EFFECTS OF BEEF CARCASS ELECTRICAL STIMULATION AND HOT BONING ON MUSCLE DISPLAY COLOR OF UNFROZEN AND FROZEN STEAKS

by

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B.S., University of Connecticut, 1980

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Sciences and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1982

Approved by:

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Major Professor

ACKNOWLEDGMENTS

The author would like to express his sincere gratitude to Dr. Donald H. Kropf for his professional guidance, friendship and genuine interest throughout the author's Master's program. Not to be sold short, the author would also like to thank; Dr. Michael Dikeman for providing the opportunity to assist him with the meat judging team which was truly a rewarding experience, and Dr. Melvin Hunt and Dr. Curtis Kastner for their encouragement, support, and friendship which will not be forgotten.

Thanks goes to the author's fellow graduate students, especially Pedro E. de Felicio, John Greathouse, Dan Hale, Mark Hinds, Jennifer Kendall, Steve Olsen, B. R. Rao, Barry Robinson, and Pam Sleper for their friendship, which made the author's stay at Kansas State most enjoyable.

Most importantly, the author extends a very special thanks to his parents, Mr. and Mrs. Richard E. Claus, his grandmother, Mrs. Amelia Claus, his sister, Deb, and brother, Dick, for their love and support, without which this thesis would not have been possible. Therefore, this thesis is dedicated in their honor.

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CHAPTER I

GENERAL INTRODUCTION

The primary goal of the meat industry is to produce a wholesome, uniform product of acceptable quality that is competitively priced and profitable. Of considerable concern presently is the development of technologies to minimize the energy requirements of processing. When developing technologies of this sort, it is important to determine what effects they have on the product through each stage of processing and marketing to consumption.

Electrical stimulation (ES) and hot boning (HB) have been used to improve the efficiency of production. ES (early postmortem) accelerates postmortem glycolysis and pH decline, and results in the rapid onset of rigor mortis (Carse, 1973; Chrystall and Hagyard, 1976). As a result, beef carcasses can be ribbed and graded earlier than conventionally handled carcasses (Savell et al., 1978c). Additionally, ES improved the tenderness of muscles from stimulated carcasses and muscle color of carcasses and retail cuts (Hall et al., 1980; McKeith et al., 1980).

Hot boning or hot processing is of interest because of the potential in energy savings, reduction in refrigeration space, and decrease in "In-plant residence time" (Henrickson, 1975; Cross, 1979; Cuthbertson, 1979).

A variety of HB techniques have been proposed. All have the potential to decrease the energy requirements of processing. Kastner

et al. (1973) evaluated the effects of HB on muscle color. Carcasses were conditioned at 16C until 2, 5 or 8 hr postmortem. The longissimus and semimembranosus muscles were excised and subsequently vacuum packaged and stored at 2C until 48 hr postmortem. They found that muscles conditioned for 2 hr were darker than muscles from conventionally chilled (2C for 48 hr postmortem) carcasses. However, the reverse was true for muscles excised at 5 and 8 hr postmortem. Schmidt and Keman (1974) found that HB (1 hr postmortem) muscle portions stored for 4 hr postmortem at 7C, then stored for 7 to 11 days at 1C were comparable to conventionally processed carcasses in taste panel and shear force determinations.

Since ES hastens the onset of rigor mortis and reduces the incidence of cold-induced toughening, researchers have combined ES with HB to minimize the undesirable effects of early postmortem muscle excision and rapid chilling (Gilbert and Davey, 1976; Will et al., 1979).

The objectives of the studies presented in Chapters III, IV and V were to determine the effects of ES, HB and combination on the muscle display color of polyvinylchloride packaged steaks (Chapter III), unfrozen vacuum packaged steaks (Chapter IV), and vacuum packaged frozen steaks (Chapter V).

CHAPTER II

GENERAL REVIEW OF LITERATURE

Muscle Color

The color of fresh beef is the single most important characteristic determining its saleability (Landrock and Wallace, 1955). Physical appearance of a retail cut is closely evaluated by consumers who select their meat on leanness and freshness which is based on brightness of color (Jeremiah et al., 1972). The ideal color for fresh beef is "cherry red" (Allen, 1968). Indeed, if the consumer is not attracted to the retail cut because of its color, the remaining sensory attributes of the product may never be experienced.

The color of meat is largely due to the sarcoplasmic protein myoglobin and its chemical state. Hemoglobin also contributes to color because even with an ideal slaughtering technique, a small amount of blood remains in the muscle. In a well bled animal, muscle tissue myoglobin constitutes 80 to 90% of the total pigment. In addition to hemoglobin, such pigments as the catalase and cytochrome enzymes may also be present but their contribution to color is minor (Forrest et al., 1975).

In live muscle tissue, myoglobin facilitates the transport of oxygen from blood hemoglobin to the mitochondria (Wittenberg, 1970).

Hemoglobin, located within the erythrocytes, carries oxygen in the blood stream and exchanges it for carbon dioxide.

Myoglobin and hemoglobin, the two major muscle pigments, are similar in structure, except that the myoglobin molecule is approximately one-fourth as large as the hemoglobin molecule (17,500 and 68,000 molecular weight, respectively, Landrock and Wallace, 1955).

Myoglobin consists of globin (protein) and a heme (non-protein) portion. The heme portion is of special interest because the color of meat is partially dependent on the chemical state of the iron within the heme ring.

When iron in the heme is oxidized (ferric state, Fe^{3+}) myoglobin cannot combine with other molecules including molecular oxygen. The resulting pigment is referred to as metmyoglobin and is brownish red. Metmyoglobin formation is visually detectable when about 60% (Brooks, 1938) or 50% (Van den Oord and Wesdorp, 1971) of myoglobin is in the oxidized state. Harrison (1981) believed metmyoglobin to be visually detectable when it constituted about 30 to 40% of the heme pigment. According to Greene et al. (1971), metmyoglobin formation of 30 to 40% is sufficient to cause rejection of the product. Metmyoglobin formation is undesirable not only because of its color but also because the ferric heme can catalyze the oxidation of unsaturated lipids (Watts et al., 1966).

In the reduced state (ferrous iron, Fe^{2+}), myoglobin will readily combine with water (purple, reduced myoglobin) or with oxygen (cherry red, oxymyoglobin).

Muscle Color Measurement Systems

Hunt (1980) reviewed various muscle color measurement systems. He reported that many color measurement systems exist; however, most of these systems are designed for a specific purpose. He further concluded that because of this, it is important that before selecting a color research methodology, the objectives of the research should be carefully evaluated in order to select the most appropriate technique.

Pigment extraction followed by transmission or absorbance readings and reflectance spectrophotometric methods are available for determining the pigment state and/or color of muscle tissue (Hunt, 1980).

Whipple (1926) evaluated a water extraction method and found that it could not be used for quantifying total muscle myoglobin. Watson (1935) confirmed this and suggested an alkaline phosphate buffer extraction for complete extraction. However, the problem with buffers is the conflict between the completeness of the extraction and the clarity of the solution, which are each maximized by different pH levels. Phosphate buffers systems with a pH of 6.5, 6.6, 6.8, 7.0, and 7.2 have provided complete extraction (Lawrie, 1950; Reynafarje, 1963; Akeson et al., 1968; Bendall, 1975; Warriss, 1979). DeDuve (1948) using a substantially lower pH acetate buffer (pH = 4.5) produced extracts that were always clear. However, 5 to 30% (DeDuve, 1948), and as high as 45% (Warriss, 1979), of the total pigment remained unextracted when using low pH buffers.

Other difficulties with extraction methods include sampling errors, changes in the chemical state of myoglobin, and sample

destruction (Hunt, 1980). Sampling is a problem since meat color is basically a surface phenomenon. Oxymyoglobin formation occurs in the outer 3 to 4mm layer of the meat sample (Lawrie, 1966) and the depth or thickness of this layer is dependent upon the penetration of oxygen. The next layer towards the sample interior is metmyoglobin. Beyond these two layers, in the heart of the sample consists primarily of reduced myoglobin. Consequently, the relative proportion of oxymyoglobin, metmyoglobin, and reduced myoglobin can vary significantly with the sample thickness taken (Snyder, 1965). Once the sample is removed and homogenized, it is inevitable that some oxygen becomes incorporated. Dean and Ball (1960), using an absorbancy ratio procedure of Broumand et al. (1958), found rather high values for oxymyoglobin and suggested that incorporation of oxygen during extraction procedures resulted in the formation of oxymyoglobin from reduced myoglobin. Although transmission spectrophotometry offers a direct measure of the different chemical states of myoglobin, it relies upon extraction for sample preparation and therefore eliminates its usefulness in determining color changes that occur with time on the same sample (Hunt, 1980).

Reflectance spectrophotometry provides an alternate method for determining meat color and/or the different pigment chemical states of myoglobin on the muscle surface. The different chemical states of myoglobin can be measured by reflectance spectrophotometry as each pigment has a unique reflectance spectra. Some inborne errors and problems exist with this method. Muscle is a complex food that is made up of a variety of chemical constituents that absorb and scatter light to some degree. Stewart et al. (1965) pointed out that even

when meat is treated so that it is devoid of heme pigments it still absorbs and scatters light. Rickansrud and Henrickson (1967) reported that reflectance is also influenced by the presence of fat (marbling) and moisture at the surface of the sample being analyzed.

Nevertheless, for an instrumental measurement, reflectance spectrophotometry offers the most desirable combination of simplicity, repeatability, and speed for determining the different pigment states of myoglobin without destroying the sample so that further color measurements can be obtained on the same sample and location without opening the package. This is of particular importance when dealing with meat that is vacuum packaged.

Visual appraisal is another color evaluation technique that has several merits. Most noteworthy is that visual color evaluation can be directly related to consumer acceptance or preference. However, some shortcomings of visual appraisal include the lack of uniformity among scoring systems and information pertaining to the selection and training of panel members (Hunt, 1980).

Packaging

Depending upon the type of packaging, either oxymyoglobin or reduce myoglobin will predominate. Many packaging materials exist and basically fall into two categories; oxygen or gas permeable and gas impermeable. Gas permeable films include polyvinylchloride (PVC), cellophane, pliofilm, and polyethylene which differ somewhat in oxygen permeability.

Oxygen Permeable

Oxygen permeability is dependent on film thickness (Landrock and Wallace, 1955). These researchers also reported that in order to maintain the bright cherry red color of oxymyoglobin, the packaging film permeability must be at least 5000 ml $O_2/m^2/24hr/1atm$ at 23.9C.

Schweigert (1956) reviewed the importance of different chemical reactions of muscle pigment myoglobin. He stated that although oxygen is required for oxygenation of myoglobin to oxymyoglobin, prolonged exposure to oxygen, particularly at low oxygen pressures and with concurrent surface dehydration results in the formation of metmyoglobin. Conditions which accelerate metmyoglobin formation and consequently decrease the salable product life of a retail cut must be thoroughly understood in order to avoid such undesirable color formation. Autoxidation of myoglobin to metmyoglobin is reported to be maximal at very low partial pressures of oxygen (pO_2 of 4mm Hg, Brooks, 1938 and 1.0 to 11.4mm Hg, George and Stratmann, 1952). Increased pO_2 above these low levels results in slower autoxidation and increased oxymyoglobin formation (Solberg, 1968). Autoxidation of myoglobin is also greatly increased with increasing temperature above freezing and decreasing pH in the range of 7.0 to 5.0 (Brown and Mebine, 1969).

Vacuum Packaging

Packaging retail cuts in oxygen permeable film such as polyvinylchloride is well established and is used throughout the industry. Use of oxygen permeable film is advantageous because it promotes the

formation of a desirable bright cherry red muscle color that consumers readily associate with freshness. However, in oxygen permeable film, beef color deteriorates rather rapidly and growth of common spoilage organisms is permitted. These inevitably limit the shelf life of fresh product (Landrock and Wallace, 1955).

Vacuum packaging is relatively new and is primarily used for packaging primal and sub-primal cuts. Most cured and smoked meats are marketed in vacuum packages.

Vacuum packaging and the use of oxygen impermeable film severely limits available oxygen and suppresses growth of spoilage organisms thereby increasing product shelf life (Kraft and Ayres, 1952). Jaye et al. (1962) supported similar findings and demonstrated that ground beef was maintained for a longer period in oxygen impermeable saran than in cellophane (oxygen permeable).

