperature measurements were taken to determine when they were critical to cold shortening. After excised muscles were aged, steaks were cut and frozen for Warner-Bratzler shear analysis and trained taste panel evaluations. In addition to analyzing steaks for tenderness, they were also evaluated for connective tissue amount, juiciness and flavor. Through our study, we hoped to determine the impact of electrical stimulation and hot boning on cold shortening. Moreover, if electrical stimulation is successful in preventing toughness, the reality of accelerated processing may be near.

EXPERIMENTAL PROCEDURE

Two groups of crossbred steers, 24 Hereford X Angus (medium type, MT) and 23 Simmental-sired (large type, LT) steers from either Chianina X Angus or Chianina X Hereford females were obtained from the R.L. Hruska US Meat Animal Research Center at Clay Center, Nebraska. They were approximately 8 months old and averaged 257.6 kg when purchased. Following a 4 week adjustment period, half of each group was allotted by weight to one of two feeding regimens.

Twelve MT and 13 LT steers were allotted to the accelerated feeding system. This system consisted of a 4 week adjustment period, then a finishing phase. The ration fed during the adjustment period consisted of 57.2% corn, 11.8% corn silage, 25.4% sorghum silage and 5.6% protein supplement. The finishing ration contained 86.7% corn, 10.0% corn silage and 4.4% protein supplement. MT-Acc (medium type-accelerated) steers were fed for 140 days while LT-Acc steers were fed for 182 days.

Twelve of each type were allotted to the conventional feeding system. This system consisted of the 4 week adjustment, backgrounding, and finishing phases. During the adjustment phase, a ration of 15.7% corn, 15.1% grain sorghum, 15.9% sorghum silage, 48.6% prairie hay, and 4.7% protein supplement was fed. A backgrounding period followed in which

a ration of 29.4% grain sorghum, 66.8% prairie hay, and 3.9% protein supplement was fed. MT cattle then were finished on 82.5% corn, 8% corn silage, 5.1% prairie hay, and 4.4% protein supplement. LT cattle were finished on a ration containing 81.3% corn, 2.5% corn silage, 11.8% sorghum silage, and 4.4% protein supplement. MT-Conv. (medium type-conventional) steers were fed for a total of 258 days and LT-Conv. (large type-conventional) were fed for a total of 306 days.

Slaughter endpoints of 430 kg and 505 kg for MT and LT, respectively, were chosen for the accelerated system. These weights represent the point at which these two types of cattle begin to reach 5% longissimus lipid (Koch et al., 1976), which is equivalent to the low Choice quality grade. For cattle on the conventional system, slaughter weight endpoints of 522 kg and 591 kg were chosen to simulate weights in which these types of cattle would be slaughtered by the industry. MT and LT cattle were started on the finishing rations at 342 and 382 kg, respectively.

Weights and feed consumptions were recorded every two weeks for each cattle type on a given feeding system. All steers were slaughtered at Kansas State University. The MT-Acc group was slaughtered first followed by LT-Acc 40 days later; MT-Conv. 120 days later; and finally, LT-Conv. 160 days later.

Cattle in each of the four groups were stunned, exsanguinated, skinned, eviscerated, and split into sides in the normal manner. The right side of each carcass underwent accelerated processing which included a 2 min period of electrical stimulation at 60 min postmortem, and hot boning at 2 hr postmortem. The electrical current delivered 600 volts, 60 Hz, and 5 amps.

The inside round and strip loin were excised hot and these cuts were placed in vacuum bags and stored in cardboard boxes at 2 C for 6 days.

The left side of each carcass served as a NES control. These sides were chilled for 48 hr at 2 C. Then sides were ribbed, and yield and quality grade data were recorded. Shortly thereafter, the inside round and the strip loin were removed and placed in vacuum bags and stored in a cardboard box at 2 C until 6 days postmortem.

