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