When comparing vacuum packaging to PVC packaging, pork loins that were vacuum packaged had lower bacterial counts, less surface discoloration but a slightly greater odor after 7 and 9 days storage (Smith et al., 1974). Vacuum packaged pork loins were still acceptable at 21 days and produced highly acceptable retail cuts in appearance, odor, and bacterial counts through 28 days of storage at 2C. Sutherland et al. (1976) also noted an acidic odor upon opening vacuum packaged beef stored for 3 to 4 weeks and attributed this in part to the presence of short chain volatile fatty acids, mainly acetic acid. Vacuum packaged wholesale beef cuts maintained an acceptable product for 15 days at 3C (Hodges et al., 1974). This is dependent on how long the carcass is conditioned and the quality grade of the carcass. Hodges

et al. (1974) noted that high grade (USDA average Good to average Choice) short loins that were vacuum packaged exhibited an increase in beef flavor intensity after a 15 day conditioning period whereas low grade (USDA low Standard to low Good) short loins vacuum packaged after a 15 day conditioning period decreased in flavor score.

Pierson et al. (1970) found that anaerobically packaged top round beef steaks stored at 3.3C for at least 10 days were equivalent (sensory evaluation) to fresh beef cut on day 0. However, aerobically packaged beef steaks evaluated for color, odor, and flavor, after 4 days of storage at 3.3C were unacceptable.

An additional benefit of gas impermeable film is that it lends itself to controlled atmosphere packaging as in the case of flushing with carbon dioxide or nitrogen gas (Enfors et al., 1979). Vacuum packaging also decreases weight loss during storage and subsequent fabrication of beef (Hodges et al., 1974). Wiggins and West (1975) stated that vacuum packaging reduced weight loss due to refacing.

Since vacuum packaging provides a more stable product, it is possible to age the cut within the package. Gutowski et al. (1979) reported that vacuum aging of beef steaks generally increased cooking loss, yet steaks were more tender, juicy, and flavorful.

Electrical Stimulation

The use of electrical shock to improve palatability is not a new concept. In 1749, Benjamin Franklin found as a beneficial side effect of euthanizing turkeys with electricity that muscle tissue became exceptionally tender (Lopez and Herbert, 1975).

In 1951, Harsham and Deatherage patented a process for electrically stimulating (ES) beef carcasses, but this technique received minimal attention at the time. It was not until New Zealand researchers developed an electrical stimulation system to prevent cold induced toughening in rapidly chilled or frozen prerigor lamb carcasses that interest in ES really started to expand.

General Effects of Electrical Stimulation

The effects of ES on postmortem glycolysis, pH decline, and tenderness are areas that have been most thoroughly studied.

ES markedly accelerates postmortem glycolysis and reduces the time period normally associated with the onset of rigor mortis (Carse, 1973; Chrystall and Hagyard, 1976; Davey et al., 1976; McCollum and Henrickson, 1977; Shaw and Walker, 1977). The rate of postmortem glycolysis is commonly determined by the rate of pH decline which is a result of depletion of ATP and breakdown of glycogen in the muscle to lactic acid. After ES, at a pH of 6.0, 50% of the initial resting content of ATP had disappeared and with a further decrease of .3 of a pH unit, more than 90% of the ATP was depleted (Bendall and Rhodes, 1976 as cited by Seideman et al., undated). Rapid declines in pH due to ES have been observed in beef, lamb, pork and goat meat, irregardless of animal age, nutritional background, carcass weight or USDA quality grade (Hallund and Bendall, 1965; McCollum and Henrickson, 1977).

The effects of ES on tenderness are somewhat less consistent. When compared to non-stimulated counterparts, Bouton et al. (1978) observed that forequarter muscles (deep pectoral and triceps brachii) from ES

sides showed less reduction in shear force due to ES than did hindquarter muscles (semimembranosus and semitendinosus) from ES sides. They postulated that the fundamental difference in response was a direct result of the difference in the distribution of the current through the carcass.

Four mechanisms have been proposed to explain the tenderizing effect of ES. Since ES causes a rapid depletion of available ATP, the muscles of the carcass "lock" into rigor before the muscle temperature is reduced to a level that would facilitate "cold shortening" (Gilbert and Davey, 1976; Savell et al., 1979b; Bouton et al., 1980). Toughening of cold shortened muscle tissue is due to extensive contraction of the muscle fibers. According to Bowling et al. (1978), the critical muscle temperature for cold shortening is 9 to 11C. Additionally, if the muscle pH is below 6.2 before the cold shortening temperature is reached, cold shortening will be avoided (Bendall, 1972). As a result of reducing the possibility of cold shortening, ES beef muscle can be chilled or frozen sooner postmortem than non-ES muscle (Bendall and Rhodes, 1976). Physical damage to muscles has also been suggested as a mechanism by which ES tenderizes meat (Dutson et al., 1980; Will et al., 1980). Light micrograph studies of ES muscle have revealed that contracture bands are apparent throughout the myofibers. In addition to finding physical disruption and stretching on either side of the contracture band, ES samples have less well defined Z lines and I bands compared to control samples (Savell et al., 1978). Savell et al. (1979b) suggested that since ES causes a rapid reduction in pH while the carcass temperature is still high, naturally occurring

lysosomal enzymes responsible for tenderization during aging degrade myofibrillar and stroma proteins at a much faster rate. They further suggested that lysosomal membranes rupture due to ES which may in part explain the increase in lysosomal enzyme activity. Dutson et al. (1980) found that following ES, the lysosomal enzymes, Beta-glucuronidase and cathepsin-C exhibited an increase in free activity of 24% and 30%, respectively. Judge et al. (1980) proposed a fourth ES tenderization mechanism. They suggested that ES induces disruption of collagen crosslinkages which results in improved tenderness. This theory was supported by their findings that ES lowers the thermal shrinkage temperature of collagen by .6C.

Electrical Stimulation Effects on Color

Grusby et al. (1976) using paired beef carcass sides designated one side as control (non-ES) and the other as ES (320 volts, 5 amperes (A) for 10 or 20 sec) immediately postmortem. Sides were assigned to two groups on the basis of carcass weight: Group I was 148 to 206 kg and group II was 52 to 107 kg. They found that ES treated sides in both groups had a more rapid postmortem pH decline but ES did not influence the color of longissimus and semimembranosus muscles. ES did improve taste panel tenderness scores and decreased shear force values for the longissimus in group I and II but resulted in little difference between treated and control sides for the semimembranosus. This indicates that inherent physical or chemical differences exist between muscles or that these muscles do not receive the same amount of ES. This phenomenon was also later observed by Tang and Henrickson (1980).

Smith et al. (1977) ES calf carcasses with 100 volts of alternating current (AC), 5 A, and 50 cycles/sec, and found that ES carcasses ribbed at 24 hr postmortem had brighter-colored, firmer lean, and did not exhibit "heat ring." Conventionally handled calf carcasses were darker, less uniform in color, had softer lean, and revealed more apparent "heat ring." Additionally, they determined that ES had little effect on color of lean in carcasses ribbed at 72 hr postmortem.

Savell et al. (1978c) determined that pulse stimulation (100 volts AC, 5 A, 50 to 60 cycles/sec) 1 hr postmortem with pulses of .5 to 1.0 sec duration and intervals between pulses of approximately 1 sec, improved USDA lean maturity score and muscle color, and decreased the severity of "heat ring" of light-weight beef carcass sides. They also found that a 75 pulse system was more effective than either 25 or 50 pulses in decreasing the occurrence of "heat ring." The authors stated that concern over "heat ring" is more prevalent when carcasses are ribbed too soon postmortem and that ES would allow cattle which are slaughtered late in the kill shift to be chilled overnight and ribbed without creating delays due to inadequate rigor development.

Effects of ES and cooler aging on light-weight heifer carcasses were evaluated by Savell et al. (1978b). ES imposed 1 hr postmortem (100 volts AC, 5 A, 50 to 60 cycles/sec, 50 pulses, each of 1 sec duration with .5 to 1.0 sec between pulses) had the following results on the longissimus muscle: (1) ES had a significant effect on lean maturity (more youthful) compared to the longissimus muscle of non-ES carcasses; (2) lean color was improved and incidence of "heat ring"

was reduced compared to non-ES; (3) ES carcasses chilled for 7 days resulted in higher marbling scores and final USDA quality grade than control sides (non-ES); and (4) lean was firmer for ES carcasses chilled for 7 days than non-ES carcasses chilled for 7 days.

A comparison of the effects of ES on unsplit calf carcasses with either hide-on or hide-off was made by Smith et al. (1979). Carcasses were stimulated 45 to 75 min postmortem with 100 volts of AC (5 A, 50 to 60 cycles/sec) for 50 impulses. Impulses ranged from 4 sec for the first 8 to 12 impulses to .5 sec for the last 8 to 12 impulses. Regardless of dressing style, ES lowered the pH of the longissimus and increased tenderness and overall palatability but did not affect muscle color, sarcomere length, thaw or cooking loss, flavor or juiciness. They concluded that no matter how the calf carcasses were dressed before stimulation, ES enhanced tenderness.

Savell et al. (1979a) studied the effects of ES on carcass sides obtained from heavy-weight steers. They stimulated sides within 1 hr postmortem with 440 volts of AC (5 A, 60 cycles/sec) for 50 impulses, each of 1 sec duration with .5 to 1.0 sec between impulses. ES: (1) improved lean color uniformity; (2) resulted in lower pH values than control treated muscle at 1 hr and 6 hr postmortem but not at 12 or 24 hr postmortem; and (3) did not affect sarcomere length nor myofibril fragmentation index.

Cross et al. (1979a) ES beef sides 1 hr postmortem with 250 to 400 volts of AC (1.5 A, 60 hertz) being delivered through the carcass for 3 min with 5 impulses per min (each pulse lasting 10 sec). They found that ES decreased the incidence of "heat ring" and improved lean

color and texture. Overwrapping carcasses in PVC did not influence muscle color.

Effect of stimulation time on 95 mature cows was evaluated by McKeith et al. (1980). Carcasses were stimulated unsplit and before evisceration or after splitting with 150 to 550 volts (AC) for 1 min (16 impulses) or 2 min (32 impulses). They determined that: (1) ES improved lean maturity score and lean color irrespective of carcass form, voltage or duration; (2) 550 volts decreased the incidence of "heat ring" and improved lean color scores as compared to 150 volt stimulation irrespective of carcass form or duration; and (3) advantages for 550 volts over 150 volts were more evident for lean color in intact carcasses than for sides.

Using 550 volts of AC (5 A, 17 impulses of 1.8 sec duration), Calkins et al. (1980) determined the influence of ES on quality-indicating characteristics of beef. They found that ES sides ribbed at 24 hr postmortem were more desirable than non-ES sides ribbed at 24 hr in marbling, lean maturity, USDA quality grade, lean firmness, and decreased the incidence of "heat ring." They also observed that the optimum chilling time (before ribbing) for maximum marbling was at 48 hr postmortem for both ES and control sides. Additionally, control sides ribbed at 48 hr had more marbling and higher quality grades than ES sides ribbed at 24 hr postmortem. They concluded that ES does not result in a higher-than-justified quality grade.

Hall et al. (1980) studied the effects of ES on the color of ground beef and steaks produced from inside round muscles. Carcasses were split and the left sides were stimulated using 550 volts of AC,

5 A and 17 impulses delivered intermittently (1.8 sec on with 1.8 sec between pulses) for 1 min. Ground beef and steaks were displayed for 3 days and 4 days, respectively, under incandescent (1030 lux) lighting. There were no differences between muscles from ES and non-ES carcasses in muscle color, surface discoloration or overall appearance for ground beef at all display times. However, ES round steaks were brighter and exhibited less surface discoloration than those from non-ES sides. It was proposed that the differences between ground beef and steaks were apparent because the grinding and mixing processes allowed for a more complete oxygenation thereby producing a more uniformly colored product which masked the differences seen in the steaks.

Lamb color is also affected by ES according to Riley et al. (1980b). Stimulating split lamb carcass sides with 550 volts of AC (5 A, 60 cycles/sec) for 17 impulses (sequence of 1.8 sec on and 1.8 sec off) within 1 hr postmortem caused ES longissimus and body cavity muscles (primary and secondary flank and intercostal) to be more youthful and brighter in color at 24 hr postmortem than controls. PVC wrapped loin chops from stimulated sides (3 days of display, 883 lux, incandescent, 1 to 3C) were not different than control (non-ES) chops in muscle color, surface discoloration, and overall appearance. However, at 4 days of display ES loin chops were more desirable.

Riley et al. (1980a) evaluated the effects of postmortem stimulation time on the storage characteristics of wholesale and retail cuts obtained from old-crop and spring lambs. Stimulation was imposed immediately following exsanguination, after removing the pelt or upon entering the cooler. Stimulation parameters were 18 impulses of 550

volts (AC), 5 A with a sequence of 1.8 sec on and 1.8 sec between pulses. Carcasses were fabricated to obtain wholesale cuts which were subsequently vacuum packaged and used after a 6 day storage period to provide boneless loin chops for the retail PVC packaged study. They found: (1) spring lambs that were stimulated immediately following exsanguination produced more desirable colored chops than lambs stimulated after entering the cooler; (2) ES of the old-crop lamb sides was most effective when applied upon entering the cooler; and (3) ES improved the retail caselife. They hypothesized that the difference between the spring and old-crop lambs may have been due to the feeding and environmental background of the lambs. The spring lambs, which were pasture fed a low energy diet, may have been stressed more due to handling and shipping. The old-crop lambs, however, were fed a concentrated diet which would have supplied a higher energy intake.

