INTRINSIC FACTORS AFFECTING GROUND BEEF COLOR STABILITY

by

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B.S., Oklahoma State University, 2004
M.S., Kansas State University, 2006

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

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Abstract

Three experiments were conducted to evaluate factors affecting ground beef color stability with the objectives: 1) To characterize color characteristics of different ground muscles from similarly fed and managed cows and steers; 2) To evaluate the contributions different muscles make to overall ground beef color stability; and 3) To determine if cow biological type (beef-type vs. dairy-type) affects ground beef color dynamics.

In general, ground muscles from fed cows appeared darker and redder than ground muscles from steers. Chronological age did not affect ground beef color stability of muscles from fed cows. Use of steroid implants or β-agonists did not affect ground muscle color stability of fed steers or fed cows. Overall color stability varied more in muscle from steers than from fed cows. Fed cow muscles tended to have a greater proportion of saturated and mono-unsaturated fatty acids to poly-unsaturated fatty acids than fed steer muscles. Ground muscles from fed cows had better color stability properties than ground muscles from steer.

When muscles of various color stability were blended to make ground beef and packaged in high-oxygen modified atmosphere (**HiO_2 MAP**), high color stability muscles (≥ 75%) in formulations maximizes display color life; however, inclusion of low color stability muscles (≥ 25%) in ground beef formulations had deleterious effects on ground beef color life.

Ground *semimembranosus* (**SM**) from dairy cows exhibited darker initial color than ground SM from beef cows when packaged in HiO_2 MAP. However, ground SM from dairy cows was more color stable than ground SM from beef cows when packaged in HiO_2 MAP. Cow trim used as a fat source in ground beef formulations improved color stability compared to young beef trim when packaged in HiO_2 MAP.

Isolating and managing muscle sources enable meat processors to better manage ground beef based upon intrinsic factors affecting ground beef color stability.

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Major Professor
Melvin C. Hunt

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To all of my friends and family who have offered me their support, whether it be lending me a buck, a hand or a kind ear . . .

. . . ***I present my greatest thanks***
and offer my friendship.

Dedication

This dissertation is dedicated to all of my benefactors. Very often, awards and scholarships bearing your name are given and quickly forgotten. I have not forgotten. I have been incredibly fortunate to receive great financial support from people I have never met. That conveys so much about your investment in and support of humankind. This is all for you. Without you, *none* of this, none of my college education, could have *ever* been possible.

Thank you.

Preface

This manuscript is written according to the style guidelines of ***Meat Science***, a scientific journal encompassing the many facets of meat science research. Some slight deviations from the journal format occur, each with the intent of better communicating the contents of this dissertation.

Chapter I is a review of the literature pertaining to factors affecting ground beef color stability. **Chapters II**, **III**, and **IV** are research chapters. Chapter II is an investigation into the color properties of six muscles from similarly managed beef steers and cull cows. Chapter III attempts to identify the color contributions that muscles of various color stabilities make to the overall color life of ground beef. Chapter IV elucidates the color effects of lean from beef-type cows and dairy-type cows, and trim from young beef cattle and mature beef cattle, on ground beef color dynamics.

Animal Care and Use Note

The meat used for the research described in Chapter II, Chapter III, and Chapter IV of this dissertation were obtained postmortem. The principal investigators of the studies for which the living animal was being evaluated provided all production management information, including animal age, diet and other descriptors of the living animal. Therefore, the research included herein was not subject to approval by the Kansas State University Institutional Animal Care and Use Committee. Moreover, all meat researched to produce this dissertation was obtained from animals slaughtered according to the guidelines, regulations, and supervision of USDA.

CHAPTER I

Review of Literature

1. General Introduction

Beef's most important point-of-purchase characteristic is color; it serves as an indicator of freshness and wholesomeness to consumers and therefore, heavily influences their purchasing decisions. Ground beef is the single largest-tonnage red meat commodity traded in the United States and its raw materials are sourced from essentially every bovine slaughtered. Ground beef is usually manufactured from lower quality and less desirable beef. All beef muscles from typical slaughter-age cattle (USDA A-maturity) and from more mature cull cattle have been characterized, including color, relative size, and tenderness. ('Cull cow' refers to a female bovine that is removed from its herd and sold, most often due to reproductive inefficiency.) This information is essential to understanding and capitalizing upon the development of new or improved value-added meat cuts, and maximizing the marketability of existing cuts. As a result, beef carcass fabrication methods are changing, increasingly involving the isolation of individual muscles.

The beef industry has deeply invested in adding value to under-utilized or under-valued beef cuts, particularly those from cow carcasses. Optimum color management of ground beef is central to its profitability. A myriad of endogenous animal characteristics, including age, gender, breed and stress susceptibility, as well as many exogenous animal production practices, such as diet and housing system affect ultimate beef color. Non-invasive postmortem processes such as electrical stimulation, proper chilling, and packaging type affect beef color. Beef color life extension has also been achieved via the surface application and/or injection of antioxidants and/or color-stabilizing ingredients such as lactates. Two omnipresent factors fundamentally linked to all of these fresh meat properties are pH and temperature. Interactions between and among the aforementioned characteristics have been reported in the literature, and these factors and their role in the integrated beef supply chain shall be reviewed.

2. Myoglobin

2.1 Myoglobin structure

Myoglobin (**Mb**) is the primary protein responsible for perceived meat color. It is a globular protein found skeletal and cardiac muscle (Giddings, 1977; Livingston & Brown, 1981). Myoglobin possesses a heme ring, the central iron of which can form 6 bonds. Five of these 6 coordination sites are occupied, and the 6^{th} site can be reversibly bound with different ligands (Behkit & Faustman, 2005). The ligand present, in conjunction with the valance state of the heme iron, determines meat color. Four major chemical forms of Mb important to fresh meat color include: deoxymyoglobin (**DMb**), oxymyoglobin (**OMb**), metmyoglobin (**MMb**), and carboxymyoglobin (**COMb**). In the absence of a 6^{th}-site ligand while iron is in the ferrous (Fe^{++}) state, Mb is in its native DMb form (Mancini & Hunt, 2005). Deoxymyoglobin appears purplish-pink or purplish-red in color (Figure 1.1).

2.2 Myoglobin oxygenation, oxidation

When the heme ring 6^{th} coordination site is exposed to diatomic oxygen and the heme is in the ferrous (Fe^{++}) state, OMb develops. When meat comes into contact with oxygen (oxygenation), OMb is formed, which is characterized by a bright, cherry-red color (Behkit & Faustman, 2005). This oxygenation of meat is commonly referred to as 'blooming' (Figure 1.1). Over time, oxygen penetrates deeper into meat, forming a thicker outer layer of OMb (Figure 1.2). Both DMb and OMb can be oxidized to form MMb, which appears brown and is readily rejected by consumers. Metmyoglobin is the product of the oxidation of the ferrous iron (Fe^{++}) to the ferric (Fe^{+++}) state, and dependent upon the availability of cofactors and substrates, can be enzymatically reduced to ferrous Mb (Behkit & Faustman, 2005). Dean and Ball recognized natural MMb reducing systems in meat in 1960. Metmyoglobin does not accumulate *in vivo* (Giddings, 1974) because of MMb reduction. Oxymyoglobin and MMb formation is influenced by many factors, including pH, oxygen partial pressure, and meat metabolism.

2.3 Other reactions, forms of myoglobin

Reduction of MMb to DMb depends upon the muscles' inherent oxygen scavenging enzymes and reducing enzymes. Also critical to MMb reduction in meat is its NADH pool. Enzymatic activity and NADH availability is depleted over time in meat. Via a similar mechanism, OMb can be deoxygenated to DMb, but must oxidize to MMb en route (Figure 1.1).

Carboxymyoglobin is the 4th form of myoglobin and has not been as long understood or studied as a form of Mb to the extent of DMb, OMb, and MMb. Carboxymyoglobin is formed when carbon monoxide binds to the 6th coordination site of the heme iron in Mb, and the resulting cherry-red color is very similar to OMb (Figure 1.2). Generally, COMb is more stable than OMb. The use of carbon monoxide in the United States for the color management of meat color is in its infancy and its mechanisms and optimal use are not yet fully understood.

2.4 Visualizing the states of myoglobin

Diagramming the inter-conversions of the forms of Mb, the meat color triangle is featured in Figure 1.1. To illustrate the formation of layers of DMb, OMb, and MMb in whole-muscle meat cuts, a schematic is supplied in Figure 1.2.

3. Other integral factors affecting beef color and color stability

3.1 Meat pH

Meat color is fundamentally linked to meat pH, and many ante- and postmortem factors that affect color do so by affecting pH. The rate of pH decline and the ultimate pH of meat affect its appearance. Normal meat pH is 5.6 and appears cherry-red when bloomed. Lighter colored lean (within species) tends to have a pH < 5.6, whereas darker colored lean (within species) has a pH higher than 5.6, usually near 6.0 (Figure 1.3). During the conversion of muscle to meat, muscle uses glycogen to generate ATP and lactic acid is produced.

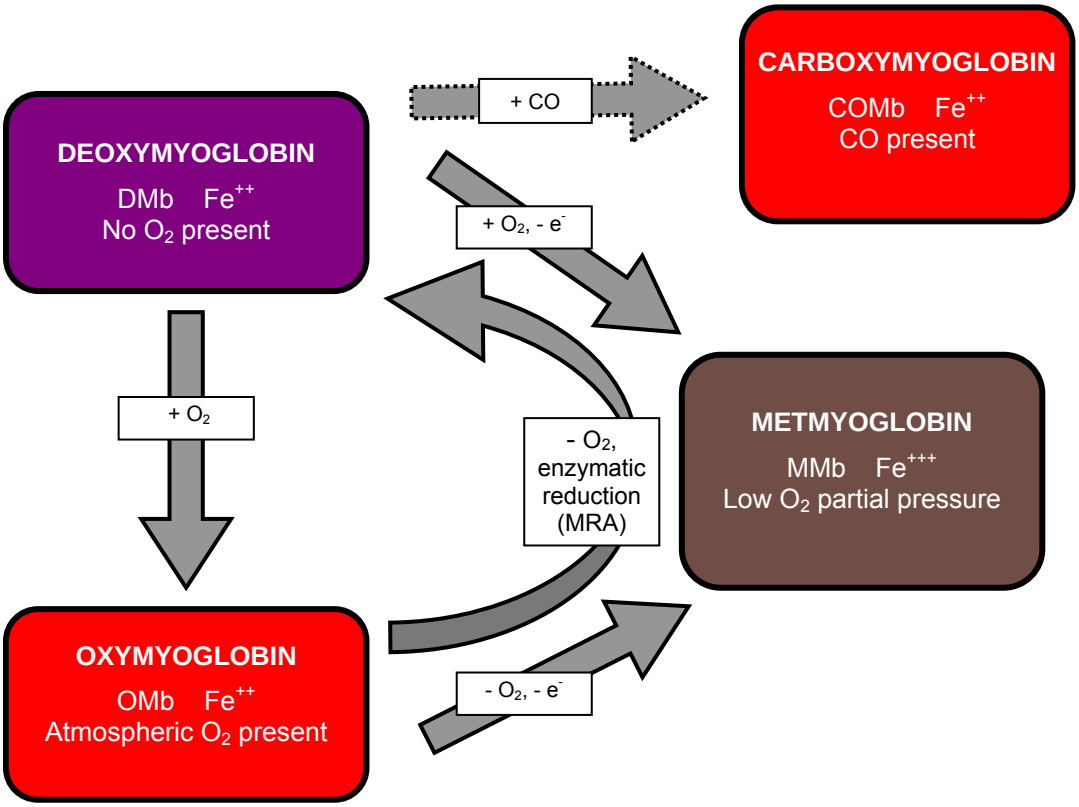

Figure 1.1. Development of myoglobin surface forms of meat

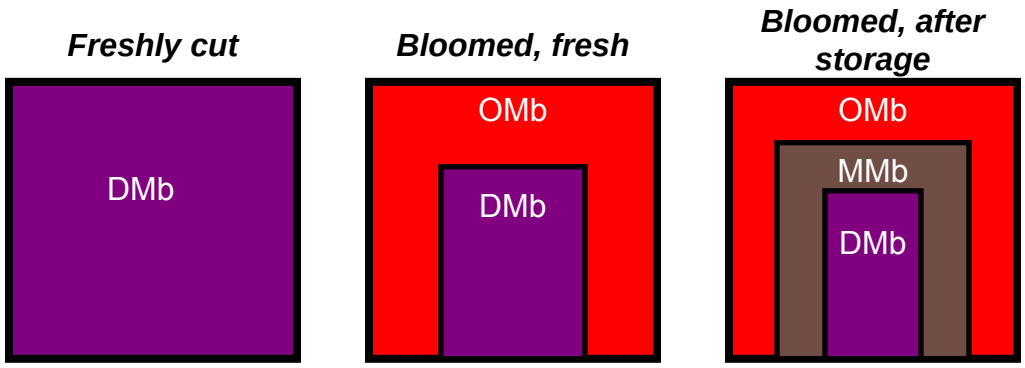

Figure 1.2. Illustration of within-muscle cross-sectional locations of myoglobin and its form in whole-muscle cuts (not to scale)

When meat pH is higher, meat is firmer and more rigid because more water is bound, producing a less porous and less oxygen-permeable meat surface. Darker lean color results because light scatter and OMb development is reduced (Lawrie, 1958). When meat pH is lower, meat is softer and has less water binding capacity, producing a more porous meat surface with increased surface water. Lighter lean color results because light scatter is greater due to greater surface water.

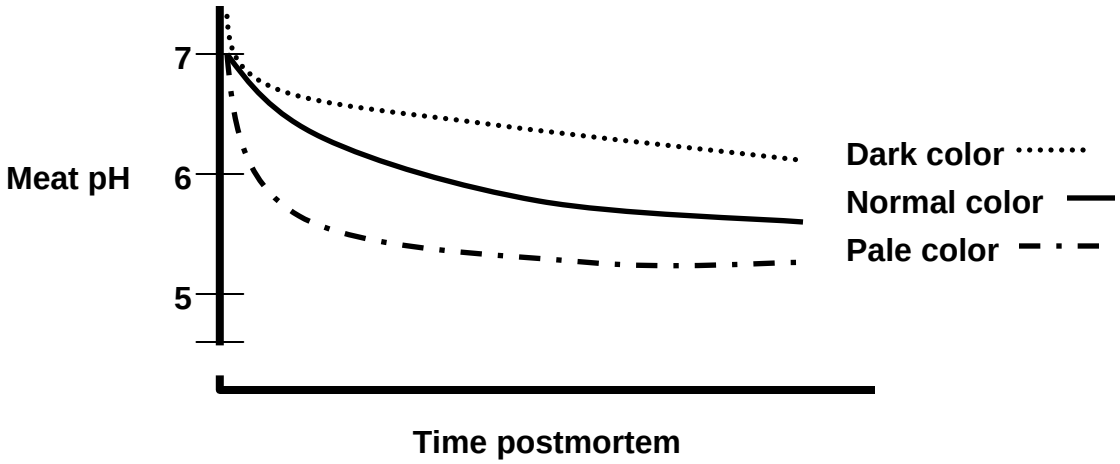

Figure 1.3 Postmortem pH decline pattern and associated meat color (Adapted from Briskey, 1964.)

Two major pH anomalies exist for meat: 1) Dark, firm and dry (**DFD**); and 2) Pale, soft and exudative (**PSE**). The DFD condition is linked to long-term antemortem stress exposure causing glycogen depletion, thereby reducing the extent of postmortem glycolysis possible, and the result is very dark maroon or purple meat. For DFD, water is very tightly bound in the muscle, lending DFD meat its dry appearance. The PSE condition is often linked to short-term antemortem stress, which causes more rapid postmortem glycolysis, and the result is very pale red (in pork and poultry, nearly white) meat. For PSE meat, water is essentially purged or released from the muscle, lending PSE meat it exudative or wet appearance.

3.2 Metmyoglobin reducing activity (MRA)

Because MMb does not accumuate *in vivo*, natural, inherent mechanism(s) for MMb reduction must exist. A NADH-dependent MMb reductase from bovine heart was isolated and elucidated by Hagler, Coppes and Herman (1979). The best-characterized reductant of MMb is NADH-cytochrome b_5 MMb reductase (Behkit & Faustman, 2005). Successful reduction of MMb to Mb by this enzyme depends on the extent of NADH-cytrochrome b_5 MMb reductase's presence, the intermediate (cytochrome b_5) and the cofactor NADH.

Postmortem MMb reductase activity is affected by many factors, including storage time temperature, and meat pH. Mikkelsen, Juncher and Skibsted (1999) observed that after 1 week of storage at -80 ºC, no MMb reductase activity was lost; however, 2 weeks of storage at -80 ºC resulted in a 14% decrease in MMb reductase activity. In that same study, higher reducing activity was observed in porcine *longissimus* was incubated at 25 ºC than when incubated at 10 ºC. Also, incubation at 37 ºC resulted in complete loss of MMb reductase activity. Metmyoglobin reducing activity increases with pH (Ledward, 1970), yet its reported optimal pH for maximal MMb reduction varies. While Hagler et al. (1979) reported pH 6.4 to be optimal for MMb reductase activity in beef, Behkit et al. (2001) reported pH 7.4 to be optimal for MMb reductase activity in lamb. Zhu and Brewer (1998) evaluated MMb reductase activity in normal, PSE and DFD pork, and found that differences in MMb reductase activity was affected by the rate and extend of postmortem, pre-rigor pH decline.

4. Antemortem factors affecting beef color

4.1 Diet, metabolic modifiers

Diet and animal growth rate affects beef quality characteristics, including beef color. Aberle, Reeves, Judge, Hunsley and Perry (1981) compared carcass characteristics of Angus-, Hereford-, and Charolais-sired beef steers fed a low-energy diet for up to 230 d or fed a high-energy diet for up to 210 d, and combinations thereof. The low-energy diet consisted of corn silage and ground corncobs; the high-energy diet

consisted of predominantly high-moisture corn. Cattle fed a low-energy diet for longer periods had darker subjective *longissimus* color, in addition to reduced marbling scores, than cattle fed the high-energy diet. No significant differences due to sire breed were observed.