Temperature and pH data from both the ES and the NES sides were collected simultaneously. PH samples from the LD muscle and temperature data from both the LD and SM muscles were obtained at 1, 2, 4, 6, 8, and 24 hr postmortem. Muscle samples were removed from the LD opposite the fifth lumbar vertebrae with a 1.27 cm coring device. Next, a 1 to 2 g muscle sample was blended with 10 ml of 5 mM NaIAc in 150 mM KCl. The NaIAc and the KCl solution were prepared according to procedures outlined by Bendall (1973).

On the sixth day postmortem, sensory and color steaks were cut. The second and third 2.54 cm steaks were taken from the anterior end of the LD muscle and the proximal end of the SM muscle for sensory evaluation. An additional 2.54 cm steak was taken from the anterior end of the LD muscle for visual color analysis. Sensory steaks were frozen and maintained at -10 C until evaluated.

Sensory steaks were thawed for 16 hr at 2 C prior to cooking. Both taste panel and shear force steaks were cooked in a 171 C oven to an internal temperature of 70 C. Taste panel samples were removed by using a drill press equipped with a 1.27 cm diameter coring device. Cores were taken perpendicular to the steak surface and kept warm in egg poacher pans filled with warm water.

The six member taste panel was trained and screened according to procedures outlined in the AMSA Guidelines for Cookery and Sensory Evaluation of Meat (1978). Eight steaks were sampled and served in a statistically randomized procedure at each session.

After cooking, steaks used for shear analysis were held at room temperature (21 C) for 2 hr. They were then cored perpendicular to the steak surface with a drill press. Finally, individual cores were sheared with a WB shear.

Display steaks from both ES and NES LD muscles were placed in a styrofoam tray, overwrapped with PVC (polyvinyl

chloride) and displayed for 4 days at 2 C under continuous (24 hr/day) General Electric Delux Warm White lighting at an intensity of 1076 lumens/m2 (100 foot candles) at the meat surface level. Lighting consisted of two 40 watt tubes 126 cm from the muscle surface.

Subjective muscle color was scored individually by four panelists under display lighting at initial display (day 0) and at one, two, three, and four days of display to the nearest 0.5 point using a scale of 1=very bright red, 2=bright red, 3=slightly dark red or brown, 4=dark red or brown and 5=exceptionally dark red or brown (Kropf et al., 1975). A visual score of 3.5 was considered marginally unacceptable.

Treatments were analyzed for differences by the ANOVA procedure and means were separated by the least significant difference procedure.

RESULTS AND DISCUSSION

Aged ESHB-LD and aged NES-LD were not different ($P > .10$) in WB shear force or taste panel scores for myofibrillar tenderness, overall tenderness, connective tissue amount or flavor (table 1). Schmidt and Gilbert (1970) and Schmidt and Keman (1974) found that if prerigor excised LD muscle was maintained at an elevated temperature (7 to 15 C) for a period of 4 to 24 hr, no significant differences existed when compared with LD excised from chilled carcasses 24 hr postmortem. Gilbert and Davey (1976) and Gilbert et al. (1976) concluded that ESHB-LD is of comparable tenderness with NES-LD from cold boned carcasses.

However, if one considers $P < .10$ significant, ESHB samples were more tender than NES samples. Electrical stimulation studies conducted by Savell et al. (1977), Chrystall (1976) and Grusby et al. (1976) all showed significant differences for ES-LD over NES-LD samples.

A significant ($P=.01$) difference for LD juiciness was found with ESHB being more desirable (table 1). Savell et al. (1977) and Davey et al. (1976) reported no significant differences in juiciness. Savell et al. (1978^b) reported that ES-LD steaks were less juicy than NES-LD steaks.

Table 1 reveals significant differences for SM shear force ($P=.01$), myofibrillar tenderness ($P=.01$), overall tenderness ($P=.01$), and connective tissue amount ($P=.02$). In

TABLE 1

Shear and Taste Panel Means for NES and ESHB/LD and SM Muscles.