The question has been raised as to how ES results in brighter colored lean. Some researchers have suggested that ES causes a physical change in the muscle tissue so as to allow for greater oxygen penetration, resulting in a change in the relative proportions of oxymyoglobin, reduced myoglobin, and metmyoglobin.

Tang and Henrickson (1980) quantitatively determined the effects of ES on myoglobin and its derivatives in heifer carcasses stimulated continuously for 30 min at 1 hr postmortem with a 300 volt direct current (1.94 A, 400 cycles/sec). Longissimus, semimembranosus, and semitendinosus muscles were removed at 4 hr postmortem, cut into steaks, wrapped in loxol paper and frozen. They found that the variation in total myoglobin concentration was greater among different muscles than

among carcasses. The semimembranosus had the highest total myoglobin and the semitendinosus had the least, with the longissimus myoglobin concentration falling between these two. Total myoglobin concentration was not different between ES and non-ES muscle. Using scanning electrophoresis for myoglobin derivatives, they observed that total oxymyoglobin content was not affected by carcass nor muscle. However, there was a significant increase in oxymyoglobin due to ES in the longissimus and especially in the semimembranosus. Oxymyoglobin content in the semitendinosus showed little difference between ES and control samples.

Hot Boning

Traditionally, carcasses are left intact after slaughter with muscles attached and restrained by the skeleton, chilled for 18 to 48 hr at 2 to 3C and fabricated and sold as sides, quarters, wholesale cuts, sub-primal cuts or boneless cuts (Cross, 1979).

A great deal of energy and space is required for carcass chilling, not only because excess fat and bone is chilled along with the muscle, but because the empty body cavity also occupies space. Furthermore, carcasses must be spaced so air can circulate to evenly and efficiently chill the entire carcass, thereby requiring more cooler space (Cross, 1979). The traditional chill system requires additional labor to move carcasses from chill coolers to storage coolers and finally to the fabrication line. This chilling system is also associated with a 2 to 4% loss in carcass weight due to evaporation of moisture from the meat surface (Cross, 1979).

Chilling fat trim and bone that is to be reheated and processed with no apparent benefit from initial chilling obviously is inefficient and adds to the cost. This inefficiency could be overcome by hot boning (hot processing). Hot boning (HB) of beef carcasses entails removing excess fat and all or part of the bone soon (i.e. 1 to 8 hr) after slaughter and before conventional chilling (Erickson et al., 1980). In light of ever increasing energy and labor costs, the feasibility of utilizing hot boning warrants strong consideration.

Removing fat and bone prior to chilling has a potential energy savings from reduced refrigeration of 30% or more when comparing an intact carcass to the edible hot processed portion of a similar 600-pound beef carcass (Henrickson, 1975). On this same size carcass, cooler space reduction may be reduced at least 75% with hot processing (Henrickson, 1975). Cross (1979) stated that HB on the rail required 35 to 40% less labor than cold boning on the table. In addition, scribing, neck pinning, and shrouding of beef carcasses could be avoided.

Several excellent reviews have been prepared on HB (Henrickson, 1975; Kastner, 1977; Cross, 1979; Cuthbertson, 1979). They reported that HB:

(1) may facilitate centralized processing and distribution,

(2) reduces chilling time,

(3) reduces refrigeration input by 40 to 50%,

(4) does not reduce cutting yield,

(5) decreases shrink (up to 2%), particularly if product is vacuum packaged prior to complete chilling,

(6) may result in greater water holding capacity,

(7) improves binding properties and cure penetration,

(8) facilitates mechanical handling as product can be conditioned and stored in boxes, and

(9) increases turnover rate and consequently decreases the "In-plant residence time."

The major disadvantages of HB are the inability of HB carcasses to be traditionally quality and yield graded, and the unconventional shape of the cuts produced which may lead to some marketing difficulties. Other possible disadvantages of HB include:

(1) increased material and equipment costs,

(2) difficulty of introduction into an established conventionally designed plant,

(3) more stringent hygiene and temperature requirements, and

(4) in some cases, greater difficulty in trimming and vacuum packaging.

Microbial quality of HB meat is at least equal to conventionally fabricated beef according to Emswiler and Kotula (1978). Fung et al. (1980) stated that HB meat that is vacuum packaged and boxed at too high temperatures and not sufficiently chilled may result in microbial problems.

Henrickson (1975) reported that the only palatability factor significantly affected by HB is tenderness. Since HB muscles are no longer restrained by the skeleton like they are on the carcass, they are subject to further contraction. Additionally with HB, separated muscles have a greater surface area and would chill more rapidly. Therefore, HB muscles are more susceptible to cold toughening. Henrickson (1975) suggested that the problem with tenderness may be overcome by

conditioning carcasses for 3 hr postmortem at 15C. Kastner et al. (1973), Falk et al. (1975), and Kastner and Russell (1975) have shown that HB beef carcasses after conditioning carcasses at 16C until 7, 8 or 10 hr postmortem minimizes or eliminates any problems with tenderness compared to conventionally handled carcasses (cold boned at 48 hr, 2C). HB beef sides at 2, 3 and 5 hr after slaughter (16C) resulted in higher shear force values than cold-boned controls (Kastner et al., 1973; Falk et al., 1975). Beef boned at 6 hr (16C) postmortem appears to be the critical point where statistical differences in tenderness are found, as carcasses boned prior to 6 hr result in a less tender product than from cold-boned carcasses (Kastner and Russell, 1975). Kastner et al. (1976) suggested an 8 hr holding period (16C) as a precautionary measure even though tenderness differences from hot boned meat at 6 hr postmortem were not great.

Beef carcasses have also been successfully HB at other postmortem boning times and conditioning periods. HB at 2 hr postmortem and conditioning muscle portions at 15C until 24 or 48 hr postmortem (Schmidt and Gilbert, 1970), boning at 1 hr postmortem and conditioning at 5 or 10C until 24 hr postmortem (Follett et al., 1974) or chilled at 7C for 4 hr, then at 1C until 24 hr postmortem (Schmidt and Keman, 1974) and stored for a 3, 7, 8 or 13 day aging period have all produced product equivalent to cold-boned counterparts in tenderness, drip loss, and microbial quality.

Lamb hot processed into bone-in primal cuts (leg, loin, and shoulder) 1 to 2 hr after slaughter followed by a 24 hr conditioning period at 10C produced highly satisfactory results. However,

hot-processed loins from mutton-ewes were less tender while primal legs were greatly improved by 10C conditioning to the same shear force level as lamb legs (McLeod et al., 1973).

Additionally, hot processing does not affect meat flavor (Kastner et al., 1973; Schmidt and Keman, 1974; Kastner and Russell, 1975).

Color of Hot-Boned Muscles

Kastner et al. (1973) excised the biceps femoris, longissimus, semimembranosus, and semitendinosus muscles from steer carcass sides after a 2, 5 or 8 hr postmortem conditioning period (16C). These muscles were then stored in cryovac bags at 2C until 48 hr postmortem. The opposite side was chilled at 2C and served as a control group with muscles being excised at 48 hr postmortem. Two steaks from each muscle were obtained and used to determine muscle color as measured by reflectance with a photovolt reflectance meter. Percent reflectance readings were converted to Munsell color values to determine the degree of lightness and darkness of the muscle. Additionally, an untrained panel was used to evaluate if muscle differences existed (triangle test) between HB and cold-boned beef. They found that HB at 2 hr postmortem produced a darker colored product ($P < .01$) than cold boning at 48 hr. However, the reverse was apparent in steaks excised and cut from carcasses conditioned at 16C until 5 hr ($P < .10$) or 8 hr ($P < .05$) postmortem. They further reported that even though differences were documented in reflectance, these differences were not perceived by the panelists.

Henrickson et al. (1974) investigated the effects of muscle boning unchilled beef carcasses on muscle color. Thirty steers were slaughtered and carcasses were split into sides. One side was designated for HB and randomly selected for a 3, 5 or 7 hr postmortem conditioning period at 16C. At the end of the conditioning period, muscles were excised and stored in cryovac bags until 48 hr postmortem (1.1C). The opposite side was used for cold boning at 48 hr (1.1C). Longissimus muscles excised from both cold-boned and HB carcasses were cut into steaks at 48 hr postmortem and evaluated on muscle color. Panelists could distinguish differences (duo-trio test) between cold-boned controls and steaks from muscles HB at 3 hr but not those excised at 5 or 7 hr postmortem. They also found a color preference for cold-boned muscle over the 3 hr excised product. Although a preference was given to the cold-boned product, no differences were determined in color acceptability of the hot-boned muscle versus the 48 hr cold-boned muscle at all conditioning periods.

Kastner and Russell (1975) studied the influence of HB beef excised after various conditioning periods on muscle color. Fifteen heifers were slaughtered and assigned to one of three postmortem holding periods. One side of each carcass was held for 6, 8 or 10 hr prior to HB. The opposite side was cold boned after being chilled 48 hr postmortem at 2C. Muscles (biceps femoris, longissimus dorsi, semimembranosus, semitendinosus and supraspinatus) were cut into steaks and allowed to oxygenate for 2 hr at 2C before reflectance readings (converted to Munsell color values) were taken. Another set of steaks were frozen at -40C, thawed at 2C and allowed to bloom.

Using a Hunterlab color difference meter, L, a, b values were collected from which delta L, delta a, and delta b values were determined. Also, steaks were evaluated by a color panel. No visually detectable color difference was observed between HB and cold-boned samples for any of the postmortem holding periods. They also concluded that:

(1) no differences in all color measurement parameters were found between HB and cold-boned muscle after a 6 hr holding period,

(2) delta L values for HB treatments were smaller and delta b values were larger than those for cold-boned product from carcasses conditioned for 8 and 10 hr at 16C, and

(3) HB product color value means were larger (i.e. brighter) for those stored 8 and 10 hr than for cold-boned means.

Despite the subtle color differences (reflectance) between HB and cold-boned muscle, researchers have consistently stated that these differences do not represent any practical problems to the retailer or consumer. Nevertheless, the earlier muscles are HB, the darker the resulting color, although it is more uniformly colored. Consequently, further research is needed to determine the optimum times and temperatures for boning that will provide an acceptable colored product that will also fit into the work schedule of commercial operations.

Electrical Stimulation and Hot Boning

In order to insure the success of HB researchers have combined ES with HB since ES minimizes the undesirable effects of early postmortem muscle excision and chilling.

Gilbert and Davey (1976) evaluated the effects of ES and HB on beef carcasses. At 30 min postmortem the right sides were stimulated for 2 min with 3600 volts (15 hertz, pulse width 5msec, 2 A). The left sides served as unstimulated controls. Both sides were placed in the cooler (4C) and monitored for temperature decline. The temperature of the longissimus had dropped to 20C in 5 hr and to 4C in 24 hr. In the same time frame the semimembranosus temperature fell to 35C and 11C, respectively. This temperature decline represents a rather fast chilling rate. At 5 hr, selected muscles from stimulated sides were excised while unstimulated sides were stored until 24 hr prior to muscle excision. The excised longissimus, gluteus medius, biceps femoris, semimembranosus and psoas major muscles were halved transversely, placed in heat-shrinkable, low permeable bags with one half of each cut immediately frozen (-18C) and the other half aged for 72 hr at 10C (before freezing). At 5 hr postmortem, the pH values of the ES biceps femoris, semimembranosus, and psoas major had reached the same endpoint as the 24 hr control. However, the longissimus was .25 pH units below the control group. They suggested that stimulated carcasses achieved rigor in 5 hr, which would permit muscle boning without the risk of cold shortening despite rapid chilling or freezing. Furthermore, muscles from stimulated carcasses boned at 5 hr, then frozen, were equivalent or slightly superior in tenderness to unstimulated muscle chilled for 24 hr.