Differences in lean color due to grain-feeding versus forage-feeding of cattle have been assessed. Wanatabe, Sato, Tsuneishi and Matsumoto (1993) reported that ultimate carcass pH of forage-fed cattle tends to be higher than the pH of grain-fed cattle. Accordingly, Vestergaard, Oksberg and Henckel (2000) suggested that forage-based diets promote oxidative muscle metabolism instead of anaerobic muscle metabolism, thereby leading to reduced glycogen storage ability and subsequently, a smaller postmortem pH decline. In their study, meat from bulls fed a limited forage-based diet had higher pH's and darker color than meat from bulls fed an *ad libitum* concentrate diet. Likewise, Bruce, Stark and Beilken (2004) found that meat from pastured steers was darker than meat from concentrate-fed steers.

In some production systems, the diet of foraged-raised cattle can be supplemented with other feedstuffs. Baublits, Brown, Pohlman, Johnson, Onks and Loveday et al. (2006) compared the carcass characteristics of forage-fed cattle raised with or without feeding soybean (*Glycine max*) hulls. Cattle fed pelleted soybean hulls had lighter colored (higher L* value) than non-soyhull-supplemented cattle.

Diet and feeding duration affects the color of meat from realimentated cows. Concentrate-fed cows had brighter, redder lean than lean from forage-fed cows (Price & Berg, 1981). Duration of feeding also affects meat color. Cull beef cows fed for 56 d antemortem had redder *M. longissimus dorsi* than cull beef cows fed for 28 d antemortem (Cranwell, Unruh, Brethour & Simms, 1996). Whiter external fat color of cull cow carcasses can be obtained by feeding for 28 to 56 d (Schnell, Belk, Tatum, Miller & Smith, 1997). Feeding concentrate- or grain-based diets to cows results in improved beef lean and fat color compared to that of forage- or non-fed cows. Boleman, Miller, Buyck, Cross and Savell (1996) found that cows fed a high-energy, high-protein diet for 28, 56, or 84 d antemortem yielded carcasses with brighter, redder lean color than cows fed a low-energy, low-protein diet fed for the same durations.

The inclusion of supplemental vitamin E, an antioxidant, in beef rations improves beef color stability. Dietary supplementation of vitamin E causes α-tocopherol to accumulate in muscle tissue (Arnold, Scheller, Arp, Williams, Buege & Schaefer, 1992). This delays lipid and pigment oxidation of meat (O'Sullivan, Galvin, Moloney, Troy, O' Sullivan & Kerry, 2004). Houben, van Dijk, Eikenelboom and Hoving-Bolink (2000) fed supplemental vitamin E (2025 IU / animal / day) to beef bulls for 136 d antemortem. Minced beef from cattle supplemented with vitamin E experienced a greater antioxidant effect than ground beef from non-vitamin E supplemented cattle when packaged in modified atmosphere. Moreover, visual panelists determined that ground beef from cattle supplemented with vitamin E was more 'attractive' than ground beef from cattle not supplemented with vitamin E.

Implanting cattle with steroids and feeding β-agonists to cattle may cause cattle to yield darker colored meat. Reiling and Johnson (2003) evaluated the effects of trenbolone acetate and zeranol on caracass characteristics and found that re-implanting cattle 60 d after an initial implanting resulted in more mature lean maturity scores. In the USDA beef system, lean maturity, as determined by lean color and texture, is balanced with skeletal maturity to determine overall carcass maturity. More mature lean color scores are associated with darker lean color. Avendano-Reyes, Torres-Rodriquez, Meraz-Murillo, Perez-Linares, Figueroa-Saavedra and Robinson (2006) found that feeding of ractopamine to steers resulted in decreased meat redness.

4.2 Age, gender

As vertebrates physiologically age, the concentration of myoglobin within muscle increases; thus, older animals tend to have darker colored lean. Current USDA beef grading standards highlight lean color as an indicator of physiological maturity, with darker lean associated with older, more mature cattle. Graafhuis and Devine (1994) found that cow beef has a higher pH, and subsequently a darker color, than young beef. Shemeis, Liboriussen and Bech Anderson (1994) evaluated meat quality traits of Danish Fresian cull cows based on age and body condition score. The cattle were classified into 3 age groups: very young (< 3 years old), young (3-5 years old), and mature (> 5 years old). Overall carcass color darkened and fat became more yellow

with age; however, only minor color changes due to age in *longissimus dorsi* were observed. Conflictingly, Sawyer, Mathis and Davis (2004) observed that lean color tends (P = 0.11) to darken as cattle age. Dunne, Keane, O'Mara, Monahan and Moloney (2004) compared the color properties of bulls and steers and reported that bull lean had a higher ultimate pH than steer lean, thus lending it a darker color.

In a study aimed at benchmarking the differences and similarities between cow and steer muscles, Patten, Hodgen, Stelzleni, Calkins, Johnson and Gwartney (2008) evaluated the color properties of nine different muscles. They found cow *gluteus medius*, *longissimus*, *triceps brachii*, *psoas major*, *rectus femoris* and *tensor facia latie* were darker (lower L*) than the same muscles from A-maturity Select-grade beef steers. The L* values of *teres major* and *infraspinatus* from fed beef cows did not differ from that of A-maturity Select-grade beef steers. Few differences in muscle a* value were observed due to animal age. Although no differences in b* value was found between fed beef cow muscles and A-maturity Select-grade steer muscles, non-fed beef muscles and muscles from both fed and non-fed diary cows were generally yellower (higher b*). Cow muscles appear darker than steer muscles, but in general, other color characteristics are not different between cows and steers.

4.3 Genetic effects on beef color

Differences in individual breed (i.e. Angus vs. Chianina) and a wider-ranging classification of cattle by biogical type (*bos taurus* vs. *bos indicus* and beef-type vs. dairy-type) affect meat color. Shackelford, Koohmaraie, Wheeler, Cundiff and Dikeman (1994) characterized *longissimus* color as a function of breed and biological type. *Bos taurus* and *bos indicus* cattle representing 23 different breeds were evaluated for lean color, and Chianina-sired cattle had darker-colored lean than all other breeds except Tarentaise and Simmental-crosses, as well as a higher incidence of unacceptably dark colored lean (dark-cutting or DFD beef). It is likely that the Chianina-sired cattle were more stress susceptible, thereby yielding darker colored meat. *Bos indicus*-sired cattle were more likely to produce carcasses with very light cherry-red lean than *bos taurus*-sired cattle. Similarly, Dunne et al. (2004) observed that Belgian Blue x Holstein-

Fresian steers had lighter colored lean and less heme pigments than purebred Fresian steers.

The relationships between cattle breed, fiber type and meat color was investigated by Wegner, Albrecht, Fiedler, Teuscher, Papstein and Ender (2000). The prevalence of different fiber types in *M. semitendinosus* of Angus, Belgian Blue, Galloway and Holstein bulls were determined and related to meat color. Belgian Blue cattle, a breed that exhibits extreme hyperplasia, had a greater prevalence of type II-β muscle fibers and a lower prevalence of type I and type II-α muscle fibers, and was lighter colored than Angus, Galloway and Holstein cattle.

Stelzlini, Patten, Johnson, Calkins and Gwartney (2007) conducted a study aimed at benchmarking differences between beef cow and dairy cow carcasses. In comparing fed versus non-fed diary cows, they found that carcass lean color was similar, yet fed dairy cows had whiter fat. Also, they found that fed beef cows had brighter lean and whiter fat than non-fed beef cows. In this study, the lean color of non-fed beef cows did not differ from non-fed dairy cows.

4.4 Muscle function, cattle housing system

Within a beef carcass, the chuck and round muscles are those responsible for locomotion in the living animal, and therefore contain muscles with predominantly red (slow-twitch; oxidative) or predominantly white (fast-twitch; glycolytic) muscle fibers (depending on muscle function). Swan and Boles (2006) investigated the functional characteristics of different ground beef sources. They noted that chuck and round muscles were lighter in color than other muscles, including strip loin and flank. Renerre and Labas (1987) determined that muscles with the poorest color stability had the highest O_2 consumption rates. These muscles have a greater prevalence of α-red fiber types. Anaerobic muscle fibers have less MMb reducing ability and are more likely to exhibit paler color. These muscles have a greater prevalence of white fiber types (Kropf, 1980).

Dunne, Monahan, O'Mara and Moloney (2005) hypothesized that exercise causes the accumulation of reactive oxygen species and may increase postmortem lipid oxidation, therefore accelerating meat discoloration. They observed that *M. longissimus*

dorsi steaks from exercised cattle were redder and had more saturated color throughout display than *M. longissimus dorsi* steaks from non-exercised cattle. Conversely, they found that *M. semimembranosus* steaks from exercised cattle were less red and less saturated than *M. semimembranosus* from non-exercised cattle. Moreover, Shorthose and Harris (1991) suggested that pasture-raised cattle exhibited more myoglobin than confinement-raised cattle due to differences in physical activity.

Cattle housing system may affect beef color due to differences in animal physical activity, and stress susceptibility at slaughter due to amount of human exposure during feeding. Vestergaard et al. (2000) found that meat from loose-housed forage-fed bulls was darker and contained more pigment compared to tie stall-housed concentrate-fed bulls. Color and pigment differences were attributed to housing conditions, not diet. In this study, meat from loose-housed forage-fed bulls had increased slow-contracting muscle fibers, was more vascularized, and exhibited greater oxidative metabolic potential than tie stall-housed concentrate-fed bulls. Bowling, Smith, Carpenter, Dutson and Oliver (1977) suggested that forage-fed (pastured) cattle may be more stress-susceptible and than concentrate-fed (feedlot) cattle because feedlot-raised cattle were raised with much human exposure and handling experience, and consequently, pasture-raised cattle may yield darker colored lean.

5. Postmortem color management

5.1 Electrical stimulation

Carcass electrical stimulation accelerates pH decline and can either improve or worsen beef lean color. Electrically stimulated carcasses have brighter colored lean than non-electrically stimulated carcasses. Boleman et al. (1996) reported that electrically stimulated cow carcasses had brighter colored lean than non-electrically stimulated cow carcasses. Steaks from electrically stimulated carcasses tend to have brighter color (Claus, Kropf, Hunt, Kastner & Dikeman 1984). Alternatively, the color of ground beef from electrically stimulated carcasses does not differ from the color of ground beef from non-electrically stimulated carcasses (Hall et al., 1980). Behkit,

Geesnik, Morton and Bickerstaffe (2001) evaluated the effects of electrical stimulation on color properties in lamb, and observed that neither electrical stimulation nor animal physical stress affects MMb reducing activity in ovine *longissimus* muscle.

5.2 Hot boning

'Hot boning' is muscle excision from a carcass prior to extended chilling. Hot-boned muscles tend to be darker in appearance (Huffman, 1980; Claus et al., 1984). Claus et al. (1984) found that hot-boned (excised 2 h postmortem and held at 5° C for 24 h) *longissimus* steaks and *semimembranosus* steaks packaged in polyvinylchloride over-wrap film were visually darker throughout display than cold-boned steaks. Claus, Kropf, Hunt, Kastner and Dikeman (1985) noted that vacuum packaged hot-boned *longissimus* steaks and *semimembranosus* steaks excised at 2 h postmortem and held at 5° C for 24 h appeared a brighter purplish-red color than cold-boned steaks.

Hot-boning improves MMb reductase activity in beef *semimembranosus*. Sammel, Hunt, Kropf, Hachmeister, Kastner and Johnson (2002) reported that hot-boning increases MMb reductase activity compared to cold-boning for beef deep *semimembranosus*. However, it did not affect MMb reducase activity for superficial *semimembranosus*. This is because *semimembranosus* is a large, thick muscle for which the deep (interior) portion chills much slower than the superficial (exterior) portion, and thus is sensitive to a temperature x pH profile effect during processing.

5.3 Chilling rate

The rate of temperature decline is often inversely related to pH decline; however, greater pH decline is not always due to slow temperature decline. As a carcass is chilled, colder temperatures are conducive to slower pH decline; thus, carcasses chilled more quickly undergo slower pH decline (Tarrant & Mothersill, 1977). This results in darker colored lean. Alternatively, more slowly-chilled carcasses undergo an accelerated pH decline (Tarrant & Mothersill, 1977). This results in lighter colored lean.

The effects of chilling rate on beef color are well illustrated by the attributes of the *semimembranosus* muscle. The results of Sammel et al. (2002) indicate that MMb reductase activity is sensitive to the temperature x pH effect observed in beef due to hot- or cold-boning. However, Behkit et al. (2001) reported that the same effect did not

impact MMb reuctase activity in lamb muscle. This may be best explained by simple differences in carcass size, and therefore, different chilling rates of muscle.

5.4 Antimicrobial ingredients, processes

The primary reason for using antimicrobial ingredients in meat products is to control pathogens, thus increasing product safety and extending shelf-life. However, antimicrobial ingredients can affect muscle pH and meat color. Pohlman, Stivarius, McElyea Johnson and Johnson (2002) found that treating beef with 1% ozonated water followed by 5% acetic acid decreases OMb content, redness, and overall color stability. This is likely because acetic acid reduced meat pH, promoting pigment oxidation. Likewise, applying 1% ozonated water followed by 0.5% cetylpyridinium chloride or 5% acetic to beef trimmings resulted in decreased meat pH (4.6) and lightened ground beef color. The application of 200 ppm chlorine dioxide followed by 10% trisodium phosphate resulted in higher meat pH (7.0) and darkened beef color. Similarly, the treatment of beef trimmings with acetic acid decreased OMb and redness (Stivarious, Pohlman, McElyea & Waldroup, 2002), and treatment of beef trimmings with hot water and lactic acid resulted in lighter-colored ground beef.

Ground beef can be irradiated as an antimicrobial measure; however, it results in accelerated oxidation and discoloration. Irradiated ground beef may appear greenish or grayish (Kim, Nam & Ahn, 2002). Ismail, Lee, Ko and Ahn (2008) reported that irradiated (2.5 kGy) ground beef was less red in color than non-irradiated (0 kGy) ground beef. The same study determined that the addition of ascorbic acid and α-tocopherol to ground beef prior to irradiation reduced irradiation-induced oxidation and therefore, ground beef maintained its redness. Irradiation generates reactive oxygen species in meat, and the browning effect observed in beef irradiated in O_2-containing environments is due to accelerated Mb oxidation (Brewer, 2002). Greenish colors in irradiated ground beef may be due to the development of sulfmyoglobin during irradiation (Brewer, 2002).

5.5 Functional ingredients

Many functional ingredients are applied to meat topically or as part of an injection enhancement solution. Antioxidants and reductants can be applied to meat to prolong

the life of OMb. Topical ascorbic acid minimizes beef bone marrow discoloration (Mancini, Hunt, Hachmeister, Kropf and Johnson, 2004), and also retards lipid and pigment oxidation in ground beef patties for up to 8 d of lighted display (Realini, Duckett & Windham, 2004). Balentine, Crandall, O'Bryan, Duong and Pohlman (2005) applied rosemary extract to beef both before and after grinding and found that ground beef with rosemary extract was redder and less oxidized than control samples after 144 h of simulated retail display. The application of either ascorbic acid or sodium erythorbate applied at 0.5, 1.0 or 1.5% to bone-in *longissimus lumborum* steaks improved vertebral redness without compromising lean color after 24 h in HiO_2 MAP (Mancini, Hunt, Seyfert, Kropf, Hachmeister, Herald and Johnson, 2006). Injection enhancement of beef with a solution containing sodium lactate or potassium lactate improves beef color stability (Kim, Hunt, Mancini, Seyfert, Loughin, Kropf, et al., 2006; Knock, Seyfert, Hunt, Dikeman, Unruh, Higgins & Monderen 2006). Similarly, Seyfert, Hunt, Grobbel, Ryan, Johnson and Monderen (2006) found that the addition of 3% potassium lactate to fresh pork sausage maximizes color stability and minimizes lipid and pigment oxidation.

Other injection enhancement solution ingredients include sodium chloride and phosphates. Sodium chloride is the most common meat processing ingredient after water (Esquerra, 1994), and is used to increase cook yields (Boles & Swan, 1997; Scanga, Delmore, Ames, Belk, Tatum & Smith, 2000), primarily by causing swelling of myofibrils (Offer & Trinick, 1983; Paterson, Parrish & Stromer, 1988). Salt also imparts its own flavor, and also intensifies beef flavor. Consequently, sodium chloride has pro-oxidative properties that lead to increased lipid and pigment oxidation (Akamittath, Brekke & Schanus, 1990), thereby imparting reduced color stability of meat. Phosphates are used in injection enhancement solutions to increase water-holding capacity by raising meat pH away from its isoelectric point (pH 5.1) (Carpenter, Saffle & Kamstra, 1961). Phosphates also counter the pro-oxidative effects of sodium chloride (Akamittath et al., 1990), thus improving meat color stability.

5.6 Packaging advancements

Fresh meat is conventionally displayed two ways in retail meat cases: 1) non-packaged, displayed in a fresh meat display case, very akin display in a butcher shop or

deli; or more commonly 2) placed on Styrofoam trays featuring an absorbent pad and over-wrapped with oxygen-permeable polyvinylchloride (**PVC**) film. An image of a conventional PVC over-wrap package is provided in Figure 1.4. In both of these systems, atmospheric oxygen is responsible for the development of OMb. Some meat is also retailed in vacuum packages, appearing purple due to the lack of oxygen and Mb being in the DMb state.

A package in which a prescribed gas fills the atmosphere around meat in a rigid tray, to which a barrier lidding film is applied, is referred to as a modified atmosphere package (**MAP**) (Eilert, 2005). An image of typical MAP packages is provided in Figure 1.4. The gases used in these atmospheres may include: oxygen, carbon dioxide, nitrogen, carbon monoxide, and combinations thereof. Two broad categories of MAP currently exist: high-oxygen (HiO_2) and ultra-low-oxygen ($LowO_2$). A HiO_2 MAP system is desirable because OMb develops and meat has its characteristic cherry-red appearance when fresh. Conversely, HiO_2 MAP is conducive to increased product discoloration, and other quality defects associated with oxidation (Grobbel, Dikeman, Hunt & Milliken, 2008). A $LowO_2$ MAP system is desirable because lean, fat, and bone is markedly less susceptible to lean, fat and bone discoloration, and other oxidative defects, because O_2 is absent. Meat in $LowO_2$ MAP, however, appears purple (DMb) and is not desirable to consumers.