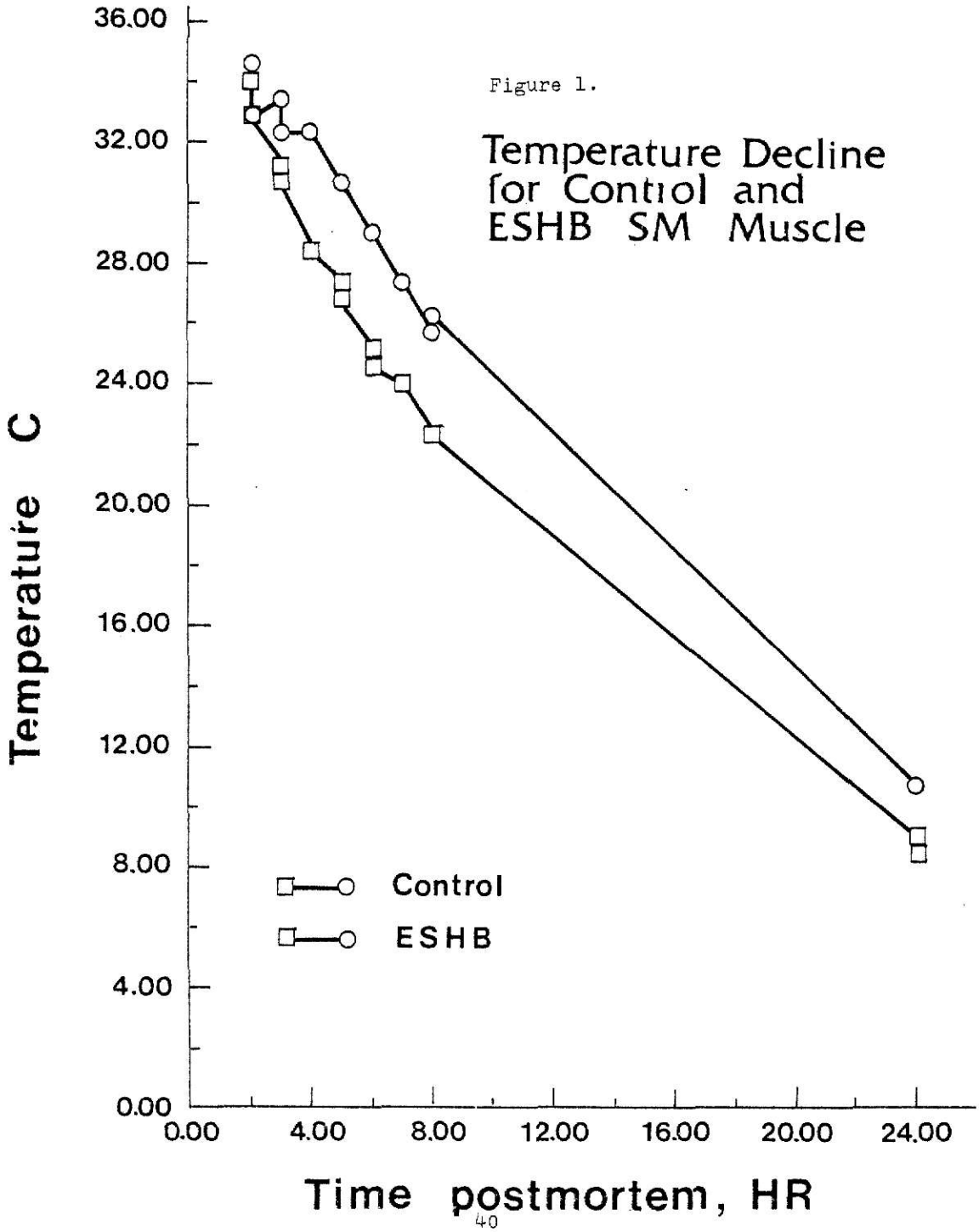
	LD			SM		
	ESHB	NES	F[1]	ESHB	NES	F[1]
Shear[2]	2.8	3.0	.10	4.1	3.6	.01
Myofibrillar Tenderness[3]	6.4	6.4	.96	5.7	6.1	.01
Overall Tenderness[3]	6.5	6.5	.62	5.6	6.0	.01
Connective Tissue Amount[4]	7.0	7.0	.15	6.2	6.4	.02
Juiciness[5]	6.6	6.4	.01	5.3	5.3	.77
Flavor[6]	6.3	6.2	.27	6.0	6.0	.36