Cross et al. (1979b) ES and HB 10 beef carcasses within 1 hr postmortem while the opposite side was chilled intact (2 to 3C) until 48 hr postmortem. Stimulated carcasses received 1.5 A of AC (250 to

400 volts) for 3 min with four 10-sec duration shocks per min. Ten boneless primal cuts were removed from each HB and cold-boned side and evaluated for lean color, fat color, and shape. Primal cuts were then vacuum packaged and stored for 20 days (2 to 3C), then again evaluated for color of lean and fat, and shape. HB cuts immediately after boning were darker ($P < .05$) than cold-boned cuts (1 hr vs 48 hr). However, after 20 days storage, the color of HB cuts was similar to cold-boned cuts. They emphasized that the similarity in color after a 20 day storage is more important than the difference at the beginning of the storage sequence. Fat color was definitely whiter for HB cuts after 20 days storage than cold-boned cuts before vacuum packaging and after cold storage. They attributed these differences in fat discoloration to a greater amount of purge in the vacuum bag of the cold-boned cuts. Shapes of the cold-boned cuts were typically rated higher (closer to normal) than HB cuts.

Seideman et al. (1979) ES beef carcasses with 440 volts of AC (5 A, 50 to 60 cycles/sec) for 25 impulses (0.5 to 1 sec duration) at 30 to 40 min post exsanguination. Sections of the longissimus and semimembranosus were cut from ES sides at 1 hr postmortem while the unstimulated sides were muscle boned at 24 hr. Steaks were cut from muscles of both treatment groups after 2 weeks of vacuum aging at 1C. They determined that ESHB beef longissimus muscle had lower juiciness ratings than those from conventionally handled sides. Semimembranosus muscles that received ES and were HB sustained lower weight losses during storage but greater cooking losses than cold-boned sides. Additionally, HB of ES sides were not different in tenderness, pH, flavor desirability or sarcomere length.

Cross and Tennent (1980) ES and HB beef carcass sides (ESHB) within 1 hr postmortem with 1.5 A of 150 to 400 volts of AC (60 hertz) for 3 min (four, 10-sec duration shocks per min). Longissimus muscles were excised at 1, 4 or 48 hr postmortem and immediately evaluated (visually) for lean color and fat color. The longissimus was then placed in a bag, vacuumized and frozen either immediately, after chilling 24 hr or after 20 days storage at 2 to 3C. At the end of the 20 day chilled (2 to 3C) storage, each muscle was again evaluated for lean and fat color, and shape. They reported that:

(1) ES improved lean-maturity and lean color over unstimulated carcasses,

(2) fat color ratings were less desirable for muscles removed at 48 hr than those excised at 1 or 4 hr and then stored 20 days,

(3) muscles removed at 1 hr or 4 hr were darker than those excised at 48 hr,

(4) muscle shape differences were not of practical importance even when excised 1 hr postmortem,

(5) as postmortem boning time increased, the weight loss during storage and amount of leakage increased,

(6) muscles from ES carcasses had lower initial pH values within 1 hr and 4 hr boning times than unstimulated counterparts,

(7) regardless of excision time, the longissimus from ES carcasses was more tender than from non-stimulated sides, and

(8) juiciness and flavor intensity were not affected by ES or boning time.

These researchers concluded that ES carcasses can be HB within 1 hr postmortem with few practical adverse effects. However, they recommended that muscles from ES carcasses not be frozen immediately following excision to avoid the risk of problems in tenderness.

Kastner et al. (1980) evaluated the effects of beef carcass ES and HB on pH decline, shear, and taste and color panel evaluations of selected muscles. ES sides received 400 to 600 volts of AC (5 A, 60 hertz) continuously for 2 min at 1 hr postmortem. Carcass sides were assigned to one of three treatments: (1) conventionally chilled for 48 hr at 2C before fabrication (C); (2) HB at 2 hr postmortem (HB); or (3) ES and HB at 2 hr postmortem (ESHB). Kastner et al. found that:

(1) ESHB was effective in increasing the rate of pH decline compared to C and HB counterparts,

(2) ESHB longissimus was not different than C longissimus in shear force. However, ESHB semimembranosus had larger (tougher) shear force values than C semimembranosus,

(3) taste panel myofibrillar tenderness means for ESHB longissimus were not different than C counterparts,

(4) semimembranosus taste panel myofibrillar tenderness means supported shear results,

(5) ESHB longissimus was more juicy than conventionally handled muscle, and

(6) mean color scores for polyvinylchloride wrapped ESHB longissimus muscles were not different ($P > 0.05$) than C at day 1 or day 4 but tended to be brighter.

Nichols and Cross (1980) stimulated beef carcass sides 1 hr postmortem for 2 min using a constant amperage (1 A) with voltage ranging from 140 to 300 volts of AC (60 cycles/sec). Sides were chilled at 5C before removing the semimembranosus and longissimus muscles. Once excised, muscles were vacuum packaged and dipped in a hot water bath (100C) to shrink the film for 2 to 3 sec. Treatment assignment was as follows:

(1) stimulated and non-stimulated,

(2) HB at 1, 2, 4 or 48 hr (control), and

(3) storage according to one of three methods:

a. immediately frozen at -30C,

b. chilled 6 hr at 3C after excision and then frozen (-30C), or

c. chilled at 3C for 5 days.

ES caused a rapid initial pH drop in the longissimus muscles which were excised and vacuum packaged 1, 2 or 4 hr postmortem. The initial pH drop caused by stimulation was further increased by delayed excision and was pronounced enough that even at -30C storage, the overall decline in the longissimus muscle was not inhibited. Compared to a -30C storage, the 3C storage temperature resulted in an even faster pH decline in stimulated muscles but the -30C storage was sufficient to hinder the decline in the non-stimulated muscle. Additionally, ES did not affect the appearance of fresh steaks (wrapped in PVC and displayed under incandescent light) from HB longissimus or semimembranosus pre-rigor beef. However, excision time did affect color and color uniformity of the semimembranosus, apparently because of existing differences in the temperature and pH relationship. Additionally, they concluded that excision times of 1 or 2 hr postmortem appear to be preferable to 4 or 48 hr postmortem excision because the high temperature and low pH combination could cause severe non-uniformity of color in those muscles located deep within the carcass.

Taylor et al. (1980) studied the effects of ES and HB on microbial growth, tenderness, sarcomere length, lean color, pigment content, and pH of selected beef muscles. Treatments were: (1) cold boned (C)

sides were chilled at 15C for 7 hr and then placed in a chillroom at 0 to 1C until 48 hr postmortem at which time they were cold boned into primal joints and vacuum packaged; (2) selected sides were HB at 1 to 2 hr postmortem and primal joints were vacuum packaged. Beginning at 3 hr postmortem, joints were chilled at 10C for 9 hr and then at 1C for an additional 18 hr; and (3) ESHB sides received 700 volts of AC (25 pulses/sec, four 30-sec periods) at approximately 50 min postmortem with HB being completed 1 to 2 hr postmortem. Joints were vacuum packaged and chilled at -1C until 24 hr postmortem. They determined:

(1) method of boning did not affect the initial level of contamination,

(2) there was no treatment effect on total viable counts after 5 or 21 days storage at 1C,

(3) tenderness and sarcomere length were not affected by treatment but tenderness was improved between 5 and 21 days,

(4) color of longissimus dorsi muscle wrapped in oxygen permeable film (determined with Hunter Color difference meter for lightness) was unaffected by treatment,

(5) total pigment content (measured as cyanmetmyoglobin) of semimembranosus muscle wrapped in oxygen permeable film was not affected by treatment at 5 or 21 day storage periods,

(6) the inner part of the cold-boned semimembranosus was lighter than the outer portion but in the HB treatment this difference was not as severe, and

(7) ultimate pH was not affected by either treatment or location within the muscle.

Taylor et al. (1980) stated that HB coupled with more rapid chilling produced a more even color across large muscles. However, this benefit was diminished when ES was incorporated, suggesting that the early fall in pH increased protein denaturation.

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CHAPTER III

EFFECTS OF BEEF CARCASS ELECTRICAL STIMULATION AND HOT BONING ON MUSCLE DISPLAY COLOR OF POLYVINYLCHLORIDE PACKAGED STEAKS

ABSTRACT

Ninety-six beef carcass sides were used to determine the effects of control (C, chilled 48 hr at 5C), electrical stimulation (ES, 45 min postmortem, 400 volts for 2 min, intermittently pulsed), hot boning (HB, 2 hr postmortem), and combination (ESHB) treatments on muscle color of longissimus (LD) and semimembranosus (SM) steaks packaged in polyvinylchloride film. LD from HB was mostly visually darker, had less oxymyoglobin, and more metmyoglobin than other treatments as was the SM, but with fewer differences between HB and ESHB. ES and ESHB muscles were visually similar, suggesting ES minimized the darkening effect of HB. Regardless of treatment, muscle color was acceptable at 0, 1, 3 and 5 days of display.

Introduction

Besides leanness (Jeremiah et al., 1972), the single most important merchandising characteristic of meat, particularly fresh beef, is meat color (Landrock and Wallace, 1955). If product is rejected because of color, the remaining sensory attributes may never be experienced.

Muscle visual color is largely due to relative proportions of oxymyoglobin, metmyoglobin, and reduced myoglobin; which are affected by packaging, length of display time (Pirko and Ayres, 1957; Pierson et al., 1970; Livingston and Brown, 1981), and processing. Electrical stimulation of carcasses, imposed early postmortem, improved the color of beef and lamb muscles (Cross et al., 1979; Riley et al., 1980). However, ES does not always improve muscle color (Grusby et al., 1976). ES carcasses ribbed at 24 hr had a brighter colored, firmer lean, and did not exhibit "heat ring" as compared to conventionally handled calf carcasses (Smith et al., 1977). When carcasses were ribbed at 68 to 72 hr postmortem, ES on unsplit calf carcasses did not affect muscle color (Smith et al., 1979). Hall et al. (1980) found no differences between muscles from ES and non-ES carcasses in muscle color, surface discoloration, or overall appearance for ground beef up to 3 days of display. However, at 5 days of display ES round steaks were brighter and exhibited less surface discoloration than those from non-ES sides. Hall et al. (1980) proposed that the grinding and mixing process allowed for more complete oxygenation.

Kastner et al. (1973) and Henrickson et al. (1974) investigated the effects of hot boning (HB) on muscle color of beef carcass muscles

excised after a 2, 3, 5 or 7 hr postmortem conditioning period at 16C, then stored in cryovac bags until 48 hr postmortem. Muscles excised at 2 and 3 hr were darker than conventionally processed counterparts.

In order to improve the success of hot boning, researchers have combined ES with HB since ES minimizes the undesirable effects of early postmortem muscle excision and chilling on tenderness (Gilbert and Davey, 1976; Seideman et al., 1979). Taylor et al. (1980) studied the effects of ES and hot boning on lean color and pigment content. Neither lean color nor total pigment of the semimembranosus muscle were affected by treatment on days 5 and 21 of storage. Hot boning coupled with more rapid chilling produced a more even color across large muscles. This benefit was diminished when ES was incorporated.

Our objectives were to determine the effects of ES, HB, and ES plus HB on muscle color of polyvinylchloride packaged beef steaks.

Materials and Methods

Forty-eight crossbred steers sired by 7/8 Simmental x 1/8 Hereford or Angus bulls out of crossbred dams were obtained from the R.L. Hruska US Meat Animal Research Center in Clay Center, Nebraska. The cattle were about eight months old and averaged 263 kg when placed on a feeding trial at Kansas State University.

Cattle were fed ad libitum under one of two feeding regimens. First, three accelerated groups (ACC) were stepped-up to a finishing diet over a 58 day period. The final diet (dry matter basis) consisted of 9.6% forage sorghum silage, 84.4% corn, and 6.0% protein and mineral supplement. ACC cattle were slaughtered in three groups after reaching

either 441 kg (139 days, ACC 1), 494 kg (178 days, ACC 2), or 560 kg (242 days, ACC 3). Secondly, the conventionally fed cattle were fed a high roughage diet for 110 days, followed by a 21 day pre-finishing adjustment phase and then finished on the same diet as the ACC groups. These cattle were slaughtered after 284 days at a mean live weight of 596 kg.

Cattle were slaughtered at the Kansas State University meat laboratory. Carcasses ranged from a group mean yield grade of 2.2 to 3.1, a quality grade of Good 21% to Good 95%, and had average carcass weights of 262 kg (ACC 1), 309 kg (ACC 2), 351 kg (ACC 3), and 358 kg (CONV).

After the animal was euthanized, bleeding time was used as time zero for all treatments. Each side was randomly assigned to one of four treatments: control (C), electrical stimulation (ES), hot boning (HB), or electrical stimulation plus hot boning (ESHB).

The C sides were chilled at 5C until 48 hr postmortem. ES was applied through stainless steel probes, one inserted in the inside round about 8 cm below the proximal attachment of the achilles tendon and the other inserted laterally along the humerus. Sides were stimulated 45 min postmortem with 400 to 600 volts of alternating current (60 hertz and .6 amp delivered through the carcass) for 2 min with a sequence of 1.6 sec on and .8 sec off and chilled until 24 hr postmortem at 5C. The longissimus (LD) and semimembranosus (SM) muscles from the HB and ESHB sides were excised 2 hr postmortem and stored until 24 hr postmortem at 2C in an oxygen impermeable bag.