PVC **MAP**

Figure 1.4 PVC over-wrap packaged and a MAP packaged beef steaks in simulated retail display.

Diatomic oxygen (O_2) is critical for the development and maintenance of OMb. Bartowski, Dryden and Marchello (1982) stated that higher O_2 levels increases the OMb life, and Seideman and Durland (1983) indicated that at least 5% O_2 is needed for sufficient OMb to develop to give meat a cherry-red appearance. The level of atmospheric O_2 within a package also affects meat metabolism and enzymatic activity, and the rate and degree of lipid and pigment oxidation. The most widely-used form of MAP is currently HiO_2 MAP; HiO_2 packages generally contain 80% O_2.

Carbon dioxide (CO_2), though not directly linked to Mb form, is antimicrobial, and because it is soluble in meat, can cause a meat surface pH reduction of 0.1 pH unit (Farber, 1991). These affect meat color. The presence of high levels (non-physiological) of CO_2 to meat may alter meat's cellular membrane and enzymatic functions, among other metabolic functions. In HiO_2 MAP (80% O_2), the remaining 20% is usually CO_2 because inclusions of 20% CO_2 or greater imparts maximal microbial control (Kropf, 2000).

Solublization of CO_2 into meat can lead to the collapse of MAP packages. Diatomic nitrogen (N_2) is used in CO_2-containing MAP packages to minimize the incidence of package collapse (Kropf, 2000), and is used to balance the atmosphere in O_2-exclusive $LowO_2$ packaging systems. In cooked and/or cured MAP meat products, N_2 is used to dilute O_2, thereby improving microbial control and reducing lipid and pigment oxidation.

Carbon monoxide (CO) has been used in fresh meat packages in Norway since 1985 (Sørheim, Nissen & Nesbakken, 1999). More recently its use has been adopted in the United States, legally limited to not exceed 0.4% of the package atmosphere (FDA, 2004). Carbon monoxide is used because it binds to Mb forming a stable, bright red pigment, COMb (Kropf, 1980).

6. Integrated supply chain management and research

6.1 Muscle profiling

Marketing changes of beef has affected the beef processing industry and supply chain, and accordingly, the approach to applied beef research has evolved. Many beef cuts have been historically marketed as bone-in cuts; however, more boneless cuts have evolved. There are differences in initial color and color stability between muscles within a carcass (Kropf, 1980). Jones, Calkins, Carpenter, Johnson and Gwartney (2005) characterized all bovine muscles, a process called muscle profiling. As a result of this process, the objective color, heme, and pH measurements, among other properties, were reported for every muscle in the beef carcass. The beef industry has suggested that one way to add value to beef carcasses, with particular emphasis on the lesser-valued chuck and round muscles, was to develop innovative fabrication techniques, later deemed the 'Beef Value Cuts' program by the National Cattlemen's Beef Association. Von Seggern, Calkins, Johnson, Brickler, and Gwartney (2005) attempted to better characterize the muscles of the beef chuck and round with the 'Beef Value Cuts' program as a primary consideration. Data regarding yield and labor need for producing these cuts is minimal. In general, as fabrication methods shift from bone-in to boneless meat cut production, cutting yield decreases (due to increased fat trim and bone removal) and fabrication time increases (Lorenzen, Martin, Griffin, Dockerty, Walter, Johnson and Savell, 1997; McKenna, Griffin, Johnson, Covington and Savell, 2003).

Accompanying the muscle color characterization by Jones et al. (2005), McKenna, Mies, Baird, Pfeiffer, Ellebracht and Savell (2005) attempted to characterize 19 beef muscles based upon the biochemical factors affecting meat discoloration. Muscles were separated into 4 groups: High color stability muscles (*M. longissimus lumborum*, *M. longissimus thoracis*, *M. semitendinosus*, and *M. tensor faciae latae*); Intermediate color stability muscles (*M. semimembranosus*, *M. rectus femoris*, *M. vastus lateralis*, *M. trapezius*, *M. gluteus medius*, and *M. latissimus dorsi*); Low color stability muscles (*M. triceps brachi* – long head, *M. triceps brachi* – lateral head, *M. biceps femoris*, *M. pectoralis profundus*, and *M. adductor*); and Very Low color stability

muscles (*M. supraspinatus*, *M. infraspinatus*, and *M. psoas major*). These categories were based upon the discoloration patterns of the $(K/S)_{572}$ / $(K/S)_{525}$ ratio, which is an indicator of surface metmyoglobin. Based upon these classifications of high, intermediate, low and very low color stability as determined by McKenna et al. (2005), sample color data for selected young beef muscles and market cow muscles from Jones et al. (2005) are listed in Table 1.1. The magnitude of difference in color measurements between muscles within the same age group is not as great as the magnitude of difference between the color measurements of the same muscles between age groups. Compared to young beef muscles, cow muscles are darker colored (lower L* values), slightly less red (slightly lower a* values), slightly less yellow (slightly lower b* values), and much more pigmented (greater total heme-iron).

Table 1.1. Sample muscle profiling color properties[1] for high, intermediate, low and very low color stability muscles. Adapted from Jones et al., 2005.

Muscle	*Young Beef*				*Cow Beef*			
	L*	**a***	**b***	**Heme**	**L***	**a***	**b***	**Heme**
Longissimus dorsi	40.55	31.13	23.98	22.02	33.86	28.06	21.66	30.98
Semimembranosus	39.44	32.56	27.00	21.22	33.20	29.47	23.01	32.89
Triceps brachi	39.47	31.5	24.78	21.53	32.24	28.53	22.14	36.38
Supraspinatus	40.82	30.92	23.83	21.47	34.2	28.92	21.95	34.00

[1]L* = instrumental measurement of lightness, higher value is lighter; a* = instrumental measurement of redness, higher value is redder; b* = instrumental measurement of yellowness, higher value is yellower; Heme = total heme-iron content (ppm)

McKenna et al. (2005) also evaluated metmyoglobin reductase activity (MRA) on the same 19 beef muscles. *M. longissimus lumborum* had high MRA and was categorized as a high color stability muscle. *M. psoas major* had low MRA and was categorized as a very low color stability muscle. Conversely, *M. semitendinosus*, *M. semimembranosus*, *M. rectus femoris*, and *M. tensor faciae latae* tended to have lower MRA, which does not correspond to their high to intermediate color stability status. Atkison & Follett (1973) found that MRA is not related to the discoloration rate of beef, pork or lamb. Recent reviews of MRA-inclusive studies suggest that differences in MRA methodologies may be responsible the reported inconsistencies (Mancini & Hunt, 2005).

In addition to MRA, oxygen consumption rate (OCR) may also be related to muscle color stability (Renerre & Labas, 1987). McKenna et al. (2005) reported that *M. biceps femoris* (low color stability) has high OCR. Conversely, the OCR of *M. longissimus lumborum*, *M. tensor faciae latae*, *M. vastus lateralis*, and *M. rectus femoris* does not correspond to their color stability class ranking based on MMb development.

6.2 Muscle profiling in relation to ground beef

To date, minimal research has been conducted to investigate the contributions that muscles differing in their color properties make to the overall color of ground beef. The color data presented in muscle profiling research is for intact, whole-muscle steaks and not ground or minced beef. Suman, Faustman, Lee, Tang, Sepe and Vasudevan et al. (2004) investigated the effects of muscle source on premature browning in ground beef. Lean was sourced from USDA Choice *posas major* to represent color labile muscles, and from USDA Choice *longissimus lumborum* to represent color stabile muscles. Muscles were trimmed of excess visible fat, ground, and formed into patties. Fat content beyond removal of external trim was not controlled. Instrumental color was measured at 15 min, 48 h and 96 h after patty manufacture. Patties made from *psoas major* had higher initial L* and lower a* values than patties made from *longissimus lumborum*. The authors attribute higher L* and lower a* values of *psoas major* patties than of *longissimus lumborum* patties to their greater fat content. For both *psoas major* and *longissimus lumborum* patties, a* values decreased during storage. Also, the total

reducing ability of all patties decreased during storage, and muscle source did not affect reducing ability.

6.3 Cow value and supply

From the 1999 National Market Cow and Beef Quality Audit, Roeber, Mies, Smith, Belk, Field, Tatum, Scanga and Smith (2001) declared that optimal management and timelier marketing of cows would mean more revenue for the beef industry. However, many valuable by-products, such as intestines, from cows have been designated as specified risk materials (SRMs; animal parts which may serve as transmission vectors of *bovine spongiform encephelopothy*), which are accompanied by lost value. In 2005, nearly 5 million cull cows, or 16% of all beef cattle, were harvested in the United States (USDA, 2006). Cull cows can generate up to 25% of a beef producer's revenue (Yager, Greer & Burt, 1980). Roeber et al. (2001) reported that marketing cows in poor condition reduces the net value of a cow by up to $27.50 per head. Feeding cows a high-energy diet antemortem, resulting in higher lean meat yield, can increase cow value by $20.00 per head (Schnell et al., 1997). Research characterizing qualitative properties cow muscles and how to optimally use them for ground beef production may increase the value of cull cows.

6.4 Case-ready ground beef

'Case-ready' is a term given to products manufactured and packaged at a central location and distributed to surrounding retail outlets. The case-ready fresh meat product market share increased from 49% in 2002 to 60% in 2004 (Mize & Kelly, 2004). The amount of case-ready ground beef increased from 56% in 2002 to 66% in 2004 (Mize & Kelly, 2004). Product convenience, reduction of display case space needed, and reduced opportunity for in-store microbial contamination justify the use of case-ready meat systems (Eilert, 2005). A simplified schematic of the case-ready distribution chain is supplied in Figure 1.3.

There are many forms of case-ready packages. Styrofoam trays over-wrapped with oxygen permeable polyvinyl chloride film are declining in popularity, decreasing from 51% in 2002 to 47% in 2004 (Mize & Kelly, 2004). This system can be used either in-store or at a central manufacturing facility. Increasing in popularity are MAP

products. Muscle profiling research assists meat processors to best identify the packaging system that fits their product, distribution network, retail outlet, and consumers' preferences.

Meat is traditionally wholesaled to retailers as vacuum-packaged subprimals, which are then cut and/or ground into the desired product in the retail store. Case-ready meat production adds cost to packaging, requires special equipment and personnel training, and introduces a new step in the meat supply chain, which subsequently creates a heightened need for optimum temperature control (Farber, 1991). Overriding these drawbacks, case-ready meat production offers improved food safety and quality control, and reduces the need for skilled labor at the retail level.

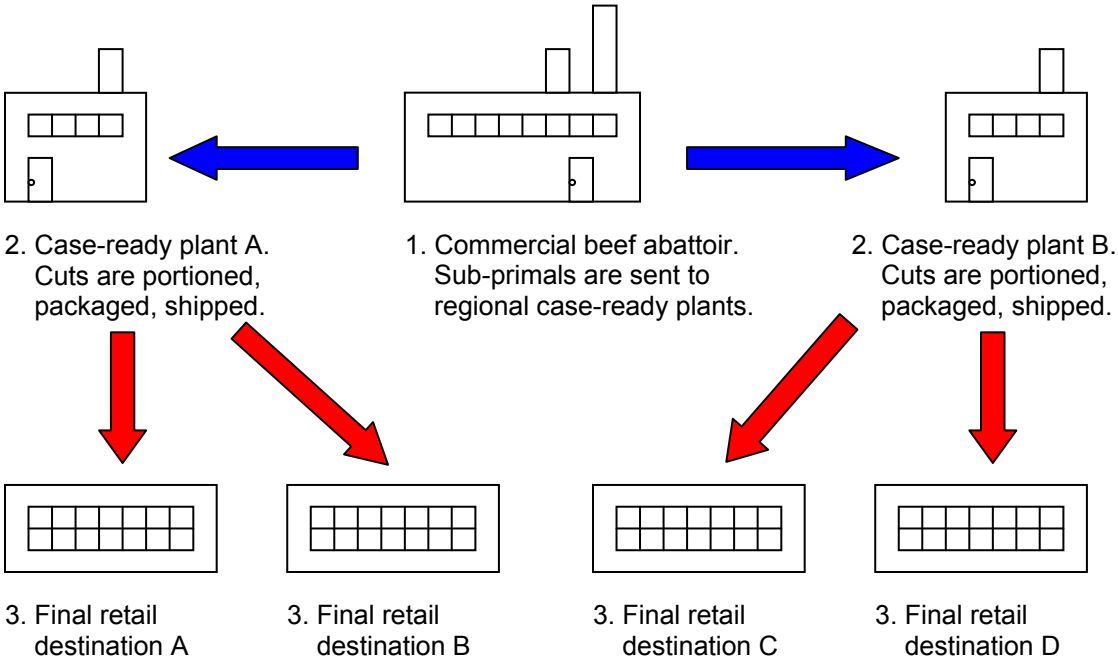

Figure 1.5. Generalization of the ground beef case-ready distribution network

Hunt (2002) summarized the advantages of case-ready meat processing, which include:

❶ Maintained or potentially increased diversity of retail meat offerings
❷ Countered shortage of skilled retail meat cutters
❸ Improved sanitation control and compliance with HACCP principles
❹ Increased product consistency
❺ More efficient meat purchasing and inventory for retailers
❻ Greater opportunities for increased profit margins

Despite the disadvantages suggested by Farber (1991), the meat industry recognizes the advantages highlighted by Hunt (2002) and is transitioning to case-ready manufacturing.

7. Conclusions

Numerous factors affect the ultimate color of beef, many of which can be optimally conditioned with proper antemortem cattle management and postmortem carcass handling. Much research has been conducted on how these ante- and postmortem factors affect whole-muscle color stability. Less research has been conducted on how these factors affect ground-muscle color stability.

Many interventions, namely ingredient addition and packaging control, to manage beef color stability exist. Muscle profiling studies indicate that individual chuck and round muscles have desirable qualitative properties; however, these have been researched only for whole-muscle cuts, not ground-muscle products. Centralized processing and packaging permits beef processors to optimally use different beef muscles by removing the ‘unknown’ factor of in-store retail product manufacturing, and garner heightened control over both food safety and inventory concerns.

8. Primary research questions

8.1 How do color properties of different muscles from fed steers and fed cows compare?

Young beef muscles and cow muscles have been characterized but addressed as two fundamentally different types of beef. How does the color stability of different muscles from young beef and cows compare when exposed to the similar antemortem conditions and handled the same way postmortem?

8.2 What is the overall color stability effect when muscles of different color stability are blended together in ground beef?

Identifying and sorting different muscles during the carcass fabrication process is not difficult. What happens to color life when muscles of high, intermediate, and/or low color stability are blended?

8.3 How does ground beef color life differ between beef cow ground beef and dairy cow ground beef?

Beef cows and dairy cows have evolved into what can be considered two different biological types of cattle. Moreover, typical production schemes differ vastly, namely by diet, housing system, and age at slaughter. Given those differences, how do their ground beef color properties compare?

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CHAPTER II

Color characterization of six ground muscles from steers and cows managed similarly during the finishing phase

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Abstract

Steers (*n*=20) and cows (*n*=20) managed similarly in the finishing phase were used in this study. Concentrate diets were fed to steers for 90 d and cows for 60 d. Steers and cows were randomly assigned to 1 of 4 treatments: 1) Control, 2) Revalor®-S200 (REV) at d 0 of feeding, 3) Optaflexx™ (OFX) for the final 28 d of feeding, or 4) a combination of REV + OFX. Cows were also separated into 3 age groups: 1) Young (3-4 years of age; n = 7), 2) Mature (6 years of age), and 3) Very mature (8-16 years of age). Six muscles differing in inherent color stability were isolated from the right side of each carcass: 1) *M. biceps femoris* (BF), 2) *M. longissimus thoracis* (LT), 3) *M. semimembranosus* (SM), 4) *M. semitendinosus* (ST), 5) *M. supraspinatus* (SS), and 6) *M. triceps brachii* (TB). Muscles were trimmed of visible fat and connective tissue, ground, formed into patties, packaged in PVC overwrap trays, and displayed for 4 d in simulated retail conditions. Fatty acid profiles for each muscle were determined. Instrumental colour was measured at 0, 12, 48, 72 and 96 h. Neither REV, OFX, or REV + OFX did not affect ($P > 0.05$) nor fed cow age affected ($P > 0.05$) ground muscle color. Ground cow muscles were darker ($P < 0.05$) colored after 24 h and redder ($P < 0.05$) at 96 h than ground steer muscles. Ground fed cow muscles exhibited greater color stability over 96 h of display than ground steer muscles. Within steers and cows, LT tended was the most color stable muscle. Muscles from fed cows contained more SFA and MFA than muscles from steers, and PUFA differences tended to differ less. LT from steers contained the most CLA ($P < 0.05$), and LT from cows contained the most stearic acid ($P < 0.05$). Ground chuck and round muscles from fed cows provided greater benefit to the overall of color life of ground beef than ground chuck and round muscles from fed steers.

Key words: Ground beef, chuck, round, color stability, fed cow

1. Introduction

Within a beef carcass, the color properties of different muscles vary (Kropf, 1980). In recent years, much research has been conducted characterizing the qualitative characteristics (i.e. color and tenderness) of different muscles from both young and mature cattle (Jones, Calkins, Carpenter, Johnson and Gwartney, 2005). The magnitude of difference in color measurements between muscles within the same age group is not as great as the magnitude of difference between the color measurements of the same muscles between age groups. Compared to young beef muscles, cow muscles are darker colored (lower L* values), slightly less red (slightly lower a* values), slightly less yellow (slightly lower b* values), and more pigmentation (greater total heme-iron).

McKenna, Mies, Baird, Pfeiffer, Ellebracht and Savell (2005) characterized beef muscles based upon the biochemical factors affecting meat discoloration. This study resulted in the classification of beef muscles into 4 groups: High color stability muscles (*M. longissimus lumborum*, *M. longissimus thoracis*, *M. semitendinosus*, and *M. tensor faciae latae*); Intermediate color stability muscles (*M. semimembranosus*, *M. rectus femoris*, *M. vastus lateralis*, *M. trapezius*, *M. gluteus medius*, and *M. latissimus dorsi*); Low color stability muscles (*M. triceps brachi* – long head, *M. triceps brachi* – lateral head, *M. biceps femoris*, *M. pectoralis profundus*, and *M. adductor*); and Very Low color stability muscles (*M. supraspinatus*, *M. infraspinatus*, and *M. psoas major*).