1. Significance level
2. Kg of force on Warner-Bratzler shear
3. 1=Extremely tough, to 8=Extremely tender
4. 1=Abundant, to 8=None
5. 1=Extremely dry, to 8=Extremely juicy
6. 1=Very bland, to 8=Very intense

all cases the NES-SM was significantly more palatable than ESHB-SM. Schmidt and Gilbert (1970) reported no significant tenderness differences when prerigor excised SM samples were compared with samples from control cuts excised 24 hr post-mortem. However, after an additional 24 hr aging at 15 C, the HB-SM was significantly more tender than controls. Schmidt and Gilbert (1970) lowered muscle temperature twice as fast as we did; it took them only 10 hr to lower muscle temperature to 15 C while it took 20 hr in our study (figure 1). Our slower muscle chilling rate, longer aging period (6 days) and lower (2 C) aging temperature may account for the differing results. Schmidt and Keman (1974) showed that steaks and roasts from the loin and round excised prerigor, held at 7 C for 4 hr, and aged for 9 to 11 days were not significantly different from the cold boned controls. Our study differed from Schmidt and Keman's in several ways. Our cuts were wrapped and placed in boxes at 2 C immediately after excision. Also, we utilized a shorter aging period. Even though Schmidt and Keman's experiment did not involve ES, our experiment should have produced similar results.

Of the eight muscles studied by Schmidt and Keman (1974), muscles from the leg region (ST, BF, and SM) were the toughest. Apparently these muscles were not inf uenced as much by a 9 to 11 day aging period as the LD. Our results also indicate poorer response from the SM compared to the LD muscle.

Figure 1.


Temperature Decline for Control and ESHB SM Muscle
Temperature C
36.00
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
Time postmortem, HR
Control
ESHB

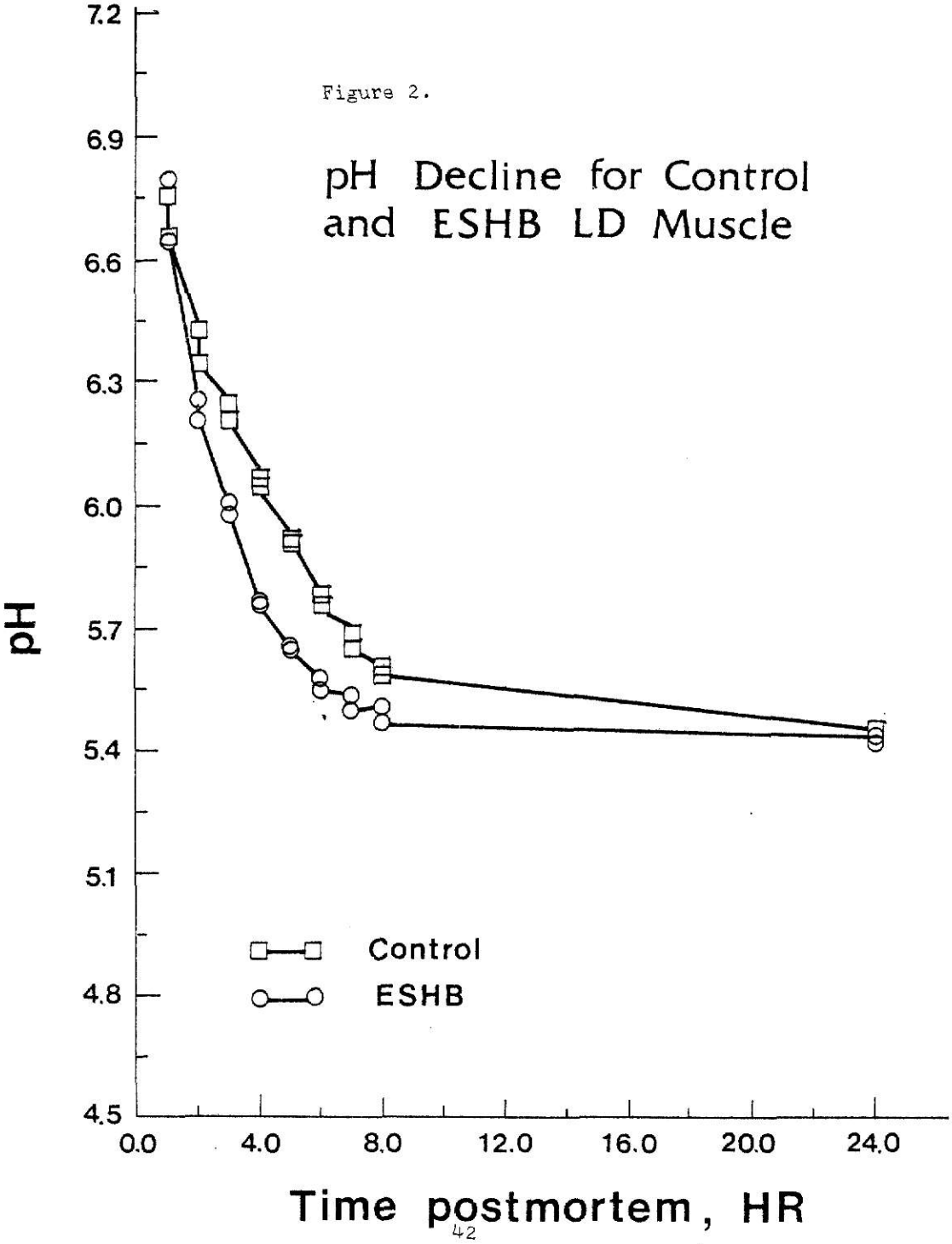
Gilbert and Davey (1976) and Gilbert et al. (1976) reported that all ESHB, unaged cuts were more tender and uniform than NES aged cuts. After aging, both ESHB-SM and NES-SM cuts were considered reasonably tender.