After the cold storage period, one steak (2.5 cm) was cut from both the LD and SM muscles. The LD steaks were cut from over the 2nd to 3rd lumbar vertebral region and the SM steaks were obtained from the distal portion of the SM. Steaks were packaged in conventional 0.8 mil polyvinylchloride film (PVC) and allowed to bloom for 2 hr before being displayed continuously (24 hr/day) at 2 to 4C under General Electric Natural fluorescent (40 watt, 1076 lumens/m^2) lighting.

Visual appraisal (four member trained panel) and reflectance spectrophotometry were used to evaluate muscle color on days 0, 1, 3 and 5 of display. Visual scores were estimated to the nearest 0.5 on a five point scale: 1=bright red, 2=dull red, 3=slightly dark red or brown, 4=dark red or brown, and 5=very dark red or brown. Reflectance at 474, 525, 580, and 630 nm were measured using a Bausch and Lomb 600 reflectance spectrophotometer adjusted to 100% reflectance with a $MgCO_3$ block.

Reflectance values were used to indicate oxymyoglobin (%R630 nm-%R580 nm and %R580 nm/%R525 nm), metmyoglobin (%R630 nm/%R525 nm), and reduced myoglobin (%R474 nm/%R525 nm). Additionally, the reflectance values collected at wavelengths 474 nm and 525 nm were converted to K/S values and the ratio K/S 474 nm / K/S 525 nm was calculated to estimate percent reduced myoglobin (Snyder, 1965). Values for K/S were calculated according to procedures outlined by Francis and Clydesdale (1975).

Results and Discussion

Visual Color Score

HB steaks (Table 1) from the LD muscles were visually darker ($P < 0.05$) than from all other treatments; except on day 1 of display, HB steaks were not darker ($P > 0.05$) than C steaks (1.7 vs 1.6). HB SM steaks were also visually darker in most comparisons except that HB SM steaks were not different ($P > 0.05$) than ESHB steaks on day 0 and 1, or ES steaks on day 5. Our data agree with those of Kastner et al. (1973) and Kastner and Russell (1975) who found that muscles HB early postmortem (2 to 6 hr) resulted in darker colored muscles than those cold boned at 48 hr. Since the HB muscles may have a tendency to chill faster (Bowles, 1981), this condition may have resulted in a conservation effect on certain biochemical reducing pathways in the muscle which would help keep muscle in a more reduced state, which might appear darker. The darker appearance of the HB steaks also may be due, in part, to a higher water holding capacity (Forrest et al., 1975) resulting from a greater binding ability of the proteins and/or a greater structural integrity of the muscle cell membranes as a result of the inhibition of proteolytic enzyme activity. With a greater water holding capacity (i.e. less free water) light is absorbed more readily by the muscle tissues producing a darker appearing muscle (Forrest et al., 1975).

ES LD steaks were brighter ($P < 0.05$) than C steaks from the LD on day 1 but were not different at the other display times. The ES SM steaks were similar to C steaks in visual color, regardless of the

Table 1. Effects of electrical stimulation and hot boning on the visual color score[d] and reflectance measurements of PVC packaged beef steaks

	Carcass Treatments[e]							
Day	C	ES	HB	ESHB	C	ES	HB	ESHB
	Visual Color Score							
	Longissimus				Semimembranosus			
0	1.4[a]	1.3[a]	1.6[b]	1.4[a]	1.5[a]	1.3[a]	1.8[b]	1.8[b]
1	1.6[bc]	1.4[a]	1.7[c]	1.5[ab]	1.6[a]	1.5[a]	2.0[b]	1.8[b]
3	2.0[a]	1.8[a]	2.4[b]	2.0[a]	2.0[a]	2.0[a]	2.6[b]	2.2[a]
5	2.5[a]	2.3[a]	2.8[b]	2.4[a]	2.5[a]	2.6[ab]	2.9[b]	2.6[a]
	%R630 nm-%R580 nm							
0	24.9[ab]	27.1[c]	23.3[a]	26.2[bc]	25.1[ab]	25.7[b]	23.7[ab]	23.1[a]
1	23.2[b]	24.2[b]	21.1[a]	24.4[b]	24.0[b]	24.0[b]	21.2[a]	22.9[ab]
3	21.5[b]	22.3[b]	17.8[a]	22.0[b]	22.2[c]	21.1[bc]	18.2[a]	19.6[ab]
5	19.5[b]	20.0[b]	15.7[a]	19.4[b]	20.0[b]	19.5[b]	16.9[a]	18.7[ab]
	%R630 nm/%R525 nm							
0	2.72[ab]	2.89[c]	2.65[a]	2.85[bc]	2.91[b]	2.93[b]	2.71[a]	2.73[a]
1	2.60[b]	2.57[b]	2.26[a]	2.52[b]	2.83[c]	2.69[bc]	2.39[a]	2.61[b]
3	2.40[b]	2.34[b]	2.19[a]	2.38[b]	2.58[b]	2.42[ab]	2.28[a]	2.38[a]
5	2.15[b]	2.15[b]	1.93[a]	2.08[b]	2.37[b]	2.31[ab]	2.20[a]	2.23[ab]
	%R474 nm/%R525 nm							
0	1.09[b]	1.05[a]	1.08[ab]	1.06[ab]	1.05	1.03	1.08	1.05
1	1.02[a]	1.04[ab]	1.07[b]	1.07[b]	1.00[a]	1.03[ab]	1.07[b]	1.06[b]
3	1.03	1.05	1.04	1.03	1.03[a]	1.02[a]	1.07[b]	1.04[ab]
5	1.07	1.05	1.07	1.07	1.02[a]	1.05[ab]	1.07[b]	1.07[b]

[abc]Means for the same muscle and row with the same or no superscript letter are not different ($P > 0.05$).

[d]Visual color score: 1=bright red, 2=dull red, and 3=slightly dark red or brown.

[e]C=control, ES=electrical stimulation, HB=hot boning, and ESHB=electrical stimulation plus hot boning.

day of display. Mixed results have been reported on the effect of ES on muscle color (Cross et al., 1979; Smith et al., 1979). Grusby et al. (1976) stimulated beef carcasses with 320 volts (5 amps) and found that ES did not affect the color of the LD or SM. McKeith et al. (1980) determined that stimulating with 550 volts was more effective in improving lean color than 150 volt stimulation.

Some of the differences in the effects of ES on color reported by numerous researchers may be accounted for by the differences in the time in which muscles were evaluated, since it appears that the sooner color is evaluated postmortem the more frequent are muscle color differences reported.

The ESHB LD steaks were not different ($P > 0.05$) than C steaks. However, the ESHB SM steaks were darker ($P < 0.05$) than C steaks on days 0 and 1. Evidently, ES alleviated the undesirable effects of HB on the color of the LD but was not as effective in the SM. This might suggest the amount of current or responsiveness of the SM was different from the LD.

%R630 nm-%R580 nm (Estimator of Oxymyoglobin)

Following the same pattern established in the visual color score data, the HB LD steaks had lower difference values (indicating less oxymyoglobin) than all other treatments at all times except for the C steaks on day 0. The SM steaks were somewhat less responsive as there were fewer color differences between treatments. HB SM steaks were lower in estimated oxymyoglobin ($P < 0.05$) than C and ES steaks except on day 0.

ESHB LD steaks had greater differences values ($P < 0.05$) indicating more oxymyoglobin (brighter) than HB steaks. However, the ESHB SM steaks were not different ($P > 0.05$) than the HB SM steaks. This again suggests that ES was not as effective in affecting muscle color of the SM either because of reduced current flow, greater resistance or lack of response of this muscle.

Both ES LD and SM steaks were not different ($P > 0.05$) than counterpart C steaks except on day 0 in which the ES LD steaks had more oxymyoglobin. Tang and Henrickson (1980) quantitatively measured the oxymyoglobin content of stimulated and non-stimulated muscle by electrophoresis. Carcasses were stimulated for 30 min at 1 hr postmortem and muscles were excised at 4 hr postmortem and frozen. They determined that the LD and SM muscles from ES carcasses had higher oxymyoglobin content than the non-stimulated controls. Since they stimulated the carcass for a longer period of time, this may explain why they observed a color difference in the SM.

Some of the apparent muscle color differences between treatments may be due to differences in oxygen penetration into the muscle. Bowles (1981) working with the same carcasses and muscles used in this experiment found that HB muscles tended to be less tender than muscles from conventionally handled carcasses as determined by taste panel and shear measurements. Therefore, the possibility exists that the toughness associated with HB steaks may be due to a tighter, more compact muscle structure which would permit less oxygen penetration. Consequently, HB steaks appear darker from having less oxymyoglobin. Although Bowles did not find any significant differences in tenderness

between ES and C steaks, there was a slight trend for ES steaks to be more tender than C steaks. It has been proposed that ES improves tenderness as a result of some chemical or direct physical alteration in the muscle tissue (Gilbert and Davey, 1976; Savell et al., 1979; Dutson et al., 1980; Judge et al., 1980). Therefore, the color improvement of ES seen early in display suggests that ES may have allowed for more and deeper oxygen penetration into the muscle tissue, possibly due to its more open structure. However, with additional display time, C steaks might have achieved the same level of oxygen penetration and subsequent oxymyoglobin formation as ES steaks, thereby eliminating the color differences observed between treatments.

%R630 nm/%R525 nm (Estimator of Metmyoglobin)

HB LD steaks had lower ratio values ($P < 0.05$) indicating more metmyoglobin than all other treatments at all times with the exception of C steaks ($P > 0.05$) on day 0. A similar trend ($P > 0.05$) in the accumulation of metmyoglobin was also apparent in the SM; however, there were fewer significant differences.

No differences in measurements of metmyoglobin were observed between ES and C for the SM steaks at all times and for the LD on days 1, 3 and 5. On day 0, the ES LD steaks had higher ratio values ($P < 0.05$) than the C steaks which suggests the ES steaks had less metmyoglobin. Also, since reflectance at 630 nm is both a reflectance peak for oxymyoglobin and a reflectance valley for metmyoglobin, a higher ratio of %R630 nm/%R525 nm could indicate more oxymyoglobin which would support the visual score data.

A greater accumulation of metmyoglobin in HB muscles may be a result of lower oxygen concentration in the muscle which would reduce the partial pressure of oxygen. Brooks (1938) and George and Stratmann (1952) reported that a lower partial pressure of oxygen favors the formation of metmyoglobin. Consequently, a slightly lower amount of oxygen in HB muscle may promote the autoxidation of myoglobin to metmyoglobin.

%R474 nm/%R525 nm (Estimator of Reduced Myoglobin)

Very few differences were found between treatments in %R474 nm/%R525 nm reflectance ratio for both muscles. Additionally, although not statistically analyzed, there was no trend in this reflectance ratio with display time in concert with apparent changes in the percentage of oxymyoglobin and metmyoglobin. Therefore, the reduced myoglobin content was either extremely stable across these treatments and times or this particular reflectance ratio was not indicative of changes in reduced myoglobin.

Additional Reflectance Measurements

Converting the reflectance values measured at 474 nm and 525 nm to K/S values was not any more sensitive to changes in reduced myoglobin than the ratio of %R474 nm/%R525 nm. The second estimator of oxymyoglobin (%R580 nm/%R525 nm) did not add any insight to the effects of ES and HB on muscle color as there were fewer differences between treatments.

Summary

HB steaks when compared to C, ES and ESHB steaks were generally the darkest, had the least oxymyoglobin, and developed more metmyoglobin.

Although ES steaks were mostly not different ($P > 0.05$) than C steaks, ES steaks tended to be brighter. Nevertheless, stimulation was sufficient to alleviate the undesirable effects of HB on muscle color.

Regardless of treatment, muscle color was acceptable at all display times of this study and would not present any practical merchandising problem.

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CHAPTER IV

EFFECTS OF BEEF CARCASS ELECTRICAL STIMULATION AND HOT BONING ON MUSCLE DISPLAY COLOR OF UNFROZEN VACUUM PACKAGED STEAKS

ABSTRACT

Ninety-six beef carcass sides were used to determine effects of control (C, chilled 48 hr at 5C), electrical stimulation (ES, 45 min postmortem, 400 volts for 2 min, intermittently pulsed), and hot boning (HB, 2 hr postmortem), and combination (ESHB) treatments on muscle color of longissimus (LD) and semimembranosus (SM) fresh, vacuum packaged steaks. HB LD muscles frequently were visually brighter purplish-red than other treatments. Compared to ESHB, ES LD was not different, but ES SM was darker. Reflectance indicators of reduced myoglobin and metmyoglobin were essentially the same across treatments in both muscles. Vacuum packaged fresh beef steaks from all treatments were acceptable in color at 0, 3, 7 and 14 days of display.