The beef industry has suggested that one way to add value to beef carcasses, with particular emphasis on the lesser-valued chuck and round muscles, was to develop innovative fabrication techniques, later deemed the 'Beef Value Cuts' program by the National Cattlemen's Beef Association. Von Seggern, Calkins, Johnson, Brickler, and Gwartney (2005) attempted to better characterize the muscles of the beef chuck and round with the 'Beef Value Cuts' program as a primary consideration. In general, as fabrication methods shift from bone-in to boneless meat cut production, cutting yield decreases (due to increased fat trim and bone removal) and fabrication time increases (Lorenzen, Martin, Griffin, Dockerty, Walter, Johnson and Savell, 1997; McKenna, Griffin, Johnson, Covington and Savell, 2003).

Although much research has been conducted to evaluate the color properties of whole-muscle cuts, minimal research has been conducted evaluating the color properties of ground muscles. Moreover, no research comparing the color properties of ground muscles from fed steers to the color properties of ground muscles from fed cows. Hence, the objective of this study was to compare the color properties of ground muscles from cows and steers fed under similar production regimes immediately prior to harvest.

2. Materials and Methods

2.1 Source cattle

Muscles obtained from similarly managed A-maturity steers and cull mature cows were used in this experiment. Cull cows were fed a concentrate ration for 60 d before harvest and steers were fed a concentrate ration for 90 d before harvest. The cattle used in this experiment were part of other studies, hence the difference in days on feed. The concentrate diet fed to cull cows is summarized in Table 2.1. The concentrate diet fed to steers was not known. Cattle were either not treated with metabolic modifiers (control) or subjected to 1 of 3 treatment combinations of metabolic modifier (Revalor R-200®, Intervet, Millsboro, DE) and β-andregenic agonist (ractopamine, Optaflexx®, Elanco, Greenfield, IN). Treatments were: 1) control, no implant, no β-agonist; 2) implant, no β-agonist; 3) no implant, β-agonist; and 4) implant, β-agonist implant. For treatments containing implants, the implant was administered at d 0 of feeding. For treatments containing the β-agonist, the ractopamine was fed as part of the ration for the last 28 days of feeding (300 mg / head per day). To examine the effects of cow age on ground beef color properties, cull cows were separated into 3 animal sourcees: young (3-4 years old; *n*=7), mature (6 years old, *n*=7), and very mature (8-16 years old, *n*=6).

2.2 Muscle sampling

Six muscles, *M. semimembranosus* (**SM**), *M. biceps femoris* (**BF**), *M. semitendinosus* (**ST**), *M. longissimus thoracis* (**LT**), *M. triceps brachii* (**TB**), and *M.*

supraspinatus (**SS**), were excised 5 d postmortem. The muscles used in this study were chosen based on their respective color stability categorization as high (LT, ST), intermediate (SM), low (BF, TB) or very low (SS) by McKenna et al. (2005). Muscles were trimmed of all visible fat and connective tissue. From the center portion of each muscle, lean was first coarse ground (1.48 cm plate) and then fine ground (0.58 cm plate) using an Oster table-top meat grinder (Model 516, Sunbeam Products, Rye, NY) and formed into three ground beef patties (each 114 g; 2 for color analysis and 1 for fatty acid analysis). The remaining intact tissue from each muscle was vacuum packaged and frozen at -40 ºC for use in later experiments.

2.3 pH

Muscle pH was measured immediately after fabrication (5 d postmortem) by inserting the tip of a pH probe (MPI pH probe, glass electrode, Meat Probes Inc., Topeka, KS) into the muscle at three different locations and averaged. For *M. semimembranosus*, deep (inner) and superficial (outer) sections of the muscle were evaluated as different muscles for pH. The pH of all other muscles was measured as that of an individual muscle and not further divided by location.

2.4 Packaging and display

The ground beef patties were packaged in 27.3 cm x 15.1 cm x 1.3 cm foam trays (10S, Cryovac Sealed Air, Duncan, SC) with oxygen permeable film (MAPAC M film, 23,250 cc/m2/24h, 72 gauge, Resinite Packaging Films, Borden, Inc., North Andover, MA). Packages were displayed for 4 d (96 h) under continuous fluorescent lighting (2153 lux, 3000K and CRI=85, Bulb Model F32T8 / ADV830 / Alto, Phillips, Bloomfield, NJ) at 2°C in coffin-type retail display case (Unit Model DMF8, Tyler Refrigeration Corp., Niles, MI). The commercial display cases used underwent twice daily defrost cycles. To maintain random case placement, packages were rotated daily.

2.5 Fatty acid analysis

A modified gas chromatography procedure of Sukhija and Palmquist (1988) was used for fatty acid analysis. Patty samples for fatty acid analysis were frozen within 4 h of manufacture at -80 °C, and later pulverized in liquid nitrogen in order to facilitate

sample uniformity for fatty acid extraction. Analysis was conducted using a gas chromatograph (Shimadzu model GC9-AM, Columbia, MD) with a flame ionization detector containing a Supelco column (SM 2560, 100 m x 0.25 mm x 0.2 µm; Supelco, Bellefonte, PA). A 1-µl injection volume was used to determine a complete fatty acid profile of the muscle samples. Samples were injected and held for 15 min at 140 °C, and then increased to 240 °C at a rate of 4 °C per min. Total runtime was 45 min per sample.

2.6 Instrumental color evaluation

Instrumental color (**L***, **a***, and **b***; Illuminant A) was measured using a HunterLab MiniScan™ XE Plus Spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer; Hunter Associates Laboratory, Inc., Reston, VA) at 0, 12, 24, 48, 72, and 96 h of display. From this data, other color properties were calculated: 1) surface discoloration: **a* / b***; 2) color saturation index: **SI** = $(a^{*2} + b^{*2})^{1/2}$; and 3) hue angle: **HA** = $\tan^{-1}$ (b*/a*).

2.7 Statistical analysis

The experiment was a split-plot design with animal source (steer and cow) serving as the whole plot factor (Figure 2.1). Management strategy was included in the subplot. Cattle were harvested in 8 different groups (1 group per week over an 8 week period), thus cattle were blocked by slaughter group to account for possible variation due slaughter date. Data were analyzed with **MIXED** procedure of **SAS** (SAS Institute, Inc., Cary, NC). Model statements contained the selected response variable and all possible interactions between management strategy, age group, muscle, and h of display (a repeated measure). Satterthwaite adjustments were used for the degrees of freedom. Pairwise comparisons of least squares means were used to determine significant differences ($P < 0.05$) when respective F-tests were significant ($P < 0.05$).

3. Results

The objective of this experiment was to elucidate differences in ground beef color properties of different muscles from fed cows and steers produced under similar management immediately prior to harvest. For both cows and steers, 3 regimens of

metabolic modifiers and a control were included in the feeding protocol, in addition to a control, and these did not affect ($P > 0.05$) meat pH nor color properties. Cows were further stratified into age groups of young (3-4 years old), mature (6 years old), and very mature (8-16 years old). Interactions between age group and evaluated color responses were not observed ($P > 0.10$). However, interactions ($P < 0.05$) for color properties between animal source (steer versus cow) and display time were observed. For those interactions, least squares means are presented, and superscript letters identifying significant differences apply to all data within the table because the objective was to evaluate differences between steers and cows, muscles, and display time.

3.1 Muscle pH

A pH main effect ($P < 0.05$) was observed (Table 2.2). An interaction between cow vs. steer and muscle pH was not observed ($P > 0.05$). The SS and TB had the highest ($P < 0.05$) pH, followed by the LT and deep SM. The ST and superficial SM had the lowest pH ($P < 0.05$). The BF pH was similar ($P > 0.05$) and intermediate between LT, deep and superficial SM, and ST.

*3.2 Lightness: L**

Differences in L* values indicate an animal source x muscle x display time of display interaction ($P < 0.05$; Table 2.3). Within muscles, all steer muscles consistently had higher ($P < 0.05$) L* values than all cow muscles after 12 h. For steers, BF L* value decreased ($P < 0.05$) from 0 h to 24 h, and LT, SM, SS, ST, and TB L* values remained constant ($P > 0.05$) over 96 h. For cows, BF L* value decreased ($P < 0.05$) from 0 to 12 h, and LT L* decreased ($P < 0.05$) from 0 h to 24 h. Interestingly, L* of cow LT and SS increased ($P < 0.05$) from 0 h to 12 h, and decreased ($P < 0.05$) from d 12 h to 24 h. This may be explained by delayed or further blooming of the ground beef.

Steer BF, LT, SM and ST had the highest L* values throughout display. For steer LT, SM and ST, L* values did not decrease ($P < 0.05$) over 96 h. Cow SM, SS and TB had among the lowest L* values on 0 h. Although cow SS was darker ($P < 0.05$) than steer SS on 0 h, their L* values did not differ at 24, 48, 72, or 96 h of display. This was not observed for SM and TB, for which cow L* values were consistently lower ($P < 0.05$) than steer L* values.

Both SS and TB had higher (P < 0.05) pH's than the other muscles, and accordingly, had the darkest (P < 0.05) 0 h L* values among steers. Similarly, cow SS and TB had slightly lower L* values than other cow muscles; however, the magnitude of difference between those and other cow muscles was not as great as what was observed for steer muscles.

*3.3 Redness: a**

An animal source x muscle x display time interaction (P < 0.05) was observed for a* value (Table 2.4). At 0 h, slight differences in a* values were observed. Steer LT, SM, and ST, and cow LT, had higher (P < 0.05) a* values than steer SS and cow BF, SS, and TB at 0 h. By 96 h, steer LT and all cow muscles (BF, LT, SM, SS, ST, BF) had higher (P < 0.05) a* values than steer BF, SM, SS, ST and TB. Except for steer LT and cow ST, a* values decreased between 0 and 12 h. Among the least red patties 96 h were those of steer BF, SM and TB.

Overall, ground beef from cow appeared redder than ground beef from steers and do not as clearly reflect color differences due to pH as L*. This is likely because the cow muscles contained more myoglobin than steer ground beef. However, when cow muscles were evaluated by age group (young, mature, or very mature), differences in a* due to age were not indicated (P > 0.05).

*3.4 Yellowness: b**

Both an animal source x display time interaction (P < 0.05) and an animal source x muscle interaction were observed (P < 0.05) for b* (Table 2.5). However, an animal source x muscle x time interaction was not observed (P > 0.05) for b*. Ground cow and steer muscle b* values gradually decrease over time, with 96 h b* values being lower (P < 0.05) than 0 h b* value for both groups. Interestingly, cow b* decreased (P < 0.05) between 0 and 12 h, and then increased (P < 0.05) from 12 to 24 h. Although b* values for SS, ST, and TB did not differ (P > 0.05) by animal source; b* values for BF, LT and SM did. Steers had more (P < 0.05) yellow BF, LT and SM than cows.

3.5 Surface discoloration: a/b**

Means for surface discoloration as indicated by the a*/b* ratio are presented in Table 2.6. For a*/b*, lower ratios are indicative of more discoloration (MMb). An animal source x muscle x display day interaction ($P < 0.05$) was observed for a*/b*. As expected, all treatments discolored during the display period. On d 0, a*/b* did not differ ($P > 0.05$) among treatments; however, reductions in a*/b* were observed for some treatments as early as 12 h. For cow BF, LT, SM and ST, and for steer ST, a*/b* did not decrease ($P > 0.05$) between 0 and 12 h, but decreased ($P < 0.05$) between 0 and 24 h. From 12 h onward, ground steer muscles tended to be more discolored than ground cow muscles within their respective h of display, most notably starting at 48 h. At 48 and 72 h, cow LT was less ($P < 0.05$) discolored than all other muscles. Also at 72 h, cow BF and SM was less ($P < 0.05$) discolored than steer BF, SM, SS, ST and TB. At 96 h, steer BF, SM, ST and TB were among the most discolored ground beef patties, and cow LT ground beef patties were the least discolored.

3.6 Saturation index

Least squares means for saturation index (**SI**) are presented in Table 2.7. For SI, an animal source x muscle x display time interaction ($P < 0.05$) was observed. At d 0, steer LT and SM, and cow LT, had a higher ($P < 0.05$) SI than steer and cow SS and TB. Other muscles were intermediate in SI. More conclusive differences in SI were observed at d 4 than other days during the display period. At 96 h, steer and cow LT had higher ($P < 0.05$) SI than steer BF, SM and TB. Steer BF had the least ($P < 0.05$) saturated color at 96 h. In general, the SI was higher for cow muscles than for steer muscles.

3.7 Hue angle

Hue angle (**HA**) experienced an animal source x muscle x display time interaction ($P < 0.05$) and least squares means are presented in Table 2.8 (higher HA indicates more MMb). Through 48 h of display, HA of all muscles did not differ ($P > 0.05$) within the same h of display. However, HA progressively increased throughout the display period indicating less red color. At 72 h, all ground cow muscles except SS and TB had lower ($P < 0.05$) HA than the same ground muscles from steers. At 96 h of

display, all cow muscles had lower ($P < 0.05$) HA than all steer muscles. Among steer muscles, BF, SM and TB had generally higher HA. Among cow muscles at 96 h, however, less discernable differences were observed, although ST had higher ($P < 0.05$) HA than cow BF, LT, and SM.

3.8 Fatty acid profile

The fatty acid profile for each muscle was determined and least squares means are reported in Table 2.9. Saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) were summed by into their respective categories (SFA, MUFA, PUFA) and evaluated.

Cow BF contained the most SFA ($P < 0.05$), and steer SM contained the least SFA ($P < 0.05$). Ranking muscles by SFA content, from the most ($P < 0.05$) CLA to the least ($P < 0.05$) CLA, indicates: Cow BF > Steer BF, ST, and Cow ST, TB > Steer SS and Cow SM, SS > Steer LT, TB > Steer SM. Cow LT was intermediate between steer BF, ST, cow ST, TB, and Steer SS, Cow SM, SS. Cow BF contained the most MUFA ($P < 0.05$) and steer SM contained the least ($P > 0.05$) MUFA. For MUFA, all cow muscles had more ($P < 0.05$) MUFA than the respective steer muscles. Cow LT contained more ($P < 0.05$) PUFA than all other muscles evaluated, and steer SM contained less ($P < 0.05$) PUFA than all other muscles evaluated.

4. Discussion

The application or feeding of metabolic modifiers to cattle used in this study did not affect meat color. When metabolic modifiers have been shown to darken lean color (Reiling and Johnson 2003), the implant regimen can be considered ‘aggressive’ (administering 2 or more implants over a given period). The color results of this study are similar to the results of Harborth (2006) and Hutchison (2007) who found that the use of β-andregenic implants or β-agonists did not affect *longissimus* color of fed cows. Muscle color as a function of age in the cow group (young, mature or very mature) was not significant in this study, analogous to the findings of Shemeis, Liboriussen and Bech

Anderson (1994) that lean color differed only nominally and not significantly by the cows age (when body condition is included as a covariate).

At 96 h of display, objective differences in the color properties of steer and cow muscles were observed. Cow muscles were generally darker (lower L*) colored and redder (higher a*), which is in agreement with the muscle profiling findings of Jones et al. (2005) and of Patten, Hodgen, Stelzleni, Calkins, Gwartney and Johnson (2008). Although Boleman, Miller, Buyck, Cross and Savell (1996) found that feeding concentrate diets to cull cows resulted in brighter colored lean compared to forage feeding of other cull cows, our results indicate that feeding cows 60 d immediately before slaughter does not improve their color characteristics such that they are comparable with young steers. Color differences in this study do not seem related to muscle pH.

Discoloration patterns indicate differences in the color stability of steer muscles compared with cow muscles. According to a*/b* ratio, ground cow muscles were generally less susceptible to discoloration than ground steer muscles. Hue angle values indicated more surface MMb for steer muscles than cow muscles.

Comparing individual muscles, LT was the most color stable ground muscle evaluated for both steers and cows. This was observed for a*,a*/b*, SI and HA, all of which can be used as an indicator for color stability. Ground LT appears to be a high color stability, ground ST and SS had intermediate colour stability, and ground BF, SM and TB had low color stability. This does not completely coincide with the color stability information determined by McKenna et al. (2005), which indicated that intact SS is a very low color stability muscle.

The reason for differences in the rank ordering of muscles from high to low color stability between intact versus ground beef data may be that grinding meat sufficiently disrupts or alters muscle metabolism to affect discoloration patterns. Why fewer discernable discoloration differences among ground muscles versus more discernable discoloration differences among ground steer muscles, however, is unclear. One plausible explanation for a lack of differences among muscles within an age group is that grinding exposed all meat to oxygen, whereas intact muscles are only exposed superficially. Not only would this give meat an opportunity to oxygenate, albeit for only

a short period before patty making, it could also alter meat respiration such that it was more equal between ground muscles than it would be for intact muscles.

Research evaluating the effects of feeding and/or animal age on carcass characteristics usually uses *longissimus* muscle, especially intact *longissimus*, as the sole indicator of carcass lean color (Aberle, Reeves, Judge, Hunsley & Perry; 1981; Bruce, Stark & Belkein, 2004, Reiling & Johnson, 2003; Shemeis, Liboriussen & Bech Anderson, 1994). Based on the results of this study, only using *longissimus* may be of positive or negative consequence depending on the objective of the study. For steers, longissimus data was indicative of more desirable meat color traits than other muscles within the carcass. *Longissimus* is one muscle; color traits of other muscles clearly vary. Given the various types and prevalence of muscle metabolism and muscle fibers, different muscles may be impacted differently. However, for fed cows, color traits tended to be less variable between muscles, thus lending the opportunity to serve as a better indicator of overall lean color (lean color throughout the carcass).

Fatty acid profiles obtained in this study are interesting and somewhat inconclusive in regard to the impact they may have on ground beef color. Generally, cow muscles contained more SFA and MUFA, and to a lesser degree more PUFA, than steer muscles. Perhaps the ratio of SFA and MUFA to PUFA, may help explain the desirable color stability of ground cow muscles. Greater relative proportions of SFA and MUFA to PUFA would render ground beef less susceptible to lipid oxidation.

5. Summary

Ground beef sourced from fed cows is darker appearing and redder than ground beef from similarly managed steers. Moreover, ground beef from fed cows discolored less than ground beef from steers. Differences in discoloration among ground steer muscles were greater than differences in discoloration among ground cow muscles. This research suggests that better color stability can be obtained from the use of ground fed cow muscles than ground steer muscles.