ES studies conducted by Savell et al. (1977), Davey et al. (1976), and Gilbert and Davey (1976) showed nonsignificant differences when ES and NES-SM taste panel tenderness means were compared. On the other hand, Chrystall and Hagyard (1975[a]) reported a significant difference for ES-SM shear force means over NES-SM means in studies conducted on lamb.

Figure 2 shows pH over time for both ESHB and NES-LD. ESHB-LD pH fell to 6 in 3 hr and was at 5.7 approximately 4 hr postmortem. NES-LD pH decline tended to be slower but was not different ($P > .05$) than ESHB-LD pH decline. NES-LD achieved pH 6 at 4 hr postmortem and was approaching a pH of 5.7 at 6 hr postmortem.

Chrystall and Hagyard (1975[a]) have shown more dramatic drops in pH when using ES on lamb. They stated that at 3 hr postmortem the pH of ES-LD lamb muscle approached 5.7, a pH value which indicates minimal ability of muscle to cold shorten. Gilbert and Davey (1976) state that beef ES-LD and ES-SM had achieved rigor by 5 hr postmortem (pH 5.5 to 5.6). Furthermore, Gilbert and Davey (1976) concluded that at 5 hr postmortem, it should be possible to hot bone without risk of cold shortening. Davey et al. (1976) stated that

Figure 2.