Introduction

Packaging retail cuts in oxygen permeable film like polyvinylchloride is well established and used throughout the industry. Use of oxygen permeable film promotes formation of a desirable, bright cherry red muscle color that consumers associate with freshness. However, in oxygen permeable film, beef color deteriorates rather rapidly and the growth of spoilage organisms is permitted which limits shelflife (Landrock and Wallace, 1955).

Vacuum packaging in oxygen impermeable film is relatively new and is primarily used for packaging primal and sub-primal cuts. This system severely limits available oxygen and suppresses growth of spoilage organisms (Kraft and Ayres, 1952; Jaye et al., 1962). Vacuum packaged pork loins had less surface discoloration and lower bacterial counts than polyvinylchloride wrapped loins (Smith et al., 1974). Vacuum packaged loins were still acceptable at 21 days and produced highly acceptable retail cuts in appearance, odor, and bacterial counts evaluated at 7 days after cutting (2C storage). Vacuum packaged wholesale beef cuts maintained an acceptable product for at least 15 days (Hodges et al., 1974). Pierson et al. (1970) found that anaerobically packaged beef top round steaks stored for 10 days were comparable to fresh beef in color, odor, and flavor, but aerobically packaged beef was unacceptable after 4 days of storage.

When ES affects longissimus dorsi color of ribbed beef carcasses or beef steaks wrapped in oxygen permeable film, it is in a favorable direction (Smith et al., 1977; Savell et al., 1978; Hall et al., 1980).

However, HB results in darker colored muscle when excised too early postmortem (Kastner et al., 1973).

Our objectives were to determine the effects of ES, HB, and their combination on muscle color display life of fresh, vacuum packaged beef steaks.

Materials and Methods

Forty-eight crossbred steers sired by 7/8 Simmental x 1/8 Hereford or Angus bulls out of crossbred dams were obtained from the R.L. Hruska US Meat Animal Research Center in Clay Center, Nebraska. The cattle were about eight months old and averaged 263 kg when placed on a feeding trial at Kansas State University.

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Cattle were slaughtered at the Kansas State University meat laboratory. Carcasses ranged from a group mean yield grade of 2.2 to 3.1, a quality grade of Good 21% to Good 95%, and had average

carcass weights of 262 kg (ACC 1), 309 kg (ACC 2), 351 kg (ACC 3), and 358 kg (CONV).

After each animal was euthanized, bleeding time was used as time zero for all treatments. Each side was assigned to one of four treatments in a completely randomized block design: control (C), electrical stimulation (ES), hot boning (HB), or electrical stimulation plus hot boning (ESHB).

The C sides were chilled at 5C for 48 hr postmortem. ES was applied through stainless steel probes, one inserted in the inside round about 8 cm below the attachment of the achilles tendon and the other laterally along the humerus. Sides were stimulated 45 min postmortem with 400 to 600 volts of alternating current (60 hertz and .6 amp delivered through the carcass) for 2 min with a sequence of 1.6 sec on and .8 sec off and chilled until 24 hr postmortem at 5C. The longissimus (LD) and semimembranosus (SM) muscles from the HB and ESHB sides were excised 2 hr postmortem and stored until 24 hr postmortem at 2C in an oxygen impermeable bag.

After chilling, a LD steak (2.5 cm) was cut from the posterior portion (over 2nd to 3rd lumbar vertebrae) of the LD and a SM steak (2.5 cm) was cut from the distal section of the SM. Steaks were vacuum packaged with a Bivac 1 packager using surlyn-saran, 3.3 mil base and a 5.2 mil top web. Steaks were stored in the dark 6 days at 5C prior to display to allow for color development.

Fresh, vacuum packaged steaks were displayed at about 2 to 4C under General Electric Natural fluorescent (40 watt) lighting providing 1076 lumens/m^2 continuously (24 hr/day) at the meat surface.

Visual appraisal (four member panel) and reflectance spectrophotometry were used to evaluate muscle color on days 0, 3, 7 and 14 of display. Visual scores were estimated to the nearest 0.5 on a five point scale: 1=bright purple red, 2=dull purple red, 3=slightly brownish purple red, 4=brownish purple red, and 5=brown. Reflectance at 474, 525, 580, and 630 nm were measured using a Bausch and Lomb 600 reflectance spectrophotometer adjusted to 100% reflectance with a $MgCO_3$ block. Reflectance values were used to indicate reduced myoglobin (%R474 nm/%R525 nm), metmyoglobin (%R630 nm/%R525 nm), and oxymyoglobin (%R630 nm-%R580 nm). Additionally, the reflectance values corresponding to 474 nm and 525 nm were converted to K/S values according to procedures outlined by Francis and Clydesdale (1975). The ratio K/S 474 nm / K/S 525 nm was calculated to estimate percent reduced myoglobin (Snyder, 1965).

Results and Discussion

Visual color scores (Table 1) for HB LD and SM steaks were frequently lower (brighter purple red) than for other treatments. ES LD steaks were visually the same ($P > 0.05$) as ESHB LD steaks, whereas ES SM steaks were darker ($P < 0.05$) than ESHB SM steaks at all display times. ES steaks were not different ($P > 0.05$) than C steaks for the LD or SM, except on day 14 in which ES SM steaks were visually darker ($P < 0.05$) than C SM steaks.

Measurements of reduced myoglobin and metmyoglobin indicated these chemical states were uniform across treatments in both muscles. ES LD steaks tended to have more oxymyoglobin than C LD steaks, whereas ES SM

Table 1. Effects of electrical stimulation and hot boning on the visual color score[d] and reflectance measurements of unfrozen vacuum packaged beef steaks

	Carcass Treatments[e]							
Day	C	ES	HB	ESHB	C	ES	HB	ESHB
	Visual Color Score							
	Longissimus				Semimembranosus			
0	1.2[b]	1.2[b]	1.0[a]	1.1[ab]	1.5[b]	1.5[b]	1.2[a]	1.3[a]
3	1.4[a]	1.4[a]	1.2[a]	1.4[a]	1.7[bc]	1.9[c]	1.5[a]	1.6[ab]
7	1.6[b]	1.7[b]	1.4[a]	1.5[b]	2.1[c]	2.1[c]	1.7[a]	1.9[b]
14	2.1	2.0	1.9	2.1	2.6[b]	2.8[c]	2.3[a]	2.5[b]
	%R474 nm/%R525 nm							
0	1.59	1.60	1.60	1.60	1.60	1.59	1.61	1.60
3	1.60	1.61	1.59	1.62	1.62[b]	1.61[ab]	1.58[a]	1.59[ab]
7	1.59	1.61	1.57	1.55	1.62	1.59	1.59	1.60
14	1.59	1.58	1.59	1.59	1.62[b]	1.56[a]	1.60[ab]	1.58[ab]
	%R630 nm/%R525 nm							
0	2.24	2.29	2.27	2.26	2.37	2.37	2.33	2.37
3	2.27	2.25	2.26	2.23	2.38[b]	2.38[b]	2.33[ab]	2.32[a]
7	2.21	2.21	2.20	2.16	2.32	2.31	2.26	2.30
14	2.24	2.24	2.28	2.26	2.45[b]	2.36[ab]	2.39[ab]	2.33[a]
	%R630 nm-%R580 nm							
0	15.8[a]	17.3[b]	16.0[a]	16.5[ab]	16.3[b]	16.6[b]	14.6[a]	15.1[a]
3	16.4[ab]	17.2[b]	16.2[a]	16.8[ab]	16.3[bc]	16.4[c]	15.2[a]	15.6[ab]
7	16.5[a]	17.4[b]	16.5[a]	17.0[ab]	16.4[b]	16.7[b]	15.5[a]	16.0[ab]
14	15.6	16.3	15.6	15.9	15.6	15.5	15.2	15.1

[abc]Means for the same muscle and row with the same or no superscript letter are not different ($P > 0.05$).

[d]Visual color score: 1=bright red, 2=dull purple red, and 3=slightly brownish purple red.

[e]C=control, ES=electrical stimulation, HB=hot boning, and ESHB=electrical stimulation plus hot boning.

steaks were not different ($P > 0.05$) than C SM steaks. HB steaks tended to have lower indications of oxymyoglobin compared to ES and C steaks which suggests more of the remaining pigment could be in the reduced form.

Since vacuum packaging removes oxygen and reduces its partial pressure, the primary chemical state of myoglobin likely is purple red, reduced myoglobin. HB muscles were mostly brighter purplish-red than muscles from conventionally handled carcasses. Working on the same carcasses and muscles, Bowles (1981) found that HB muscles had slightly faster temperature declines than those cold boned at 48 hr. The faster temperature decline may have caused a conservation effect on the reducing pathways in the muscle. In Chapter III, it was proposed that HB muscles may have a greater reducing capacity in a polyvinylchloride (oxygen permeable) packaging system. However, in vacuum packaged muscle, evidence of this conservation was not supported by reflectance measures of reduced myoglobin, as there were mostly no differences between treatments.

Although HB muscles tended to have darker pigment, these muscles were more purplish-red, indicative of more reduced myoglobin. Yet, ES muscles appeared faded and lighter colored. These differences may be due to a more rapid drop in pH and subsequent changes in the water holding capacity. This applies particularly well to the SM, as the ES SM deep within the round muscles of the hindquarter would have a higher temperature at a given pH than C or HB muscles. HB SM muscles were more rapidly chilled (Bowles, 1981), thereby possibly preserving the muscle cell membrane integrity and hydrophilic nature of proteins

and other constituents. In cold-boned muscle, the inner portion of the SM that was set deep within the muscles of the round was lighter in color than the outer portion. However, in HB muscle this difference was not as severe and this observation is supported by Taylor et al. (1980).

Savell et al. (1979), Dutson et al. (1980), and Judge et al. (1980) proposed that ES improves the tenderness of muscles by a direct physical disruption or by some chemical effect on the muscle or connective tissue. Consequently, the tenderness improvement of ES may be associated with a more open muscle structure, which in turn may result in greater reflective properties of the muscle causing it to appear lighter.

Few differences existed between treatments in reflectance measures of reduced myoglobin and metmyoglobin. Pierson et al. (1970) studied the initial pigment change at 3.3C of anaerobically packaged beef. They determined that the oxymyoglobin content of freshly vacuum packaged SM steaks rapidly decreased and was negligible after 4 hr. During the oxymyoglobin decline, both metmyoglobin and reduced myoglobin increased and at about 4 hr metmyoglobin peaked and then declined until no longer measurable after 8 hr. Reduced myoglobin continued to increase until 100% of the pigment was in this state (8 hr). Reduced myoglobin content of anaerobically packaged sliced beef remained very constant (100%) throughout a 15 day storage period.

In comparison to what was observed in polyvinylchloride packaged steaks (Chapter III), muscle color of vacuum packaged unfrozen beef steaks appeared to be much more uniform across treatment groups. Also, vacuum packaging provided a more stable color with display time which

agrees with what Pierson et al. (1970) found in anaerobically packaged beef steaks. Vacuum packaged retail cuts also have the advantage of being more microbially stable and consequently result in a longer shelf-life compared to cuts packaged in oxygen permeable film (Kraft and Ayres, 1952; Smith et al., 1974). If consumers were properly introduced to the purplish-red color of vacuum packaged beef and would accept it, then this packaging system could be used to extend the shelf-life of unfrozen beef. Besides consumer acceptance and the cost of vacuum packaging, a major disadvantage is the lack of a visual indicator of freshness to assess microbial and/or organoleptic soundness. Also, with extended display time, some off odors have been observed upon opening the package (Sutherland et al., 1976).

Summary

In conclusion, although subtle visual differences in muscle color were observed, few differences were found in the reflectance indicators of reduced myoglobin, metmyoglobin, and oxymyoglobin. Additionally, regardless of treatment, muscle color was acceptable at all display times.

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CHAPTER V

EFFECTS OF BEEF CARCASS ELECTRICAL STIMULATION AND HOT BONING ON MUSCLE DISPLAY COLOR OF VACUUM PACKAGED FROZEN STEAKS

ABSTRACT

Ninety-six beef carcass sides were used to determine effects of control (C, chilled 48 hr at 5C), electrical stimulation (ES, 45 min postmortem, 400 volts for 2 min, intermittently pulsed), hot boning (HB, 2 hr postmortem), and combination (ESHB) treatments on muscle color of longissimus (LD) and semimembranosus (SM) vacuum packaged frozen steaks. Although mostly not different, both HB (SM) and ES (LD and SM) steaks tended to be brighter purplish-red than C counterpart steaks. Few differences were observed in reflectance indicators of reduced myoglobin and metmyoglobin. HB LD steaks mostly had more oxymyoglobin than C steaks. Frozen steaks were mottled in appearance rendering reflectance measurements somewhat unreliable.