6. Conclusions

1) Neither administering Revalor®-200 nor feeding Optaflexx® during the finishing period affects ground beef color stability.

2) Cow chronological ages does not affect ground beef color stability when cattle are fed for 60 d immediately before slaughter.

3) At the beginning of display, ground beef redness (a*) will not differ between steers and fed cows.

4) Ground beef sourced from fed cows is darker appearing and redder than ground beef from similarly managed steers.

5) Cow ground beef exhibits better color stability than steer ground beef.

7. Implications

Case-ready ground beef can be produced using ground fed-cow muscles while maintaining color properties similar to, if not ever better than, ground steer muscles, likely at a reduced cost to the processor. Ground beef manufacturers can produce ground beef with improved color stability by using muscles from fed cows, especially if selecting for color stable muscles.

8. References

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Figure 2.1 Simplified experimental design and general project flow diagram

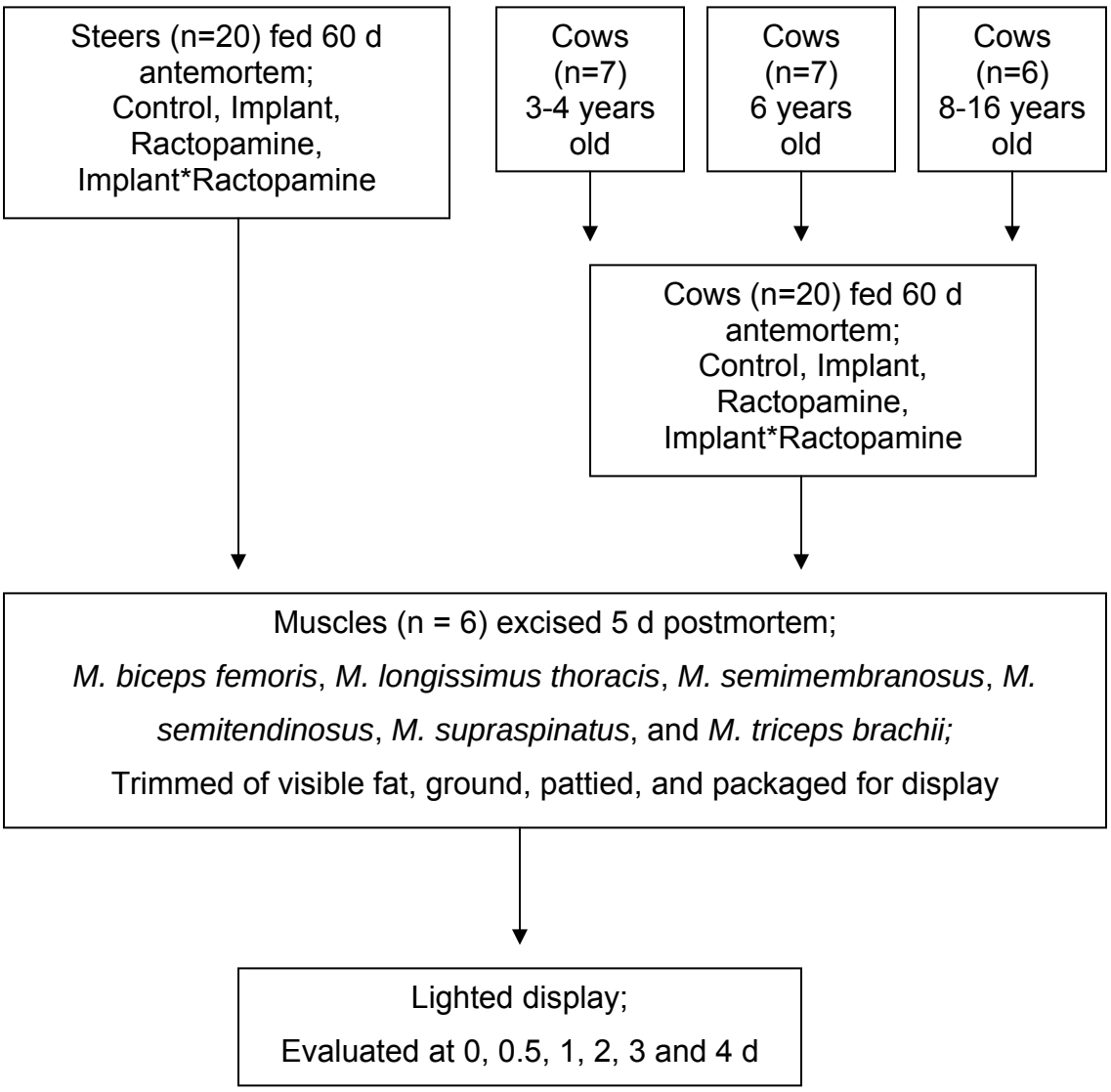

Table 2.1 Cow diet composition summary on a percentage dry matter basis

Ingredient	Diet 1[a]	Diet 2[b]	Diet 3[c]	Diet 4[d]
Grain sorghum wet distillers grains	20.00	20.00	20.00	20.00
Alfalfa hay	40.00	31.33	22.67	14.00
Steam flaked corn	35.89	44.56	53.22	61.89
R/T premix[e]	2.23	2.23	2.23	2.23
Mineral premix	1.88	1.88	1.88	1.88

[a] Fed d 1-3
[b] Fed d 4-6
[c] Fed d 7-9
[d] Fed d 10-60
[e] Premix to provide 300 mg monensin and 90 mg tylosin / cow per day

Table 2.2 pH least squares means for superficial and deep *M. semimembranosus* (SM), *M. biceps femoris* (BF), *M. semitendinosus* (ST), *longissimus thoracis* (LT), *M. triceps brachii* (TB), and *M. supraspinatus* (SS) muscles from fed steers and cows

Muscle	pH	Standard Error
Superficial SM	5.49[c]	0.049
Deep SM	5.60[b]	0.052
BF	5.54[bc]	0.052
ST	5.50[c]	0.048
LT	5.58[b]	0.051
TB	5.67[a]	0.053
SS	5.69[a]	0.047

[a-c] Means in any column or row with a common superscript letter do not differ ($P > 0.05$)

Table 2.3 L* least squares means (SE = 0.43-0.52) for six ground muscles from fed steers and cows displayed for 96 h under simulated retail conditions

Animal source[a]	Muscle[b]	*Display time, h*					
		0	**12**	**24**	**48**	**72**	**96**
S	**BF**	44.8^{c}	43.3^{cd}	43.4^{cd}	43.0^{d}	42.8^{d}	43.6^{cd}
S	**LT**	44.4^{c}	44.0^{c}	44.2^{c}	43.6^{cd}	43.3^{cd}	43.4^{cd}
S	**SM**	46.6^{c}	45.5^{c}	45.0^{c}	45.1^{c}	44.6^{c}	45.0^{c}
S	**SS**	41.7^{e}	40.8^{ef}	40.6^{ef}	40.9^{ef}	39.9^{ef}	40.1^{ef}
S	**ST**	46.1^{c}	45.0^{c}	45.9^{c}	44.9^{c}	44.9^{c}	45.8^{c}
S	**TB**	42.9^{d}	41.6^{de}	41.2^{de}	41.2^{de}	41.1^{de}	41.6^{de}
C	**BF**	40.2^{e}	40.9^{e}	38.2^{f}	38.1^{f}	38.4^{f}	38.6^{f}
C	**LT**	41.8^{de}	43.1^{de}	38.8^{fg}	39.2^{f}	39.3^{f}	39.4^{ef}
C	**SM**	40.8^{ef}	42.7^{de}	38.9^{fg}	38.5^{f}	38.0^{f}	39.0^{f}
C	**SS**	39.5^{f}	42.2^{d}	37.7^{f}	38.6^{f}	38.3^{f}	38.4^{f}
C	**ST**	42.4^{d}	43.1^{de}	40.5^{e}	40.6^{e}	40.4^{e}	40.5^{e}
C	**TB**	40.0^{f}	41.1^{e}	38.2^{f}	38.0^{f}	37.8^{f}	37.9^{f}

[a] Animal source: S = Steer; C = Cow
[b] Muscle: BF = *Biceps femoris*; LT = *Longissimus thoracis*; SM = *Semimembranosus*; SS = *Supraspinatus*; ST = *Semitendinosus*; TB = *Triceps brachii*
[c-f] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 2.4 a* least squares means (SE = 0.48-0.52) for six ground muscles from fed cows and steers displayed for 96 h under simulated retail conditions

Animal source[a]	Muscle[b]	*Display time, h*					
		0	**12**	**24**	**48**	**72**	**96**
S	**BF**	26.7^{cd}	22.6^{e}	21.7^{ef}	18.8^{g}	16.5^{i}	14.1^{j}
S	**LT**	28.1^{c}	26.2^{cd}	25.4^{d}	23.3^{e}	21.0^{ef}	19.6^{fg}
S	**SM**	27.9^{c}	24.7^{d}	22.5^{e}	20.6^{f}	17.6^{h}	15.5^{ij}
S	**SS**	25.2^{d}	22.4^{e}	22.2^{e}	20.6^{f}	18.5^{gh}	17.2^{hi}
S	**ST**	27.0^{c}	24.4^{de}	22.7^{e}	21.5^{ef}	18.5^{gh}	16.2^{i}
S	**TB**	26.0^{cd}	22.8^{e}	21.1^{ef}	20.0^{f}	17.4^{h}	15.5^{ij}
C	**BF**	25.2^{d}	22.0^{e}	22.0^{e}	20.2^{f}	19.4^{fg}	19.4^{fg}
C	**LT**	27.6^{c}	23.6^{de}	24.3^{d}	22.7^{e}	22.3^{e}	21.6^{ef}
C	**SM**	26.8^{cd}	22.5^{e}	22.4^{e}	20.2^{f}	20.2^{f}	19.8^{fg}
C	**SS**	25.4^{d}	22.6^{e}	22.2^{e}	19.7^{fg}	19.8^{fg}	19.3^{fg}
C	**ST**	26.4^{cd}	24.3^{d}	22.3^{e}	20.9^{ef}	20.2^{f}	18.8^{fg}
C	**TB**	25.6^{d}	21.7^{e}	21.9^{e}	20.1^{f}	18.9^{fg}	19.1^{fg}

[a] Animal source: S = Steer; C = Cow
[b] Muscle: BF = *Biceps femoris*; LT = *Longissimus thoracis*; SM = *Semimembranosus*; SS = *Supraspinatus*; ST = *Semitendinosus*; TB = *Triceps brachii*
[c-f] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 2.5 b* least squares means for six ground muscles from fed steers and cows displayed for 96 h under simulated retail conditions

Age Class	*Hour of display*						*Standard Error*
	0	**12**	**24**	**48**	**72**	**96**	
Steer	20.9^{b}	19.9^{bc}	19.5^{bc}	18.9^{c}	18.4^{cd}	18.0^{d}	0.51
Cow	20.5^{b}	18.0^{d}	19.3^{bc}	18.2^{cd}	18.3^{cd}	18.4^{cd}	0.49
	***Muscle*[a]**						***Standard Error***
	BF	**LT**	**SM**	**SS**	**ST**	**TB**	
Steer	18.7^{d}	20.5^{b}	19.7^{c}	18.6^{d}	19.5^{c}	18.6^{de}	0.50
Cow	18.3^{e}	19.7^{c}	18.7^{d}	18.5^{de}	19.2^{cd}	18.4^{e}	0.51

[a] Muscle: BF = *Biceps femoris*; LT = *Longissimus thoracis*; SM = *Semimembranosus*; SS = *Supraspinatus*; ST =*Semitendinosus*; TB = *Triceps brachii*

[b-e] Within days of display, or among muscles, means lacking a common superscript letter differ ($P < 0.05$)

Table 2.6 a* / b* least squares means (SE = 0.02-0.03) for six ground muscles from fed steers and cows displayed for 96 h under simulated retail conditions

Animal source[a]	Muscle[b]	*Display time, h*					
		0	**12**	**24**	**48**	**72**	**96**
S	**BF**	1.28^{c}	1.19^{ef}	1.14^{gh}	1.04^{ij}	0.91^{kl}	0.80^{m}
S	**LT**	1.29^{c}	1.24^{de}	1.20^{ef}	1.14^{gh}	1.09^{hi}	1.01^{jk}
S	**SM**	1.27^{cd}	1.19^{ef}	1.14^{gh}	1.07^{hi}	0.95^{jkl}	0.86^{lm}
S	**SS**	1.29^{c}	1.19^{ef}	1.16^{fg}	1.09^{hi}	1.01^{jk}	0.98^{jk}
S	**ST**	1.27^{cd}	1.21^{def}	1.16^{fg}	1.11^{gh}	0.98^{jk}	0.89^{l}
S	**TB**	1.29^{c}	1.18^{fg}	1.13^{gh}	1.10^{ghi}	0.96^{jkl}	0.86^{lm}
C	**BF**	1.28^{c}	1.28^{c}	1.16^{fg}	1.13^{gh}	1.10^{ghi}	1.06^{ij}
C	**LT**	1.28^{c}	1.30^{c}	1.20^{ef}	1.19^{ef}	1.14^{gh}	1.11^{gh}
C	**SM**	1.26^{cd}	1.26^{cd}	1.17^{fg}	1.13^{gh}	1.11^{gh}	1.08^{hi}
C	**SS**	1.29^{c}	1.25^{de}	1.17^{fg}	1.12^{gh}	1.08^{hi}	1.08^{hi}
C	**ST**	1.26^{cd}	1.27^{cd}	1.16^{fg}	1.13^{gh}	1.08^{hi}	1.06^{hi}
C	**TB**	1.29^{c}	1.25^{de}	1.15^{fg}	1.11^{gh}	1.06^{ij}	1.04^{ij}

[a] Animal source: S = Steer; C = Cow
[b] Muscle: BF = *Biceps femoris*; LT = *Longissimus thoracis*; SM = *Semimembranosus*; SS = *Supraspinatus*; ST = *Semitendinosus*; TB = *Triceps brachii*
[c-f] Means lacking a common superscript letter differ ($P < 0.05$)

Table 2.7 Saturation index[a] (SE = 0.41-0.50) least squares means for and ground muscles from fed steers and cows displayed for 96 h under simulated retail conditions

Animal source[a]	Muscle[b]	*Display time, h*					
		0	**12**	**24**	**48**	**72**	**96**
S	**BF**	33.9^{de}	29.6^{fg}	28.9^{fg}	26.0^{hij}	24.5^{kl}	22.6^{l}
S	**LT**	35.6^{d}	33.7^{de}	33.0^{ef}	30.9^{ef}	28.6^{fg}	27.6^{gh}
S	**SM**	35.5^{d}	32.3^{ef}	30.0^{ef}	28.1^{gh}	25.5^{kl}	24.0^{jkl}
S	**SS**	31.8^{ef}	29.3^{fg}	29.2^{fg}	27.9^{gh}	25.9^{kl}	24.5^{jk}
S	**ST**	34.3^{de}	31.7^{ef}	30.1^{ef}	28.9^{fg}	26.5^{hi}	24.5^{jk}
S	**TB**	32.9^{ef}	29.9^{fg}	28.2^{gh}	27.1^{hi}	25.0^{jk}	23.5^{kl}
C	**BF**	32.0^{ef}	28.0^{gh}	29.2^{fg}	27.3^{hi}	26.2^{hij}	26.6^{hi}
C	**LT**	35.0^{d}	29.9^{fg}	31.6^{ef}	29.6^{fg}	27.9^{gh}	29.0^{fg}
C	**SM**	34.2^{de}	28.8^{fg}	29.6^{fg}	27.0^{hi}	27.2^{hi}	27.0^{hi}
C	**SS**	32.3^{ef}	29.0^{fg}	29.2^{fg}	26.5^{hi}	26.9^{hi}	26.4^{hi}
C	**ST**	33.8^{de}	30.9^{ef}	29.4^{fg}	28.0^{gh}	27.6^{gh}	26.4^{hi}
C	**TB**	32.5^{ef}	27.9^{gh}	29.0^{fg}	27.1^{hi}	26.1^{ijk}	26.4^{hi}

[a] Saturation index: SI = $(a^{*2} + b^{*2})^{1/2}$
[b] Animal source: S = Steer; C = Cow
[c] Muscle: BF = *Biceps femoris*; LT = *Longissimus thoracis*; SM = *Semimembranosus*; SS = *Supraspinatus*; ST = *Semitendinosus*; TB = *Triceps brachii*
[d-l] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 2.8 Hue angle[a] least squares means (SE = 1.04-1.15) for six ground muscles from fed steers and cows and displayed for 96 h under simulated retail conditions

Animal source[a]	Muscle[b]	*Display time, h*					
		0	**12**	**24**	**48**	**72**	**96**
S	**BF**	38.4^{hi}	39.9^{gh}	40.1^{gh}	44.7^{fg}	48.1^{de}	52.4^{d}
S	**LT**	37.2^{hi}	38.2^{hi}	38.8^{ghi}	41.1^{gh}	44.2^{f}	45.7^{f}
S	**SM**	36.3^{hi}	38.6^{hi}	40.9^{gh}	41.9^{gh}	46.4^{ed}	49.7^{de}
S	**SS**	36.4^{hi}	39.6^{gh}	40.0^{gh}	41.8^{gh}	44.3^{fg}	46.6^{ef}
S	**ST**	35.8^{i}	37.6^{hi}	40.4^{gh}	41.9^{gh}	47.8^{e}	48.3^{de}
S	**TB**	35.7^{i}	39.2^{ghi}	42.6^{g}	42.7^{g}	46.8^{ef}	49.7^{de}
C	**BF**	36.0^{i}	39.8^{gh}	40.4^{gh}	41.7^{gh}	43.0^{g}	42.9^{g}
C	**LT**	36.6^{i}	39.9^{gh}	39.1^{ghi}	41.1^{gh}	41.3^{g}	42.2^{g}
C	**SM**	34.6^{i}	39.9^{gh}	39.9^{gh}	42.3^{g}	42.0^{g}	42.4^{g}
C	**SS**	35.9^{i}	39.3^{ghi}	39.6^{gh}	42.9^{g}	43.0^{g}	43.3^{fg}
C	**ST**	36.6^{hi}	38.6^{hi}	39.0^{ghi}	42.6^{g}	43.5^{gf}	45.3^{f}
C	**TB**	36.0^{i}	40.3^{gh}	39.9^{gh}	42.5^{g}	44.9^{f}	43.7^{fg}