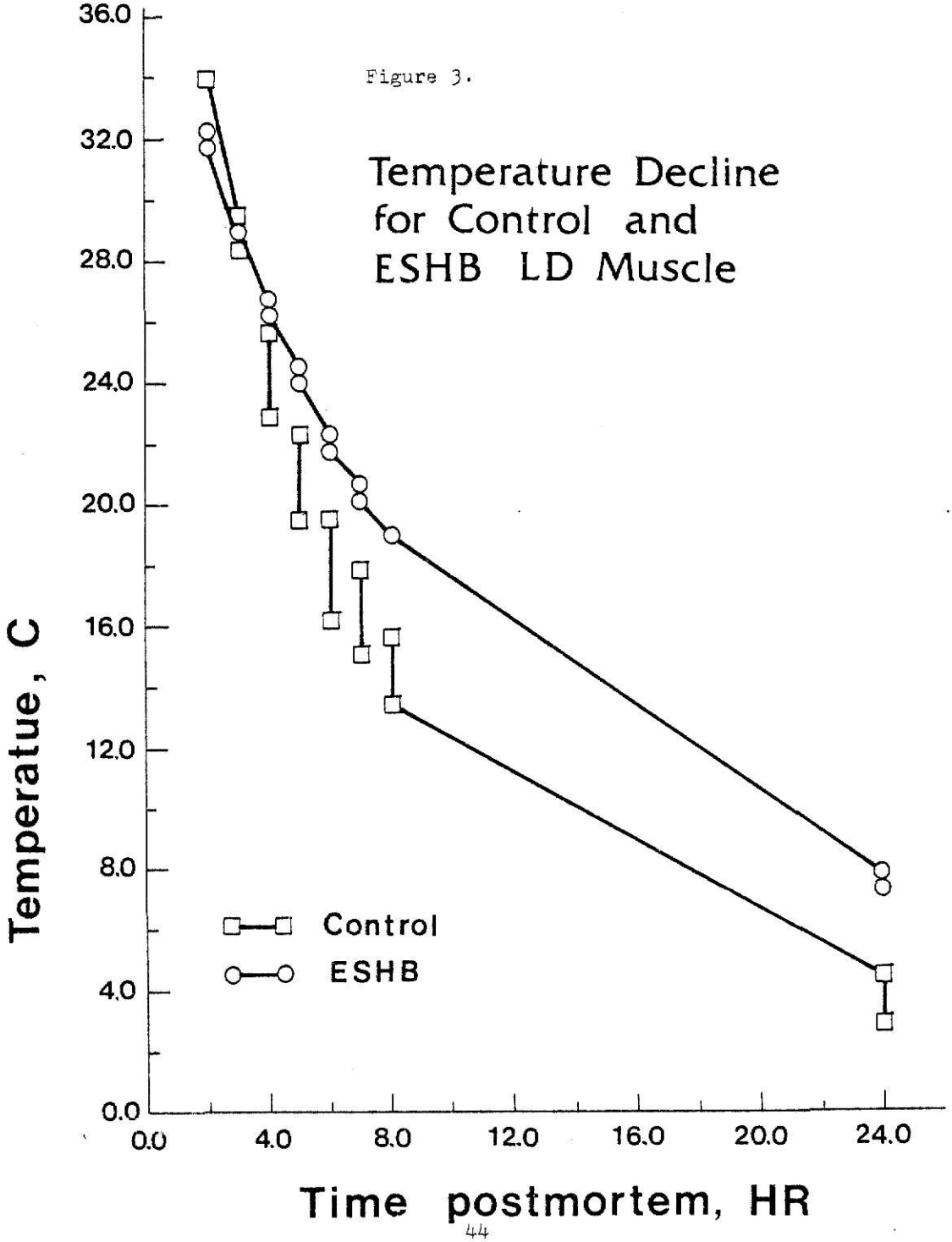

pH Decline for Control and ESHB LD Muscle
pH
7.2
6.9
6.6
6.3
6.0
5.7
5.4
5.1
4.8
4.5
0.0
4.0
8.0
12.0
16.0
20.0
24.0
Control
ESHB
Time postmortem, HR

the pH of ES-LD at 5 hr postmortem had fallen below 6 and was within approximately 0.3 pH units of the ultimate pH. But, NES carcasses had hardly approached rigor at 24 hr postmortem. Bendall et al. (1976) reported that with 700 V, no muscles in the beef carcass took more than 1.1 hr to reach pH 6 or more than 2 hr to reach pH 5.7.

When comparing the pH decline obtained by these researchers, and pH decline in our study, indications are that an improved rate of pH decline may be possible if modifications were made in our equipment. Such changes include lowering the frequency from 60 Hz to a value between 25 and 15 Hz as suggested by Bendall (1976) and Chrystall and Hagyard (1975[a]). Similarly, Chrystall and Hagyard (1975[a]) and Devine (1976) have shown advantages through administering ES in a series of short impulses.