Introduction

The major function of a meat package is to present the product to the consumer in the most attractive manner possible, in addition to protecting the product from physical damage, microbial spoilage, and chemical deterioration (Mills and Urbin, 1960). Frozen meat has several advantages over cuts displayed in the fresh state. Sandberg (1970) stated that fresh meat color is relatively stable for about 72 hr and beyond this time, oxidative color changes begin to occur. Sandberg also pointed out that fresh packaged meat compared to frozen product is more subject to bacterial discoloration and spoilage, which greatly reduces its shelf-life. Since frozen meat is less perishable, this would facilitate centralized processing and distribution. However, there are some problems with freezing such as two toning of cuts, partial discoloration of muscles, ice crystal formation, desiccation (bleaching) and frost accumulation in packages (Sandberg, 1970).

Much research has been done on the effects of freezing and frozen storage on muscle color (Kropf, 1971; Ledward and Macfarlane, 1971; Hunt et al., 1975). However, little is known about the effects of electrical stimulation and hot boning on the color of frozen meat. Electrical stimulation has been shown to improve muscle color at the carcass level and in fresh (unfrozen) retail cuts (Smith et al., 1977; Cross et al., 1979; Hall et al., 1980). However, hot boning results in some muscle darkening if muscles are excised and chilled too early postmortem (Kastner et al., 1973; Henrickson et al., 1974).

Our objectives were to determine the effects of electrical stimulation and hot boning on muscle color of vacuum packaged frozen beef steaks.

Materials and Methods

Forty-eight crossbred steers sired by 7/8 Simmental x 1/8 Hereford or Angus bulls out of crossbred dams were obtained from the R.L. Hruska US Meat Animal Research Center in Clay Center, Nebraska. The cattle were about eight months old and averaged 263 kg when placed on a feeding trial at Kansas State University.

Cattle were fed ad libitum under one of two feeding regimens. First, three accelerated groups (ACC) were stepped-up to a finishing diet over a 58 day period. The final diet (dry matter basis) consisted of 9.6% forage sorghum silage, 84.4% corn, and 6.0% protein and mineral supplement. ACC cattle were slaughtered in three groups after reaching either 441 kg (139 days, ACC 1), 494 kg (178 days, ACC 2), or 560 kg (242 days, ACC 3). Secondly, the conventionally fed cattle were fed a high roughage diet for 110 days, followed by a 21 day pre-finishing adjustment phase and then finished on the same diet as the ACC groups. These cattle were slaughtered after 284 days at a mean live weight of 596 kg.

Cattle were slaughtered at the Kansas State University meat laboratory. Carcasses ranged from a group mean yield grade of 2.2 to 3.1, a quality grade of Good 21% to Good 95%, and had average carcass weights of 262 kg (ACC 1), 309 kg (ACC 2), 351 kg (ACC 3), and 358 kg (CONV).

After each animal was euthanized, bleeding time was used as time zero for all treatments. Each side was assigned to one of four treatments in a completely randomized block design: control (C), electrical stimulation (ES), hot boning (HB), or electrical stimulation plus hot boning (ESHB).

The C sides were chilled at 5C for 48 hr postmortem. ES was applied through stainless steel probes, one inserted in the inside round about 8 cm below the attachment of the achilles tendon and the other laterally along the humerus. Sides were stimulated 45 min postmortem with 400 to 600 volts of alternating current (60 hertz and .6 amp delivered through the carcass) for 2 min with a sequence of 1.6 sec on and .8 sec off and chilled until 24 hr postmortem at 5C. The longissimus (LD) and semimembranosus (SM) muscles from the HB and ESHB sides were excised 2 hr postmortem and stored until 24 hr postmortem at 2C in an oxygen impermeable bag.

After the cold storage period, one steak (2.5 cm) was cut from both the LD and SM muscles. The LD steaks were cut from over the 13th thoracic vertebral location and the SM steaks were cut from the proximal portion of the muscle. Steaks were vacuum packaged with a Bivac 1 packager using surlyn-saran, 3.3 mil base and a 5.2 mil top web. Steaks were stored in the dark for 48 hr at 2C prior to being blast frozen at -26C to allow for color development and then stored for 4 days (in dark) at -26C before being displayed.

Frozen vacuum packaged steaks were displayed at about -26C under General Electric Natural fluorescent (40 watt) lighting providing 1076 lumens/m^2 continuously (24 hr/day) at the meat surface.

Visual appraisal (four member panel) and reflectance spectrophotometry were used to evaluate muscle color on days 0, 3, 7 and 14 of display. Visual scores were estimated to the nearest 0.5 on a five point scale: 1=bright purple red, 2=dull purple red, 3=slightly brownish purple red, 4=brownish purple red, and 5=brown. Reflectance at 474, 525, 580, and 630 nm were measured using a Bausch and Lomb 600 reflectance spectrophotometer adjusted to 100% reflectance with a $MgCO_3$ block. Reflectance values were used to indicate reduced myoglobin (%R474 nm/%R525 nm), metmyoglobin (%R630 nm/%R525 nm), and oxymyoglobin (%R630 nm-%R580 nm). Additionally, the reflectance values corresponding to 474 nm and 525 nm were converted to K/S values according to procedures outlined by Francis and Clydesdale (1975). The ratio K/S 474 nm / K/S 525 nm was calculated to estimate percent reduced myoglobin (Snyder, 1965).

Results and Discussion

Visual color scores (Table 1) for HB LD and SM steaks were not different ($P > 0.05$) than C steaks at all display times except on day 14, when the HB SM steaks were brighter purple red ($P < 0.05$). Although HB SM steaks were not different ($P > 0.05$) on days 0, 3 and 7, HB SM steaks tended to be brighter than C SM steaks. ES LD and SM steaks were brighter ($P < 0.05$) than C steaks on day 3 but were not different ($P > 0.05$) on days 0, 7 and 14 of display. HB steaks were similar in muscle color to ESHB steaks at all display times. This suggests that regardless of treatment, freezing provided a relatively uniform colored product across different processing techniques. This generalization

Table 1. Effects of electrical stimulation and hot boning on the visual color score[c] and reflectance measurements of frozen vacuum packaged beef steaks

	Carcass Treatments[d]							
Day	C	ES	HB	ESHB	C	ES	HB	ESHB
	Visual Color Score							
	Longissimus				Semimembranosus			
0	1.8	1.7	1.8	1.7	2.0	1.9	1.9	1.9
3	2.1[b]	1.9[a]	2.0[ab]	1.9[ab]	2.3[b]	2.1[a]	2.2[ab]	2.3[b]
7	2.2	2.1	2.3	2.2	2.5	2.4	2.2	2.4
14	2.5	2.5	2.6	2.5	2.7[b]	2.7[b]	2.5[a]	2.6[ab]
	%R474 nm/%R525 nm							
0	1.47	1.45	1.47	1.48	1.43	1.41	1.42	1.43
3	1.46	1.46	1.45	1.45	1.45	1.44	1.43	1.41
7	1.46	1.43	1.43	1.48	1.41	1.39	1.44	1.40
14	1.39	1.40	1.37	1.42	1.37	1.35	1.39	1.41
	%R630 nm/%R525 nm							
0	2.40[ab]	2.37[a]	2.44[ab]	2.47[b]	2.32[a]	2.52[b]	2.45[ab]	2.37[ab]
3	2.37	2.44	2.42	2.44	2.42	2.46	2.42	2.36
7	2.52[b]	2.31[a]	2.38[ab]	2.43[ab]	2.29[a]	2.35[ab]	2.48[b]	2.29[a]
14	2.26	2.28	2.20	2.31	2.29	2.28	2.24	2.34
	%R630 nm-%R580 nm							
0	14.6[a]	14.7[a]	17.0[b]	15.8[ab]	12.3[a]	14.1[b]	13.3[ab]	13.6[b]
3	14.7	15.0	16.6	15.1	13.7	14.0	13.7	13.3
7	13.9[a]	13.9[a]	15.6[b]	15.1[ab]	12.4	12.7	12.9	12.6
14	13.3[a]	13.9[ab]	14.9[b]	14.3[ab]	12.7	13.0	12.6	12.0

[ab]Means for the same muscle and row with same or no superscript letter are not different ($P > 0.05$).

[c]Visual color score: 1=bright purple red, 2=dull purple red, and 3=slightly brownish purple red.

[d]C=control, ES=electrical stimulation, HB=hot boning, and ESHB= electrical stimulation plus hot boning.

was supported by the reflectance measurements %R474 nm/%R525 nm and %R630 nm/%R525 nm which are indicators of reduced myoglobin and metmyoglobin, respectively. HB LD steaks had a greater difference value ($P < 0.05$) for %R630 nm-%R580 nm (indicating more oxymyoglobin) than C steaks on days 0, 7 and 14 of display but was not different ($P > 0.05$) than C steaks on day 3. The HB SM steaks were not different ($P > 0.05$) than C steaks in %R630 nm-%R580 nm. In Chapter IV, the fresh vacuum packaged HB LD steaks were not different than C steaks while the HB SM steaks had smaller difference values (less oxymyoglobin) than C steaks.

Some of the discrepancy was no doubt due to the problems associated with measuring the muscle color of frozen product. The surface of frozen steaks was irregular in shape which led to some difficulty in positioning the steak surface flush against the viewing port of the spectrophotometer. Because of the irregular nature of the steak surface, this also altered the focal length of the light path from the sample surface to the recording mechanism of the spectrophotometer which would add to the variability in the color determination.

Another problem with determining the muscle color of frozen product was two toning of the cut surface with areas that appeared bleached or faded. This particular phenomenon was also observed and described by Sandberg (1970). This mottled appearance made reflectance measurements quite unreliable because of the uncertainty of where the color measurement was actually taken. Additionally, when relating reflectance data to visual scores, the fact that visual appraisal was determined as an overall average of the entire surface rather than as

one small, presumably representative area, as measured with the spectrophotometer, these comparisons should be made with some reserve. Therefore, because of the problems associated with reflectance measurements of frozen muscle color, most emphasis should be given to the visual color scores.

Summary

In summary, there were few significant differences in the visual color of steaks among treatments. Furthermore, additional research is needed to determine how best to utilize reflectance spectrophotometry for a color measurement system on frozen meat.

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APPENDIX

Appendix Table 1. Treatment[a] significance for visual color score.

Day	Longissimus	Semimembranosus
	Polyvinylchloride	
0	ES	HB
1	ES,HB	HB
3	all	HB,ESHB
5	ES,HB	ESHB
	Unfrozen Vacuum Packaged	
0	HB	HB
3	--	ES,HB
7	ES,HB	HB
14	--	ES,HB
	Frozen Vacuum Packaged	
0	--	--
3	ES	ESHB
7	--	--
14	--	HB

[a]Where treatment listed (C, ES, HB or ESHB), significant at $P < 0.05$ (Analysis of Variance).

Appendix Table 2. Treatment[a] significance for reflectance

	Longissimus				Semimembranosus			
	Polyvinylchloride							
	Day				Day			
Reflectance	0	1	3	5	0	1	3	5
%R630 nm-%R580 nm	ES,HB	ES,ESHB	all	all	HB	HB	HB	HB
%R580 nm/%R525 nm	ES	HB	ES,HB	HB	HB	HB,ESHB	HB	--
%R474 nm/%R525 nm	ES	HB	--	--	--	HB	HB	HB
%R630 nm/%R525 nm	ES	HB	ESHB	HB	HB	HB,ESHB	HB,ESHB	HB
K/S 474 nm / K/S 525 nm	ES	HB	--	--	--	HB,ESHB	HB	HB
	Unfrozen Vacuum Packaged							
	Day				Day			
Reflectance	0	3	7	14	0	3	7	14
%R630 nm-%R580 nm	ES	ES	ES	--	HB	HB	HB	--
%R580 nm/%R525 nm	ES	ES	--	--	--	--	--	--
%R474 nm/%R525 nm	--	--	--	--	--	HB	--	ES
%R630 nm/%R525 nm	--	--	--	--	--	HB	--	ES
K/S 474 nm / K/S 525 nm	--	ES	--	--	--	HB	--	--

Appendix Table 2. (Continued)

	Longissimus				Semimembranosus			
	Frozen Vacuum Packaged							
	Day				Day			
Reflectance	0	3	7	14	0	3	7	14
%R630 nm-%R580 nm	HB	--	HB	HB	ES	--	--	--
%R580 nm/%R525 nm	--	--	--	--	--	--	--	--
%R474 nm/%R525 nm	--	--	--	--	--	--	--	--
%R630 nm/%R525 nm	HB	--	ESHB	--	ESHB	--	ESHB	--
K/S 474 nm / K/S 525 nm	--	--	--	--	--	--	--	--

[a]Where treatment listed (C, ES, HB or ESHB), significant at $P < 0.05$ (Analysis of Variance).