[a] Hue angle: HA = $\tan^{-1}$(b*/a*)fg
[b] Animal source: S = Steer; C = Cow
[c] Muscle: BF = *Biceps femoris*; LT = *Longissimus thoracis*; SM = *Semimembranosus*; SS = *Supraspinatus*; ST = *Semitendinosus*; TB = *Triceps brachii*
[d-i] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 2.9 Stearic acid (C18:0), conjugated linoleic acid (CLA), and total saturated fatty acid (SFA), monounsaturated fatty acid (MUFA), and polyunsaturated acid (PUFA) least squares means for six ground muscles from fed cows and steers

Age Class[a]	Muscle[b]	*Percentage of sample*				
		C18:0	**CLA**	**SFA**	**MUFA**	**PUFA**
S	**BF**	0.381^{ef}	0.036^{d}	1.768^{e}	1.962^{de}	0.311^{de}
S	**LT**	0.600^{d}	0.110^{c}	1.145^{f}	1.234^{e}	0.281^{e}
S	**SM**	0.266^{g}	0.006^{f}	0.928^{g}	0.946^{f}	0.276^{e}
S	**SS**	0.520^{de}	0.010^{e}	1.635^{e}	1.184^{e}	0.319^{de}
S	**ST**	0.311^{f}	0.010^{e}	1.927^{e}	1.802^{e}	0.279^{e}
S	**TB**	0.445^{e}	0.006^{f}	1.191^{f}	1.182^{e}	0.282^{e}
C	**BF**	0.556^{d}	0.023^{e}	3.370^{c}	4.325^{c}	0.385^{c}
C	**LT**	1.214^{c}	0.020^{e}	1.901^{de}	2.370^{d}	0.341^{cd}
C	**SM**	0.355^{ef}	0.017^{e}	1.765^{e}	1.982^{de}	0.308^{bc}
C	**SS**	0.549^{d}	0.006^{f}	1.723^{e}	1.927^{de}	0.289^{e}
C	**ST**	0.437^{e}	0.009^{ef}	2.058^{d}	2.542^{d}	0.322^{d}
C	**TB**	0.662^{d}	0.013^{e}	2.230^{d}	2.388^{d}	0.340^{cd}
Standard Error		0.051	0.008	0.322	0.038	0.012

[a] Animal source: S = Steer; C = Cow
[b] Muscle: BF = *Biceps femoris*; LT = *Longissimus thoracis*; SM = *Semimembranosus*; SS = *Supraspinatus*; ST = *Semitendinosus*; TB = *Triceps brachii*
[c-f] Means within column lacking a common superscript letter differ ($P < 0.05$)

CHAPTER III

Contributions of muscles of various color stabilities to the overall color life of ground beef

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Abstract

The effects of blending ground muscles of different color stability on ground beef display color life were investigated. Ground muscles were pre-ranked as high (**HCS**, *M. longissimus thoracis*), intermediate (**ICS**, *M. semimembranosus*) or low color stability (**LCS**, *M. triceps brachii*). Six formulations combining HCS, ICS, and LCS muscles were: 50% HCS + 50% ICS; 50% HCS + 50% low; 50% ICS + 50% LCS; 33.3% HCS + 33.3% ICS + 33.3% LCS; 75% HCS + 25% LCS; and 25% HCS + 75% LCS. Formulations were adjusted to 90% and 80% lean using young beef trim resulting in 12 treatment combinations. Patties (114 g) for each treatment (n = 4 replications) were packaged in HiO_2 MAP, held in dark storage 5 d, then displayed 4 d. Visual color and instrumental color were evaluated. The 80% lean patties containing ≥ 50% HCS had the highest ($P < 0.05$) initial visual color. At d 2 and 3 of display, the 75% HCS + 25% LCS at both lean points had the most cherry-red ($P < 0.05$) display color. In general, patties with higher proportions of HCS had greater metmyoglobin reducing activity throughout display. All packages were unacceptably discolored by d 4 of display. Combinations of HCS, ICS and LCS muscle can be mixed without adverse color affects, provided LCS muscle is ≤ 25%, and HCS muscle is ≥ 50% of the blend.

Key Words: Ground beef, color stability, beef color, cow meat

1. Introduction

Minimal research is available comparing the contributions of muscles differing in their color properties make on the overall color of ground beef. Suman, Faustman, Lee, Tang, Sepe and Vasudevan et al. (2004) investigated the effects of muscle source on premature browning in ground beef. Lean was sourced from USDA Choice *posas major* to represent color-labile muscles, and from USDA Choice *longissimus lumborum* to represent color-stabile muscles. Muscles were trimmed of excess visible fat, ground, and formed into patties. Fat content beyond removal of external fat was not controlled. Instrumental color was measured at 15 min, 48 h and 96 h after patty manufacture. Patties made from *psoas major* had higher initial L* and lower a* values than patties made from *longissimus lumborum*. The authors attributed higher L* and lower a* values of *psoas major* patties to greater fat content compared with *longissimus lumborum* patties. For both *psoas major* and *longissimus lumborum* patties, a* values decreased during storage. Also, the total reducing ability of all patties decreased during storage, and muscle source did not affect reducing ability.

The color data presented in muscle profiling research is for intact, whole-muscle steaks and not ground or minced beef. McKenna, Mies, Baird, Pfeiffer, Ellebracht and Savell (2005) characterized beef muscles based upon the biochemical factors affecting meat discoloration, and muscles were separated into 4 groups: High color stability muscles (*M. longissimus lumborum*, *M. longissimus thoracis*, *M. semitendinosus*, and *M. tensor faciae latae*); Intermediate color stability muscles (*M. semimembranosus*, *M. rectus femoris*, *M. vastus lateralis*, *M. trapezius*, *M. gluteus medius*, and *M. latissimus dorsi*); Low color stability muscles (*M. triceps brachi* – long head, *M. triceps brachi* – lateral head, *M. biceps femoris*, *M. pectoralis profundus*, and *M. adductor*); and Very Low color stability muscles (*M. supraspinatus*, *M. infraspinatus*, and *M. psoas major*).

McKenna et al. (2005) also evaluated metmyoglobin reductase activity (MRA) of the same muscles. *M. longissimus lumborum* had high MRA and was categorized as a high color stability muscle. *M. psoas major* had low MRA and was categorized as a very low color stability muscle. Conversely, *M. semitendinosus*, *M. semimembranosus*, *M. rectus femoris*, and *M. tensor faciae latae* tended to have lower MRA, which does not correspond to their high to intermediate color stability status. Atkison & Follett

(1973) found that MRA is not related to the discoloration rate of beef, pork or lamb. Recent reviews of MRA-inclusive studies suggest that differences in MRA methodologies may be responsible the reported inconsistencies (Mancini & Hunt, 2005).

The objective of the research described in this chapter was to identify the color contributions that muscles of varying color stability make to the overall color life of ground beef when blended and displayed.

2. Materials and Methods

2.1 Sampling

Ground muscles from fed mature cows were ranked according to color stability, from which the individual cow muscles exhibiting the highest, most intermediate, and lowest a* values over the display period were thawed and used from the muscle color characterization described in Chapter 2. The following muscles were used: *M. longissimus thoracis* (high color stability - **HCS**), *M. semimembranosus* (intermediate color stability - **ICS**), and *M. triceps brachii* (low color stability - **LCS**).

Six ground beef formulations combining muscles of varying color stability were used: 1) 50% HCS + 50% ICS; 2) 50% HCS + 50% LCS; 3) 50% ICS + 50% LCS; 4) 33.3% HCS + 33.3% ICS + 33.3% LCS; 5) 75% HCS + 25% LCS; and 6) 25% HCS + 75% LCS. Each mixture was formulated at both 90% and 80% lean points for a total of 12 treatment combinations. Trim from USDA A-maturity beef carcasses was obtained 2 d postmortem and was used to achieve the desired lean point for each treatment. Trim was obtained by sampling from 4 combos from one shift's production (Cargill Meat Solutions, Dodge City, KS). The denuded muscles and beef trim were coarse-ground (1.58 cm plate), evaluated for their respective fat content (AOAC 98515), blended according to their prescribed lean point, and then fine-ground (0.48 cm plate) using a Hobart grinder (Hobart Corp., Troy, OH). Two patties (each 114 g) from each batch were made by hand using a mold. All samples were produced and packaged at the Cargill Meat Solutions Product Development Center (Wichita, KS), and transported to the Kansas State University Meat Color Laboratory for further analyses.

2.2 Packaging, storage, and display

Ground beef patties were packaged in 4.32 cm-deep rigid plastic trays (CS977, Cryovac Sealed Air Corp., Duncan, SC) and covered with oxygen-barrier film (Lid 550; 1.0 mils; < 20.0 oxygen transmission cc/24 h/m^2 at 4.4 °C and 100% relative humidity (RH); and less than 0.1 moisture vapor transmission g/24 h/645.2 cm^2 at 4.4°C and 100% RH; Cryovac Sealed Air Corp., Duncan, SC). Patties were packaged (Ross Jr. S-3180, Ross, Midland, VA) in a high-oxygen (80% O_2, 20% CO_2; AirGas certified gas, MidSouth, Inc., Tulsa, OK) modified atmosphere (**HiO_2 MAP**). Because measuring instrumental color in MAP requires opening a package, 2 extra packages of each treatment were made for d 0 and d 2 of display only, and those for use on d 4 were also those evaluated by the visual panel. Packages were stored in dark conditions for 5 d at 2±1 °C. Packages were displayed for 4 d under continuous fluorescent lighting (2153 lux, 3000K and CRI=85, Bulb Model F32T8/ADV830/ Alto, Phillips, Bloomfield, NJ) at 2°C in coffin-type retail display case (Unit Model DMF8, Tyler Refrigeration Corp., Niles, MI). To maintain random case placement, packages were rotated daily.

2.3 pH

Ground muscle pH was measured by inserting the tip of pH probe (MPI pH probe, glass electrode, Meat Probes Inc., Topeka, KS) into the ground muscles. The pH was measured in triplicate and averaged.

2.4 Instrumental color evaluation

Instrumental color (**L***, **a***, and **b***; Illuminant A) was measured using a HunterLab MiniScan™ XE Plus Spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer; Hunter Associates Laboratory, Inc., Reston, VA) at 0, 2, and 4 d of display. Instrumental color was scanned in triplicate and averaged. From this data, the following instrumental color measurements were made or calculated: 1) surface discoloration: **a* / b***; 2) color saturation index: **SI** = $(a^{*2} + b^{*2})^{1/2}$; and 3) hue angle: **HA** = $\tan^{-1}$ (b*/a*).

2.5 Visual color evaluation

Visual panelists (*n* = 6) were required to pass the Farnsworth Munsell 100-hue test (Macbeth, Newsburgh, NY) and conducted visual color evaluations during 4 d of lighted display. On d 0, initial color was evaluated on an 8-point scale, and panelists were instructed to score patties to the nearest 0.5 visual color unit. The scale used for initial color was: 1 = bleached, pale red, 2 = slightly cherry red, 3 = moderately light cherry red, 4 = cherry red, 5 = slightly dark red, 6 = moderately dark red, 7 = dark red, and 8 = very dark red. Display visual color was scored on an 8-point scale to the nearest 0.5 unit according to the following scale: 1 = very bright red or pinkish-red, 2 = bright red or pinkish-red, 3 = dull red or pinkish-red, 4 = slightly dark red or pinkish-red, 5 = reddish-tan or pinkish-tan, 6 = moderately dark red or reddish-tan or moderately dark pinkish-red or pinkish-tan, 7 = tannish-red or tannish-pink, and 8 = tan to brown. Panelists considered a score of 5.5 to be borderline acceptable color.

2.6 Thiobarbituric acid reactive substances (TBARS) analysis

A modified procedure of Witte, Krause, and Bailey (1970) was used for thiobarbituric acid reactive substances (**TBARS**) extraction and quantification. The TBARS samples were taken on d 0, 2 and 4 of display and pulverized in liquid nitrogen. Ten g of pulverized sample was combined with 10 ml of perchloric acid and 20 ml of cold distilled water. A Whatman No. 2 filter paper was used to filter the blended samples, and the TBARS reagent was added. Samples were stored at approximately 27 °C for 24 h. Absorbance was at 529.5 nm, and then a standard equation was used to determine TBARS concentration. The TBARS are reported at mg malonaldehyde per 1 g meat sample.

2.7 Metmyoglobin-reducing activity (MRA)

A modified procedure of Sammel, Hunt, Kropf, Hachmeister, and Johnson (2002) was used to quantify metmyoglobin-reducing activity (**MRA**). A 2.54 cm x 2.54 cm x 1.5 cm section was taken from the center of each ground beef patty sampled on d 0, 2 and 4 of display. Samples were then submerged in a 0.3% $NaNO_2$ (Sodium nitrite, Sigma-Aldrich, St. Louis, MO) solution for 20 min to induce metmyoglobin (**MMb**) development. Samples were carefully removed from solution to prevent crumbling, lightly blotted, and

vacuum packaged (3-mil, standard-barrier nylon/polyethylene, 0.6 cm^3 oxygen / 645.16 cm^2 / 24 h at 0 °C; Koch Supplies, Inc., Kansas City, MO). Immediately after vacuum packaging, samples were scanned twice using a HunterLab MiniScan™ XE Plus Spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer; Hunter Associates Laboratory, Inc., Reston, VA). Because the ground beef samples did not maintain a three-dimensional shape after packaging, the 2.54-cm aperture could be used. Samples were then incubated at 30 °C for 2 h (Thelco Model 4, Precision Scientific, Chicago, IL) to induce the reduction of MMb to deoxymyoglobin. Following incubation, samples were rescanned twice. Pre- and post-incubation MMb was calculated as a percentage using K/S ratios and equations (AMSA, 1991). This equation was used to determine MRA: MRA = (∆% surface MMb ÷ pre-incubation surface MMb) x 100.

2.8 Fatty acid analysis

A modified gas chromatography procedure of Sukhija and Palmquist (1988) was used for fatty acid analysis. Muscle samples for fatty acid analysis were pulverized in liquid nitrogen in order to facilitate fatty acid extraction and sample uniformity. Analysis was conducted using a gas chromatograph (Shimadzu model GC9-AM, Columbia, MD) with a flame ionization detector containing a Supelco column (SM 2560, 100 m x 0.25 mm x 0.2 µm; Supelco, Bellefonte, PA) was used. A 1-µl injection volume was used to determine a complete fatty acid profile of the muscle samples. Samples were injected and held for 15 min at 140 °C, and then increased to 240 °C at a rate of 4 °C per min. Total runtime was 45 min per sample.

2.9 Statistical analysis

This experiment was a split-plot design with the whole plot being lean combination treatment. Lean point was the subplot. Day of display served as a repeated measure. The experiment was replicated 4 times. Data were analyzed with **MIXED** procedure of **SAS** (SAS Institute, Inc., Cary, NC). The model statement included the selected response and all possible interactions between lean combination, lean point and day of display. Satterthwaite adjustments were used for the degrees of

freedom. Pairwise comparisons of least squares means were used to determine significant differences ($P < 0.05$) when respective F-tests were significant ($P < 0.05$).

3. Results

3.1 Visual color

Prior to display, packages were held in dark storage (2 ºC) to mimic shipment and retail storage conditions of meat in MAP. For initial color, a muscle combination x lean point combination interaction was observed ($P < 0.05$; Table 3.1). Figure 3.2 illustrates the approximate initial color of each treatment. The trained panel scored the treatments of 50% HCS + 50% ICS, 50% HCS + 50% LCS, and 75% HCS + 25% LCS at the 80/20 lean point to have the most cherry-red color ($P < 0.05$). The 50% HCS + 50% ICS, 75% HCS + 25% LCS, and 50% HCS + 50% LCS combinations at 90/10 were intermediate in initial color scores. The initial color score of 50% ICS + 50% LCS at both lean points did not differ ($P > 0.05$). As expected, the 25% HCS + 75% LCS combination had the lowest ($P < 0.05$) initial color score within each lean point.

Display color scores experienced a treatment x lean point x day interaction ($P < 0.05$; Table 3.2). As expected, treatments of 75% HCS + 25% LCS and 50% HCS + 50% ICS, at both lean points, had the most bright red (lowest score, $P < 0.05$) display color scores, and maintained that advantage through 2 d of display. At d 2 and d 3, the combination of 90/10 75% HCS + 25% LCS had the most cherry-red (lowest score, $P < 0.05$) display color score. By d 2, visual color scores 90/10 50% HCS + 50% LCS, 50% ICS + 50% LCS, and 25% HCS + 75% LCS exceeded the visual color acceptability threshold of 5.5. By d 4, all samples had visual scores beyond the acceptability threshold, with the combinations of 75% HCS + 25% LCS and 50% HCS + 50% ICS at 80/20 and 90/10 still having the lowest ($P < 0.05$) visual color scores.

3.2 Instrumental color

A treatment x lean point x day interaction ($P < 0.05$) also was observed for instrumental color measurements. For lightness (L*), combinations containing $\geq$ 50% HCS lean and < 50% LCS lean experienced minor decreases in L* during the 4 d

display period. The 90/10 combinations were darker (lower L*) in color for each treatment, though not always statistically significant ($P > 0.05$). By d 4, 90/10 and 80/20 25% HCS + 75% LCS had the darkest ($P < 0.05$) instrumental color.

The 80/20 75% HCS + 25% LCS had the reddest (largest a*, $P < 0.05$) color by d 4, followed by 90/10 75% HCS + 25% LCS (Table 3.4). At d 0, however, few differences within or among lean points were observed. At d 2, both lean points for 75% HCS + 25% LCS had superior ($P < 0.01$) a* values. Interestingly, at d 2, 80/20 and 90/10 50% HCS + 50% ICS and 50% ICS + 50% LCS had lower ($P < 0.05$) a* values than 80/20 and 90/10 25% HCS + 75% LCS. The 80/20 50% HCS + 50% ICS had the next progressively reddest ($P < 0.05$) color at d 4. The 80/20 25% HCS + 75% LCS had the least red color at d 4. Combinations containing ≥ 50% LCS muscles generally had lower a* values by d 4 of display.