Cold boned NES-LD tended to chill more rapidly than ESHB-LD although no significant difference ($P > .05$) was found. The tendency of NES-LD to chill more rapidly than ESHB-LD resulted from chilling ESHB in cardboard boxes. At 4 hr postmortem the ESHB-LD temperature had declined to 26 C (figure 3) and the pH was approximately 5.75. At this temperature and pH, cold shortening should have been completely avoided. Palatability data tends to support this since the ESHB-LD was not different ($P > .05$) in tenderness from the cold boned NES control.

Figure 3.


Temperature Decline
for Control and
ESHB LD Muscle
Temperatue, C
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
Control
ESHB
0.0
4.0
8.0
12.0
16.0
20.0
24.0
Time postmortem, HR

Similarly, cold boned NES-SM temperature tended to decline more rapidly than ESHB-SM although no significant difference ($P > .05$) was found (figure 1). The slow rate of chill for the ESHB-SM is again attributed to chilling in cardboard boxes. Since the ESHB-SM was still at a relatively high temperature 8 hr postmortem, the possibility of toughening from cold shortening should be remote. However, palatability data showed a significant toughening of the ESHB-SM. Therefore, heat shortening (Locker and Hagyard, 1963) may have been a possible cause for the increased toughening. Furthermore, heat induced shortening or shortening due to excision may have been enhanced by a high collagen content (Herring et al., 1965) and contributed to further toughening of ESHB-SM.

Table 2 shows color scores for ESHB-LD steaks and NES-LD steaks. No significant differences for color were found between the ESHB-LD and the NES-LD with the exception of day 1. One day 1, ESHB-LD was brighter ($P < .05$) than the NES-LD. Similarly, there was a trend for the ESHB-LD to be brighter than the NES-LD throughout display. Type by treatment and system by treatment interactions were not significant ($P > .05$). Even though 3 out of 4 days showed no significance for fresh ESHB-LD color, our work tends to support the findings of Savell et al. (1978[a]) and Smith et al. (1977).

TABLE II

Treatment Means for Color of NES and ESHB/LD Steaks Displayed in PVC Film at 2 C.

Treatment	Day 0[a]	Day 1	Day 2	Day 3	Day 4
C	1.65[b]	1.76	1.86	2.10	2.27
ESHB	1.54[c]	1.57	1.77	1.94	2.18

[a] 1=Extremely bright, 2=bright red, 3=slightly dark red or brown, 4=dark red or brown, 5=exceptionally dark red or brown.

[b,c] Means in the same column with different superscripts are different ($P < .05$).

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APPENDIX

Electrical Stimulation Parameters of Selected Studies

Researchers	Voltage, Frequency, Current, Duration	Species	Muscles Sampled
Bendall J.R. 1976.	250 V 15 Hz .8 A 2 min	Rabbit	LD
Bendall, J.R. and D.N. Rhodes. 1976.	100-700 V 5-25 Hz .5-.3 min	Beef	LD, BF, SM, TB
Bouton et al. 1978.	10-110 V 1.5-4 min	Beef	ST, TB, SM, BF
Bowling et al. 1978.	100 V 50-60 Hz 5 A 50 impulses	Lamb	LD, BF, SM
Carse W.A. 1973.	0-250 V 3-17.5 Hz 30 min	Lamb	LD, SM, GM, BF
Chrystall, B.B. and C. J. Hagyard 1975a.	3600 V 15 Hz 1 min	Lamb	LD, GM, BF, SM, AD
Chrystall, B.B. and C. J. Hagyard. 1975b.	3600 V 15 Hz 2 A 55 sec	Lamb	LD, BF, GM, SM, AD, QF
Davey, et al. 1976.	3600 V 15 Hz 2 A 1-2 min	Beef	LD, GM, BF, Sm