Appendix Table 3. Effects of electrical stimulation and hot boning on the reflectance ratio of %R580 nm/%R525 nm[c] of beef steaks packaged and displayed by three different systems

	Carcass Treatments[d]							
Day	C	ES	HB	ESHB	C	ES	HB	ESHB
	Polyvinylchloride							
	Longissimus				Semimembranosus			
0	.670[ab]	.645[a]	.682[b]	.642[a]	.677[ab]	.648[a]	.690[b]	.681[b]
1	.656[a]	.669[a]	.717[b]	.699[ab]	.666[a]	.691[a]	.733[b]	.696[ab]
3	.686[a]	.670[a]	.739[b]	.692[a]	.690[a]	.696[a]	.732[b]	.701[a]
5	.719[ab]	.711[a]	.746[b]	.730[ab]	.701	.722	.742	.721
	Unfrozen Vacuum Packaged							
0	.813[b]	.797[a]	.807[ab]	.803[ab]	.826	.820	.826	.827
3	.812[b]	.813[ab]	.799[a]	.802[ab]	.824	.821	.830	.826
7	.814	.821	.812	.790	.826	.821	.829	.825
14	.823	.824	.833	.822	.838	.839	.852	.832
	Frozen Vacuum Packaged							
0	.888	.880	.881	.888	.910	.912	.909	.897
3	.889	.889	.887	.904	.915	.912	.889	.909
7	.912	.884	.912	.878	.938[a]	.908[ab]	.901[a]	.882[a]
14	.924	.921	.927	.919	.921	.917	.940	.963

[ab]Means for the same packaging system, muscle, and row with the same or no superscript letter are not different ($P > 0.05$).

[c]Lower ratio indicates more oxymyoglobin.

[d]C=control, ES=electrical stimulation, HB=hot boning, and ESHB= electrical stimulation plus hot boning.

Appendix Table 4. Effects of electrical stimulation and hot boning[d] on the reflectance ratio of K/S 474 nm / K/S 525 nm of beef steaks packaged and displayed by three different systems

	Carcass Treatments[e]							
Day	C	ES	HB	ESHB	C	ES	HB	ESHB
	Polyvinylchloride							
	Longissimus				Semimembranosus			
0	.893[a]	.939[b]	.907[ab]	.938[b]	.944	.966	.908	.946
1	.972[b]	.946[ab]	.910[a]	.914[a]	1.010[c]	.961[bc]	.910[a]	.933[ab]
3	.960	.942	.954	.967	.966[b]	.979[b]	.924[a]	.960[b]
5	.915	.957	.926	.916	.983[b]	.946[ab]	.923[a]	.928[a]
	Unfrozen Vacuum Packaged							
0	.539	.528	.539	.535	.545	.546	.540	.547
3	.534[ab]	.524[a]	.538[b]	.522[a]	.532[a]	.537[ab]	.553[c]	.545[bc]
7	.537	.513	.546	.560	.528	.540	.545	.539
14	.540	.543	.541	.538	.536	.560	.546	.556
	Frozen Vacuum Packaged							
0	.613	.624	.604	.607	.647	.662	.653	.636
3	.621	.618	.616	.623	.629	.634	.642	.651
7	.629	.636	.635	.608	.661	.686	.641	.657
14	.662	.654	.666	.642	.680	.710	.669	.655

[abc]Means for the same packaging system, muscle, and row with the same or no superscript letter are not different ($P > 0.05$).

[d]Lower ratio indicates a higher percentage of reduced myoglobin.

[e]C=control, ES=electrical stimulation, HB=hot boning, and ESHB= electrical stimulation plus hot boning.

Appendix Table 5. Correlation between visual color score and selected reflectance values

	Longissimus				Semimembranosus			
	Polyvinylchloride							
	Day				Day			
Reflectance	0	1	3	5	0	1	3	5
%R630 nm-%R580 nm	-.23*	-.16	-.35**	-.26**	-.28**	-.51**	-.59**	-.59**
%R580 nm/%R525 nm	.41**	.30**	.26*	.47**	.44**	.48**	.49**	.47**
%R474 nm/%R525 nm	.36**	.27**	.33**	.42**	.31**	.36**	.34**	.27**
%R630 nm/%R525 nm	-.39**	-.26*	-.27**	-.36**	-.29**	-.53**	.41**	-.43**
K/S 474 nm / K/S 525 nm	-.35**	-.27**	-.31**	-.35**	-.30**	-.36**	-.36**	-.27**
	Unfrozen Vacuum Packaged							
	Day				Day			
Reflectance	0	3	7	14	0	3	7	14
%R630 nm-%R580 nm	.17	.36**	.43**	.09	.12	-.11	.10	-.22*
%R580 nm/%R525 nm	-.10	-.41**	-.28**	.05	.20*	.05	-.07	.28**
%R474 nm/%R525 nm	.17	.08	-.19	-.32**	.19	.25*	.13	-.27**
%R630 nm/%R525 nm	.06	-.16	-.24*	-.14	.18	.22*	.16	.24*
K/S 474 nm / K/S 525 nm	-.25*	-.27**	.17	.20	-.15	-.15	-.14	.34**

Appendix Table 5. (Continued)

	Longissimus				Semimembranosus			
	Frozen Vacuum Packaged							
	Day				Day			
Reflectance	0	3	7	14	0	3	7	14
%R630 nm-%R580 nm	-.21*	.13	-.25*	-.08	-.11	.16	.14	-.06
%R580 nm/%R525 nm	.03	-.00	-.03	.09	.05	-.16	-.05	-.04
%R474 nm/%R525 nm	-.35**	-.07	-.13	-.33**	-.20	-.13	-.27**	-.29**
%R630 nm/%R525 nm	-.09	.12	.14	.08	.20	.13	.26**	.23*
K/S 474 nm / K/S 525 nm	.34**	.06	.22*	.32**	.19	.11	.31**	.31**

* $P < 0.05$.

** $P < 0.01$.

Appendix Table 6. Slaughter group[f] and treatment[g] interactions on the visual color score of displayed semimembranosus steaks

Slaughter group * HB

Unfrozen Vacuum Packaged Steaks

	Day 0		Day 7		Day 14	
	NHB	HB	NHB	HB	NHB	HB
ACC 1	1.1^{a}	1.1^{a}	1.7^{bc}	1.5^{a}	2.7^{c}	2.5^{b}
ACC 2	1.8^{c}	1.0^{a}	2.4^{e}	1.8^{c}	3.1^{d}	2.7^{bc}
ACC 3	1.5^{b}	1.5^{b}	2.2^{de}	2.1^{d}	2.5^{b}	2.5^{bc}
CONV	1.5^{b}	1.4^{b}	2.1^{d}	1.6^{ab}	2.5^{b}	2.0^{a}

Slaughter group * ES

Frozen Vacuum Packaged Steaks

	Day 0		Day 3	
	NES	ES	NES	ES
ACC 1	2.1^{de}	2.3^{e}	2.3^{bc}	2.5^{d}
ACC 2	2.3^{e}	2.1^{de}	2.4^{cd}	2.3^{bc}
ACC 3	1.7^{b}	1.5^{a}	2.4^{cd}	2.2^{ab}
CONV	1.9^{bc}	2.0^{cd}	2.0^{a}	2.3^{bc}

[abcde] Means within same packaging system and day with same superscript letter are not different ($P > 0.05$).

[f] ACC 1 = accelerated fed group 1 (4/15 and 16/80)
ACC 2 = accelerated fed group 2 (5/27 and 28/80)
ACC 3 = accelerated fed group 3 (7/28 and 29/80)
CONV = conventionally fed group (9/9 and 10/80).

[g] HB=hot boned, NHB=not hot boned, ES=electrically stimulated, and NES=not electrically stimulated.

Appendix Table 7. Slaughter group[d] and electrical stimulation[e] interactions on selected reflectance measurements of displayed polyvinylchloride packaged semimembranosus steaks

	%R474 nm/%R525 nm			
	Day 0		Day 5	
	NES	ES	NES	ES
ACC 1	1.00[a]	1.00[a]	1.02[a]	1.01[a]
ACC 2	1.04[a]	1.02[a]	.99[a]	1.00[a]
ACC 3	1.20[c]	1.09[b]	1.12[b]	1.09[b]
CONV	1.03[a]	1.05[ab]	1.04[a]	1.12[b]

	K/S 474 nm / K/S 525 nm			
	Day 0		Day 5	
	NES	ES	NES	ES
ACC 1	1.00[c]	1.00[c]	.97[b]	.99[b]
ACC 2	.96[bc]	.97[c]	1.00[b]	1.00[b]
ACC 3	.77[a]	.90[b]	.87[a]	.89[a]
CONV	.97[c]	.95[bc]	.96[b]	.86[a]

[abc]Means for same reflectance measurement and day with same superscript letter are not different ($P > 0.05$).

[d]ACC 1 = accelerated fed group 1 (4/15 and 16/80)
ACC 2 = accelerated fed group 2 (5/27 and 28/80)
ACC 3 = accelerated fed group 3 (7/28 and 29.80)
CONV = conventionally fed group (9/9 and 10/80).

[e]ES=electrically stimulated and NES=not electrically stimulated.

EFFECTS OF BEEF CARCASS ELECTRICAL STIMULATION AND HOT BONING ON MUSCLE DISPLAY COLOR OF UNFROZEN AND FROZEN STEAKS

BY

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B.S., University of Connecticut, 1980

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Sciences and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1982

Ninety-six sides from 48 U.S.D.A. Good and Choice grade carcasses were used to determine the effects of control (C), electrical stimulation (ES), hot boning (HB), and combined electrical stimulation and hot boning (ESHB) on muscle display color of polyvinylchloride (PVC) packaged steaks (Study I), and unfrozen (Study II) and frozen (Study III) vacuum packaged steaks. C sides were chilled at 5C until 48 hr postmortem. ES sides were stimulated 45 min postmortem with 400 to 600 volts of alternating current (60 hertz and .6 amp delivered through the carcass) for 2 min with a sequence of 1.6 sec on and .8 sec off and chilled until 24 hr postmortem at 5C. The longissimus (LD) and semimembranosus (SM) muscles from HB and ESHB sides were excised 2 hr postmortem and stored until 24 hr postmortem at 2C in oxygen impermeable bags. After cold storage, three steaks (2.5 cm each) were cut from the LD and SM muscles with one steak from each muscle packaged in PVC (displayed at 2 to 4C after a 2 hr bloom period), another vacuum packaged and displayed unfrozen (at 2 to 4C after a 6 day dark storage) and a third vacuum packaged (stored in dark, 48 hr postmortem at 2 to 4C and then frozen 96 hr at -26C) and displayed frozen (beginning at 6 days postmortem at -26C). Visual appraisal and reflectance spectrophotometry were used to evaluate muscle color on days 0, 1, 3 and 5 for PVC packaged steaks and on days 0, 3, 7 and 14 for vacuum packaged steaks. Reflectance was measured with a Bausch and Lomb 600 reflectance spectrophotometer. Reflectance values were taken at selected wavelengths and were used to indicate oxymyoglobin (%R630 nm-%R580 nm), metmyoglobin (%R630 nm/%R525 nm), and reduced myoglobin (%R474 nm/%R525 nm).

In Study I, HB steaks packaged in oxygen permeable PVC compared to C, ES, and ESHB steaks were generally darkest, had the least oxymyoglobin, and developed more metmyoglobin. Although ES steaks were mostly not different ($P > 0.05$) than C steaks, ES steaks tended to be brighter cherry red. Nevertheless, stimulation was sufficient to alleviate the undesirable effects of HB on muscle color. Regardless of treatment, muscle color was acceptable at all display times of this study and would not present any practical merchandizing problem.

In Study II, fresh vacuum packaged HB LD muscles were generally brighter (visual) purplish red than all other treatments. Compared to ESHB, ES LD was not different, but ES SM was darker purplish red. Even though subtle visual differences in muscle color were observed, few differences were found in the reflectance indicators of reduced myoglobin, metmyoglobin, and oxymyoglobin. Fresh vacuum packaged beef steaks were more uniform in color across different processing techniques and were more stable in color with display time than PVC packaged steaks.

In Study III, vacuum packaged frozen HB (SM) and ES (LD and SM) steaks tended to be brighter purplish red than C counterpart steaks. Frozen steaks were mottled in appearance, rendering reflectance measurements somewhat unreliable.