Athough b* values underwent a muscle combination x lean point x display day interaction ($P < 0.05$), few differences were observed (Table 3.5). For 80/20 and 90/10 75% HCS + 25% LCS did not decrease ($P > 0.05$) during the 4 d display period. Conversely, all other treatments had lower ($P < 0.05$) b* values by d 4, with treatments containing higher proportions of LCS tending to have lower b* values.

A muscle combination x lean point x display day interaction ($P < 0.05$) indicated a general decline in a*/b* ratio, or increase in surface discoloration, over the 4 d display period (Table 3.6). At d 0, no differences ($P > 0.05$) for a*/b* was observed. However, by d 4, 80/20 75% HCS + 25% LCS had the least ($P < 0.05$) a*/b* discoloration. The 90/10 50% HCS + 50% LCS was less ($P < 0.05$) than its 80/20 counterpart at d 4.

The 90/10 75% HCS + 25% LCS and 33% HCS + 33% ICS + 33% LCS had less ($P < 0.05$) saturated color at d 0 than other treatments. By d 4, 80/20 and 90/10 75% HCS + 25% LCS had the most ($P < 0.05$) saturated color. Saturation index values decreased ($P < 0.05$) between d 0 and d 2 for all treatments except 75% HCS + 25% LCS. Overall, the 75% HCS + 25% LCS at both lean points exhibited the least decline in SI over the display period

Hue angle values are presented in Table 3.8. A d 0, HA did not differ ($P > 0.05$) among muscle combination or lean point. Though not necessarily statistically

significant, both lean points for 75% HCS + 25% LCS had the lowest HA values by d 4, indicating the least trending toward metmyoglobin development.

3.3 Fatty acid profiles

Differences in fatty acid profile between lean source combination treatments within lean point were not significant ($P > 0.2$). This is not surprising because the same fat source was used to achieve the desired 90/10 and 80/20 lean points. As expected, the 80/20 lean point samples had higher ($P < 0.05$) concentrations of stearic acid, total SFA, and total MUFA. Total PUFA did not differ ($P > 0.05$) between 80/20 and 90/10 lean point combinations.

3.4 Thobarbituric acid reactive substances (TBARS)

Interactions between treatment, lean point, and display day was not observed in this study ($P > 0.05$). At times, the standard error of the least squares means were nearly equal to that of the TBARS value of the sample. Even so, general trends can be identified that support the color data, and TBARS data is summarized in Table 3.9. Sample TBARS were very high (>2.00 mg malonaldehyde / g meat) at the onset of display (d 0). Packages were stored in a HiO_2 modified atmosphere for 5 d prior to display, and it is possible that the large increase in TBARS occurred during the dark storage. At the time of fabrication, all treatment combinations had TBARS < 1.20 mg malonaldehyde / g meat and the oxidative age of the fat source was acceptable. As expected, the 80/20 combinations for each treatment had higher TBARS values than the 90/10 combinations or each day of display. In addition, the treatments of 50% HCS + 50% ICS and 75% HCS + 25% LCS had the lowest TBARS values at d 2 and d 4 of display.

3.5 Metmyoglobin-reducing activity (MRA)

The percentage of MMb reduced to DMb was the highest ($P < 0.05$) for 75% HCS + 25% LCS and 33% HCS + 33% ICS + 33% LCS at both lean points at d 0 (Table 3.11). Similar MRA patterns were observed throughout display. The lowest ($P < 0.05$) MRA observed was for 80/20 25% HCS + 75% LCS. The 80/20 and 90/10 50% HCS +

50% LCS and 25% + 75% LCS generally exhibited the least MRA throughout the display period.

4. Discussion

Overall, the inclusion of HCS muscle in ground beef proportionately improved the display color life of ground beef, and the inclusion of LCS muscle decreased the overall color life of ground beef. With the advent of MAP packaging and overall trend for its increased use (Eilert, 2005; Mize & Kelly, 2004), the results of this study indicate that incorporation of high proportions (75%) of HCS into ground beef formulations may be beneficial to maximizing the display color life of ground beef packaged in HiO_2 MAP.

As opposed to maximizing display life of HiO_2 MAP ground beef, means by which to reduce rapid discoloration are also of great interest to the meat industry. In this study, the inclusion of ≥ 50% LCS resulted in reduced display color life, in addition to contributing a darkening affect to the display color of ground beef.

Suman et al. (2004) are among the only researchers to report color data of ground muscles emphasizing their respective color stability classification. Even so, literature reporting interactions, or lack of interactions, of ground muscles of differing color to the overall color stability of ground beef have not been published.

The 75% HCS + 25% LCS and 33% HCS + 33% ICS + 33% LCS reduced the most MMb to DMb, and also had more desirable color stability data than the other treatments. From this, one may suspect that those treatments had a greater pool of NAD to drive MMb reduction since MMb reductase is largely NAD-dependant enzyme (Behkit & Faustman, 2005). Blends containing > 33% HCS and no LCS reduced less MMb to DMb. This may be due to procedural flaws in MRA evaluation since the procedure used was designed for intact muscle and not ground muscle.

This suggests that LCS muscles can be incorporated into ground beef up to a level of 25% while in combination with HCS muscles without adverse color life effects. Increased use of ICS also has potential to improve the display color stability of ground beef. Inclusion of > 25% LCS muscles had overall negative effects on the instrumental color measurements during the display period.

5. Summary

Certain muscles from cows can be viably used in ground beef operations to optimize ground beef display color life. When muscle color stability is known, or when muscle characterization can be applied in a commercial setting, combinations of high, intermediate and low color stability muscle can be mixed, provided the inclusion rate of low color stability muscle does not exceed 25%, and that high color stability muscle comprises at least 50% of the blend. Moreover, the use of high color stability can be more optimally managed to lengthen display color life of ground beef.

6. Conclusions

1) Using ≥ 25% LCS in ground beef formulations shortens ground beef color life.

2) Ground beef color life is optimized when ≥ 50% of the lean source is HCS.

7. Implications

Inclusion of low levels (~33%) of low color stability muscle has deleterious effects on ground beef display color life. Minimizing product discounting and/or discarding due to discoloration is obtainable by avoiding the use of low color stability lean in ground beef blends. For ground beef intended to be displayed fresh, longer color life can be obtained by **(1)** using intermediate to high color stability muscles and by **(2)** avoiding low color stability muscles. Other points-of-sale for low color stability ground beef includes foodservice or ground beef sold in vacuum chubs.

8. References

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Figure 3.1 Experimental design and general project flow diagram

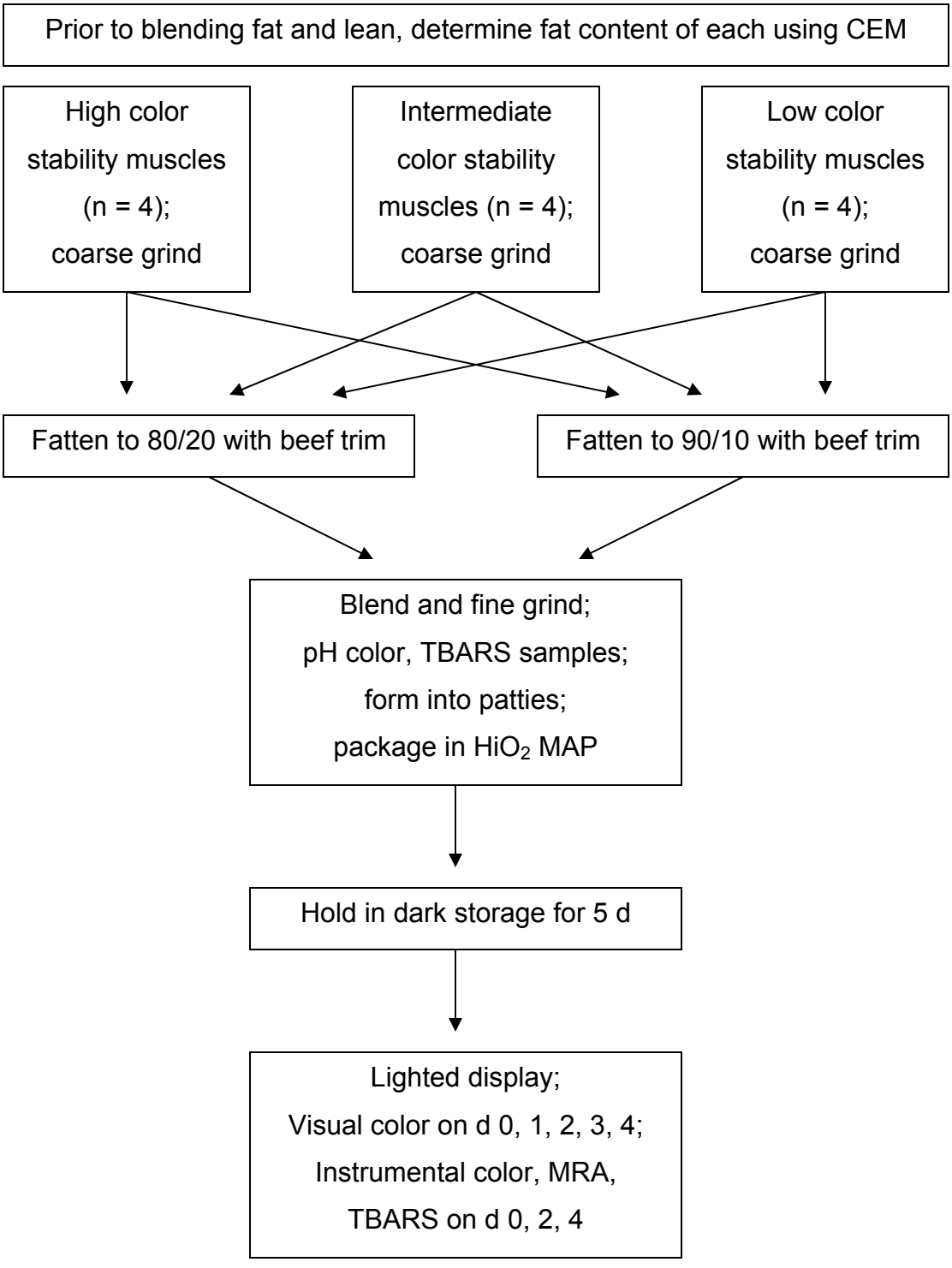
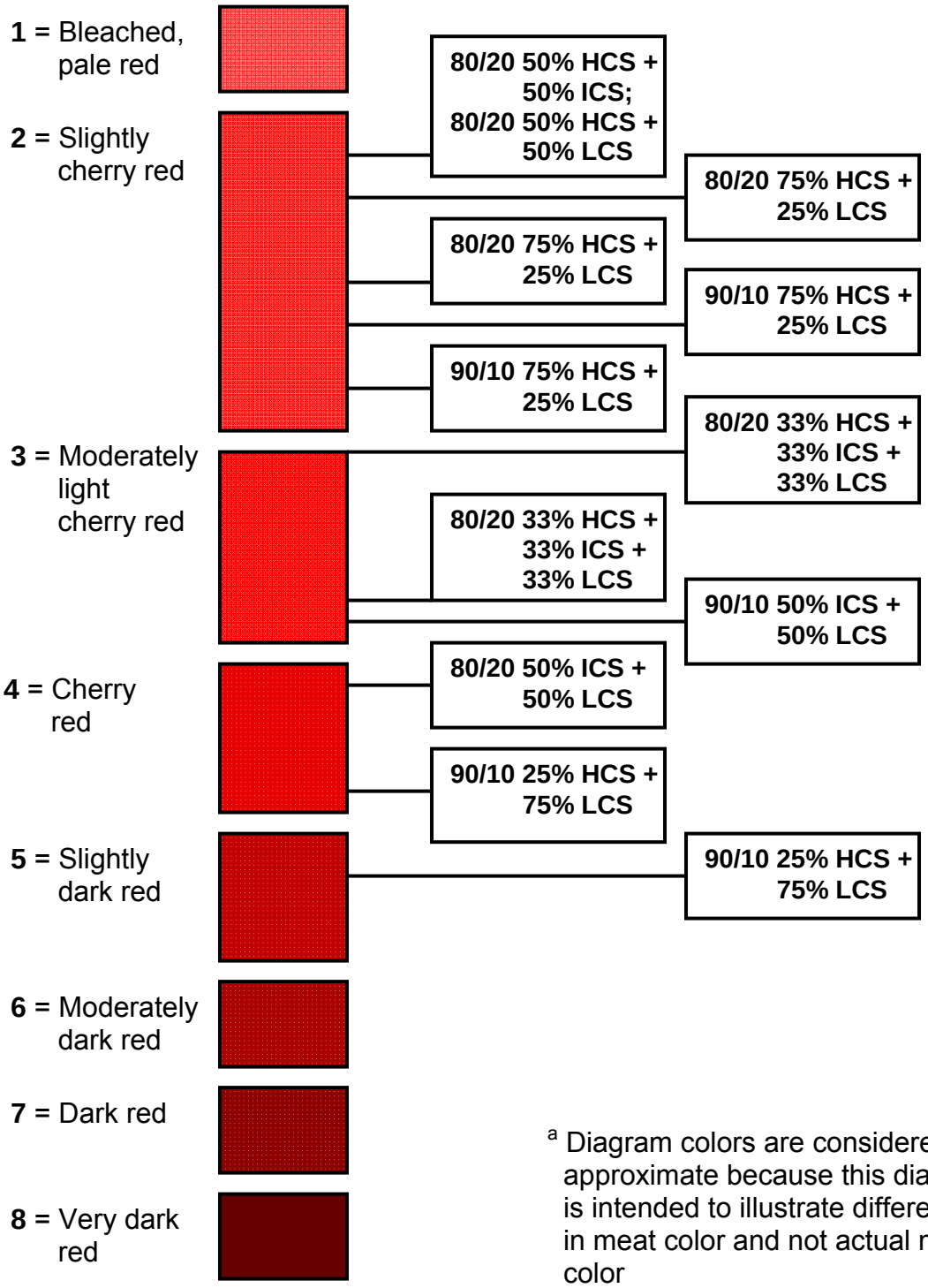


Figure 3.2 Map of approximated[a] initial visual color scores for ground beef formulated with different proportions of high color stability (HCS), intermediate color stability (ICS), and low color stability (LCS) muscles blended to 80/20 and 90/10 lean points



[a] Diagram colors are considered approximate because this diagram is intended to illustrate differences in meat color and not actual meat color

Table 3.1 Initial color score[a] least squares means (SE = 0.1-0.2) for ground beef patties sourced from muscles of high (HCS), intermediate (ICS), and low color stability (LCS) formulated to 80% and 90% lean points

Muscle combination	Lean point	
	80/20	**90/10**
75% HCS + 25% LCS	2.4[b]	2.7[cd]
50% HCS + 50% ICS	2.3[b]	2.6[c]
50% HCS + 50% LCS	2.3[b]	2.9[d]
50% ICS + 50% LCS	3.8[e]	3.9[e]
33% HCS + 33% ICS + 33% LCS	3.0[d]	4.1[e]
25% HCS + 75% LCS	4.9[f]	5.4[g]

[a] 1 = bleached, pale red, 2 = slightly cherry red, 3 = moderately light cherry red, 4 = cherry red, 5 = slightly dark red, 6 = moderately dark red, 7 = dark red, 8 = very dark red

[b-g] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 3.2 Display color score[a] least squares means (SE 0.22-0.31) for ground beef patties sourced from muscles of high (HCS), intermediate (ICS), and low color stability (LCS) formulated to 80% and 90% lean points displayed for 4 d in high oxygen MAP

Muscle combination	*Lean point within day of display*									
	d 0		d 1		d 2		d 3		d 4	
	80/20	90/10	80/20	90/10	80/20	90/10	80/20	90/10	80/20	90/10
75% HCS + 25% LCS	1.8^{b}	2.1^{b}	2.2^{b}	2.4^{c}	2.8^{cd}	3.1^{d}	3.2^{d}	3.3^{d}	6.3^{i}	6.7^{ij}
50% HCS + 50% ICS	2.0^{b}	2.1^{b}	2.6^{c}	2.7^{cd}	3.7^{e}	4.4^{ef}	3.5^{d}	4.6^{f}	7.2^{j}	7.0^{ij}
50% HCS + 50% LCS	2.4^{c}	2.5^{c}	3.2^{d}	3.4^{d}	5.4^{g}	5.8^{h}	3.8^{e}	5.9^{e}	8.0^{k}	8.0^{k}
50% ICS + 50% LCS	3.4^{d}	3.4^{d}	3.8^{e}	3.9^{e}	5.1^{f}	5.9^{h}	5.9^{h}	6.0^{h}	8.0^{k}	7.9^{k}
33% HCS + 33% ICS + 33% LCS	3.1^{d}	3.3^{d}	3.3^{d}	3.6^{de}	4.7^{f}	5.0^{f}	4.6^{f}	5.5^{g}	8.0^{k}	8.0^{k}
25% HCS + 75% LCS	3.8^{e}	4.1^{e}	4.0^{e}	4.2^{e}	6.7^{i}	6.5^{i}	7.6^{jk}	7.5^{j}	8.0^{k}	8.0^{k}

[a] 1 = very bright red or pinkish red, 2 = bright red or pinkish red, 3 = dull red or pinkish red, 4 = slightly dark red or pinkish red, 5 = reddish tan or pinkish tan, 6 = moderately dark red or reddish tan or moderately dark pinkish red or pinkish tan, 7 = tannish red or tannish pink, and 8 = tan to brown

[b-k] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 3.3 L* values least squares means (SE = 0.78-1.0) for ground beef patties sourced from muscles of high (HCS), intermediate (ICS), and low color stability (LCS) formulated to 80% and 90% lean points displayed for 4 d in high oxygen MAP