Devine, C.E. 1976.	150-190 V 50 Hz .45 A 3 min	Beef	Ster.
Forest, J. C. and E.J. Briskey. 1967.	5-200 V 20 sec	Pork	
Gilbert, K.V. and C.L. Davey. 1976.	3600 V 15 Hz 2 min	Beef	LD, GM, SM, BF, PM
Gilbert, et al. 1976.	3600 V 15 Hz 2 min	Beef	LD, GM, BF, SM, PM
Grusby et al. 1976.	320 V 5 A 10-20 sec	Beef	ST, LD
McCollum, P.D. and R.L. Henrickson. 1977.	300 V 400 Hz 15-30 min	Beef	LD, SM, PM
Savell et al. 1977.	100 V 50 Hz 5 A 16-68 sec	Beef Lamb Goat	LD, BF, SM
Savell et al. 1978 a.	100 V 50-60 Hz 5 A	Beef	LD
Shaw, F.D. and D.J. Walker. 1977.	20-110 V 10-40 Hz 6-35 min	Beef	SM, BF, LD, TS
Smith et al. 1977.	100 V 50 Hz 5 A	Goat Lamb Beef	

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THE EFFECT OF ELECTRICAL STIMULATION AND HOT BONING ON BOVINE MEAT PALATABILITY AND COLOR

by

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

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Department of Animal Science

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Manhattan, Kansas

1980

Two groups of crossbred steers, 24 Hereford X Angus (medium type) and 23 Simmental-sired steers (large type) from either Chianina X Angus or Chianina X Hereford females were utilized. Steers were purchased at 8 months of age and after a 4 week adjustment period, half of each group was allotted by weight to one of two feeding regimens. Twelve medium type and 13 large type steers were allotted to the accelerated feeding system which consisted of a four week adjustment phase and a finishing phase. Twelve of each type were allotted to the conventional feeding system which consisted of a 4 week adjustment, backgrounding, and a finishing phase.

Cattle were slaughtered in the normal manner; however, the right side of each carcass underwent accelerated processing which involved a 2 min period of electrical stimulation (ES) at 60 min postmortem and hot boning. The electrical current delivered 600 volts, 60 hertz and 5 amps. At 2 hr postmortem both the inside round and strip loin were excised, placed in vacuum bags and stored in cardboard boxes at 2° C for 6 days.

The left side of each carcass served as a conventionally chilled, nonstimulated control (NES). Inside rounds and strip loins were excised at 48 hr postmortem, placed in vacuum bags and stored in cardboard boxes 6 days at 2 C.

PH samples from the LD muscle, and temperatures from both the LD and SM muscles were obtained at 1, 2, 4, 6, 8, and 24 hr postmortem.

On the sixth day postmortem, sensory and color steaks were cut and evaluated by a trained sensory panel and the Warner-Bratzler shear.

Color steaks were displayed in PVC film for 4 days under continuous General Electric Deluxe Warm White lighting. Subjective muscle color was scored individually by four panelists.

Treatments were analyzed for differences by the ANOVA procedure and means were separated by the least significant difference procedure.

Palatability data for the LD muscle shows no differences ($P > .05$) in shear force, myofibrillar tenderness, overall tenderness, connective tissue amount or flavor between NES and ESHB treatments. However, a significant difference for juiciness in favor of ESHB meat ($P=.01$), was found. Conversely, palatability data for the SM muscle reveals significant differences for shear force ($P=.01$), myofibrillar tenderness ($P=.01$), overall tenderness ($P=.01$) and connective tissue amount ($P=.01$). For each of these traits, the NES SM was significantly better than the ESHB.

ESHB LD dropped to a pH of six in 3 hr and was at 5.75 approximately 4 hr postmortem. NES LD pH decline was slower,

but was not different ($P > .05$).

Cold boned, NES LD tended ($P > .05$) to chill more rapidly than ESHB LD. At 4 hr postmortem, the ESHB LD temperature had declined to 26 C and the pH was approximately 5.75. At this temperature cold shortening and resulting toughness should have been completely avoided. According to the palatability data, toughening due to hot boning and cold or heat shortening was avoided.

Similarly, NES SM temperature tended ($P > .05$) to decline more rapidly than ESHB SM temperature. The slow rate of chill in the ESHB SM may have contributed to heat shortening. Heat induced shortening or muscle shortening at excision may have caused the toughening detected by the sensory panel and shear force analysis.

ESHB LD steaks tended to be brighter than the NES steaks although the differences were not significant ($P > .05$).