Muscle combination	*Lean point within day of display*					
	d 0		**d 2**		**d4**	
	80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
75% HCS + 25% LCS	57.0^{a}	55.2^{b}	54.6^{b}	54.2^{b}	57.2^{a}	52.1^{bc}
50% HCS + 50% ICS	59.4^{a}	57.9^{ab}	57.5^{b}	55.8^{b}	57.2^{a}	54.6^{b}
50% HCS + 50% LCS	56.3^{ab}	55.5^{b}	56.8^{ab}	54.8^{b}	49.5^{c}	49.1^{c}
50% ICS + 50% LCS	51.5^{bc}	49.6^{c}	55.4^{b}	49.8^{c}	54.4^{b}	51.3^{bc}
33% HCS + 33% ICS + 33% LCS	56.8^{ab}	56.9^{ab}	55.8^{b}	54.2^{b}	52.2^{bc}	50.4^{c}
25% HCS + 75% LCS	49.3^{c}	48.5^{cd}	50.3^{c}	47.7^{d}	47.5^{d}	47.8^{d}

$^{a-d}$ In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 3.4 a* value least squares means (SE = 1.32-1.43) for ground beef patties sourced from muscles of high (HCS), intermediate (ICS), and low color stability (LCS) formulated to 80% and 90% lean points displayed for 4 d in high oxygen MAP

Muscle combination	*Lean point within day of display*					
	d 0		**d 2**		**d4**	
	80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
75% HCS + 25% LCS	30.5^{a}	27.3^{b}	26.6^{b}	25.2^{b}	23.4^{b}	19.9^{c}
50% HCS + 50% ICS	30.5^{a}	31.0^{a}	17.5^{d}	20.1^{c}	16.5^{d}	14.9^{e}
50% HCS + 50% LCS	30.1^{ab}	30.9^{a}	14.4^{e}	14.6^{e}	10.7^{h}	13.7^{eg}
50% ICS + 50% LCS	31.5^{a}	33.1^{a}	11.7^{g}	13.5^{f}	12.5^{g}	12.1^{g}
33% HCS + 33% ICS + 33% LCS	30.0^{ab}	26.5^{b}	18.1^{d}	20.5^{c}	12.5^{g}	13.5^{eg}
25% HCS + 75% LCS	32.2^{a}	31.8^{a}	19.5^{cd}	18.0^{d}	10.1^{h}	13.0^{eg}

$^{a-d}$ In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 3.5 b* value least squares means (SE = 0.61-0.69) for ground beef patties sourced from muscles of high (HCS), intermediate (ICS), and low color stability (LCS) formulated to 80% and 90% lean points displayed for 4 d in high oxygen MAP

Muscle combination	*Lean point within day of display*					
	d 0		**d 2**		**d4**	
	80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
75% HCS + 25% LCS	21.6^{a}	21.3^{a}	20.0^{a}	18.2^{c}	19.9^{ab}	19.3^{ab}
50% HCS + 50% ICS	22.8^{a}	22.6^{a}	19.4^{ab}	18.4^{c}	16.9^{bc}	17.1^{bc}
50% HCS + 50% LCS	21.7^{a}	22.3^{a}	17.8^{b}	17.6^{bc}	14.7^{cd}	15.6^{c}
50% ICS + 50% LCS	21.8^{a}	21.6^{a}	14.5^{c}	16.3^{c}	14.6^{cd}	15.2^{c}
33% HCS + 33% ICS + 33% LCS	22.7^{a}	21.8^{a}	16.8^{bc}	15.5^{c}	13.8^{cd}	13.7^{cd}
25% HCS + 75% LCS	22.3^{a}	22.7^{a}	18.3^{b}	18.7^{ab}	12.2^{d}	14.4^{cd}

$^{a-d}$ In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 3.6 a*/b* value least squares means (SE = 0.07-0.09) for ground beef patties sourced from muscles of high (HCS), intermediate (ICS), and low color stability (LCS) formulated to 80% and 90% lean points displayed for 4 d in high oxygen MAP

Muscle combination	*Lean point within day of display*					
	d 0		**d 2**		**d4**	
	80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
75% HCS + 25% LCS	1.35^{ab}	1.28^{b}	1.03^{d}	1.38^{a}	1.18^{c}	1.03^{c}
50% HCS + 50% ICS	1.34^{ab}	1.37^{a}	0.90^{e}	1.09^{c}	1.02^{c}	0.87^{e}
50% HCS + 50% LCS	1.39^{a}	1.39^{a}	0.81^{e}	0.83^{e}	0.73^{f}	1.01^{c}
50% ICS + 50% LCS	1.44^{a}	1.44^{a}	0.79^{e}	0.83^{e}	0.86^{e}	0.89^{e}
33% HCS + 33% ICS + 33% LCS	1.43^{a}	1.43^{a}	1.08^{c}	1.32^{b}	0.91^{e}	0.80^{e}
25% HCS + 75% LCS	1.44^{a}	1.44^{a}	1.06^{d}	0.96^{c}	0.83^{e}	0.90^{e}

$^{a-f}$ In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 3.7 Saturation index[a] least squares means (SE = 1.33-1.64) for ground beef patties sourced from muscles of high (HCS), intermediate (ICS), and low color stability (LCS) formulated to 80% and 90% lean points displayed for 4 d in high oxygen MAP

Muscle combination	*Lean point within day of display*					
	d 0		**d 2**		**d4**	
	80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
75% HCS + 25% LCS	38.0[a]	34.6[b]	33.3[b]	31.1[bc]	30.7[bc]	27.7[c]
50% HCS + 50% ICS	38.1[a]	38.4[a]	26.1[c]	27.3[c]	23.6[d]	22.7[d]
50% HCS + 50% LCS	37.1[a]	38.1[a]	22.9[d]	22.9[d]	18.2[e]	20.8[de]
50% ICS + 50% LCS	38.3[a]	39.5[a]	18.6[e]	21.2[de]	19.2[e]	19.4[e]
33% HCS + 33% ICS + 33% LCS	37.6[a]	34.3[b]	24.7[c]	25.7[c]	18.6[e]	19.2[e]
25% HCS + 75% LCS	39.2[a]	39.1[a]	26.7[c]	26.0[c]	15.8[f]	19.4[e]

[a-f] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 3.8 Hue angle[a] least squares means (SE = 1.7-1.9) for ground beef patties sourced from muscles of high (HCS), intermediate (ICS), and low color stability (LCS) formulated to 80% and 90% lean points displayed for 4 d in high oxygen MAP

Muscle combination	*Lean point within day of display*					
	d 0		**d 2**		**d4**	
	80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
75% HCS + 25% LCS	35.3[a]	38.0[ab]	40.6[ab]	35.8[a]	40.4[ab]	44.1[bc]
50% HCS + 50% ICS	36.8[a]	36.1[a]	47.9[cd]	42.5[b]	45.7[c]	48.9[cd]
50% HCS + 50% LCS	35.8[a]	35.9[a]	51.0[d]	50.3[d]	53.9[d]	48.7[cd]
50% ICS + 50% LCS	34.8[a]	33.1[a]	51.1[d]	50.4[d]	49.3[d]	51.5[d]
33% HCS + 33% ICS + 33% LCS	37.1[a]	39.4[a]	42.9[b]	37.1[a]	47.8[cd]	45.4[c]
25% HCS + 75% LCS	34.7[a]	35.5[a]	43.0[bc]	46.1[c]	50.1[cd]	47.9[cd]

[a-d] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 3.9 Observed TBARS (SE = 1.87-2.30) for ground beef patties sourced from muscles of high (HCS), intermediate (ICS), and low color stability (LCS) formulated to 80% and 90% lean points displayed for 4 d in high oxygen MAP

Muscle combination	*Lean point within day of display*					
	d 0		**d 2**		**d4**	
	80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
75% HCS + 25% LCS	2.49	2.13	5.03	2.62	4.43	3.21
50% HCS + 50% ICS	3.10	2.65	3.65	3.81	4.59	4.54
50% HCS + 50% LCS	2.74	2.37	3.67	3.18	5.41	4.50
50% ICS + 50% LCS	2.92	2.50	4.03	3.40	6.13	4.77
33% HCS + 33% ICS + 33% LCS	2.87	2.47	3.77	3.02	5.87	3.84
25% HCS + 75% LCS	2.63	2.00	4.11	3.62	5.03	4.75

Table 3.10 Metmyoglobin reducing activity (MRA[a]) least squares means (SE = 2.18-2.55) for ground beef patties sourced from muscles of high (HCS), intermediate (ICS), and low color stability (LCS) formulated to 80% and 90% lean points displayed for 4 d in high oxygen MAP

Muscle combination	*Lean point within day of display*					
	d 0		**d 2**		**d 4**	
	80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
75% HCS + 25% LCS	27.3[a]	25.8[a]	13.7[bc]	15.6[b]	8.2[d]	7.1[de]
50% HCS + 50% ICS	15.7[b]	11.8[c]	9.4[cd]	8.9[d]	5.4[f]	5.7[f]
50% HCS + 50% LCS	11.9[c]	9.7[cd]	7.6[de]	6.8[e]	3.8[g]	3.6[g]
50% ICS + 50% LCS	12.6[c]	14.3[b]	10.2[cd]	8.7[d]	5.4[f]	4.8[fg]
33% HCS + 33% ICS + 33% LCS	28.7[a]	29.4[a]	16.7[b]	15.3[b]	10.7[cd]	11.6[c]
25% HCS + 75% LCS	7.8[d]	8.9[d]	5.6	6.8[e]	2.7[h]	3.8[g]

[a] MRA = (∆% surface MMb ÷ pre-incubation surface MMb) x 100
[b-h] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

CHAPTER IV

Cow biological type affects ground beef color stability

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Abstract

The objective was to determine if cow biological type (beef versus dairy) affects the color stability of ground beef. *M. semimembranosus* from commercially identified beef cows (**BSM**) and dairy cows (**DSM**) were obtained 5 d postmortem and trimmed of all visible fat. Three lean source blends were made: 100% BSM; 50% BSM + 50% DSM; 100% DSM. Formulations were adjusted to 90% and 80% lean points using young beef trim (**YBT**) or beef cow trim (**BCT**). Four replications of 12 treatment combinations were made into 114 g patties and packaged in high oxygen (80% O_2) modified atmosphere. Packages were held in dark storage 5 d then displayed 4 d. The 80/20 blend of 100% BSM had the brightest cherry-red ($P < 0.05$) initial color. The 80/20 blend of 100% DSM with BCT and 90/10 blend of 50% BSM + 50% DSM with BCT had the darkest ($P < 0.05$) initial color. Patties containing 100% DSM with BCT at both lean points had the best ($P < 0.001$) color stability at d 4. Patties from 100% BSM discolored by d 2 of display. Ground DSM combinations exhibited greater ($P < 0.05$) metmyoglobin reducing activity than ground BSM combinations. Patties fattened with BCT also contained more conjugated linoleic acid than patties fattened with YBT. Using BCT improved overall color life. Color stability of patties made from DSM had equal or better color stability compared to patties made from BSM.

Key Words: Ground beef, Color stability, Dairy cow, Beef cow

1. Introduction

Selective breeding based on the desired function or ultimate output of cattle has resulted in two distinct biological types of cattle: beef-type and dairy-type. Complimenting the prescribed use of the animal while optimizing the economics of animal rearing, two general systems of animal management production systems for mature cows have developed: non-confined housing + low-energy diets (typical to beef cow management), and confined housing + high-energy diets (typical to dairy cow management). Moreover, dairy-type cows are slaughtered at a younger average age than beef-type cows, largely due to differences in animal productivity as a function of age. Breed-type, housing system, diet, and age are all considered factors that affect beef color.

Stelzlini, Patten, Johnson, Calkins and Gwartney (2007) conducted a study aimed at benchmarking differences between beef cow and dairy cow carcasses. In comparing fed versus non-fed diary cows, they found that carcass lean color was similar, yet fed dairy cows had whiter fat. Also, they found that fed beef cows had brighter lean and whiter fat than non-fed beef cows, and that lean color of non-fed beef cows did not differ from non-fed dairy cows.

Wanatabe, Sato, Tsuneishi and Matsumoto (1993) reported that ultimate carcass pH of forage-fed cattle tends to be higher than that the pH of grain-fed cattle. Accordingly, Vestergaard, Oksberg and Henckel (2000) suggested that forage-based diets promote oxidative muscle metabolism instead of anaerobic muscle metabolism, thereby leading to reduced glycogen storage ability and subsequently, a smaller postmortem pH decline. Likewise, Bruce, Stark and Beilken (2004) found that meat from pastured steers was darker than meat from concentrate-fed steers. Concentrate feeding of cows results in brighter, redder lean than compared to forage-fed cows (Price & Berg, 1981). Boleman, Miller, Buyck, Cross and Savell (1996) found that cows fed a high-energy, high-protein diet for 28, 56, or 84 d antemortem yielded carcasses with brighter, redder lean color than cows fed a low-energy, low-protein diet fed for the same durations.

Dunne, Monahan, O'Mara and Moloney (2005) hypothesized that exercise causes the accumulation of reactive oxygen species and may increase postmortem lipid

oxidation, therefore accelerating meat discoloration. Vestergaard et al. (2000) found that meat from loose-housed forage-fed bulls was darker and contained more pigment compared to tie stall-housed concentrate-fed bulls. Color and pigment differences were attributed to housing conditions, not diet. In this study, meat from loose-housed forage-fed bulls had increased slow-contracting muscle fibers, was more vascularized, and exhibited greater oxidative metabolic potential than tie stall-housed concentrate-fed bulls. Bowling, Smith, Carpenter, Dutson and Oliver (1977) suggested that forage-fed (pastured) cattle may be more stress-susceptible than concentrate-fed (feedlot) cattle because feedlot-raised cattle were raised with much more handling and human exposure.

Graafhuis and Devine (1994) found that cow beef has a higher pH, and subsequently a darker color, than young beef. Shemeis, Liboriussen and Bech Anderson (1994) reported that carcass color darkened and fat became more yellow as cattle become older; however, only minor color changes due to age in *longissimus dorsi* were observed due to age. In contrast, Sawyer, Mathis and Davis (2004) observed that lean color tends (P = 0.11) to darken as cattle age.

Cow beef is generally accepted to be lower quality (i.e., considered less tender, darker colored, and more likely to exhibit off-flavors) than young beef and therefore, a greater proportion of cow beef is used to produce ground beef. Although these two types of cattle differ in many ways that are linked to meat color, ground beef color and color stability related to cow biological type has not been investigated. The objective of the experiment described in the following pages was to determine whether or not cow biological type (beef-type versus dairy-type) affects the overall color dynamics of ground beef.

2. Materials and Methods

2.1 Sampling

Inside rounds from beef cows (n = 4) and dairy cows (n = 4) were obtained 3 d postmortem from a commercial abattoir (Cargill Meat Solutions, Milwaukee, WI). Plant

employees determined carcass classification as beef-type or dairy-type. *M. semimembranosus* is considered an intermediate color stability muscle, hence its use in this experiment. All cuts were trimmed of visible external fat. Trimmed inside rounds were separately coarse-ground (1.58 cm plate; Hobart grinder, Hobart Corp, Troy, OH). Young beef trim (**YBT**) was obtained 2 d postmortem by sampling 4 different combos from 1 day's production (Cargill Meat Solutions, Dodge City, KS). Beef cow trim (**BCT**) was obtained 2 d postmortem by sampling from 4 different combos from one shift's production (Cargill Meat Solutions, Milwaukee, WI). The YBT and BCT also were coarse ground. After coarse grinding, three lean combinations were formed: 100% beef cow lean (**BSM**), 50% BSM and 50% dairy cow lean (**DSM**), and 100% DSM. For each combination, the ground beef was formulated to both 90% and 80% lean points, for a total of 12 (3 lean combinations x 2 fat sources x 2 lean points) treatment combinations. The fat content of BSM, DSM, YBT and BCT was determined using the CEM (AOAC 98515) method prior blending to facilitate accurate lean point formulation. After formulation, blends were mixed and fine-ground (0.48 cm plate; Hobart grinder, Hobart Corp, Troy, OH). The process was replicated four times. Sufficient product per replication was made such that 12 patties (114 g each) could be made using a hand mold. All samples were produced at the Cargill Meat Solutions Product Development Center (Wichita, KS), and then transported to the Kansas State University Meat Color Laboratory for further analyses.

2.2 Packaging, storage, and display

Ground beef patties were packaged (n = 2 patties per package) in 4.32 cm-deep rigid plastic trays (CS977, Cryovac Sealed Air Corp., Duncan, SC) and covered with oxygen-barrier film (Lid 550; 1.0 mils; < 20.0 oxygen transmission cc/24 h/m^2 at 4.4 °C and 100% relative humidity (RH); and less than 0.1 moisture vapor transmission g/24 h/645.2 cm^2 at 4.4°C and 100% RH; Cryovac Sealed Air Corp., Duncan, SC). Patties were packaged (Ross Jr. S-3180, Ross, Midland, VA) in a high-oxygen (80% O_2, 20% CO_2; AirGas certified gas, MidSouth, Inc., Tulsa, OK) modified atmosphere (**HiO_2 MAP**). Because measuring instrumental color in MAP requires opening a package, 2 extra packages of each treatment were made for d 0 and d 2 of display only, and those for

use on d 4 were also those evaluated by the visual panel. Packages were stored in dark conditions for 5 d at 2±1 °C. Packages were displayed for 4 d under continuous fluorescent lighting (2153 lux, 3000K and CRI=85, Bulb Model F32T8/ADV830/Alto, Phillips, Bloomfield, NJ) at 2°C in coffin-type retail display case (Unit Model DMF8, Tyler Refrigeration Corp., Niles, MI). To maintain random case placement, packages were rotated daily.

2.3 pH

The pH of each ground beef formulation was measured by inserting the tip of pH probe (MPI pH probe, glass electrode, Meat Probes Inc., Topeka, KS) into ground beef. The pH was measured in triplicate and averaged.

2.4 Instrumental color evaluation

Instrumental color (L*, a*, and b*; Illuminant A) was measured using a HunterLab MiniScan™ XE Plus Spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer; Hunter Associates Laboratory, Inc., Reston, VA) at 0, 2, and 4 d of display. Instrumental color was scanned in triplicate and averaged. From the instrumental color data, the following color measurements were calculated:Lightness: 1) surface discoloration: **a* / b***; 2) color saturation index: **SI** = $(a^{*2} + b^{*2})^{1/2}$; and 3) hue angle: **HA** = $\tan^{-1}$ (b*/a*)

2.5 Visual color evaluation

Visual panelists (*n* = 6) were required to pass the Farnsworth Munsell 100-hue test (Macbeth, Newsburgh, NY) and conducted visual color evaluations during 4 d of lighted display. On d 0, initial color was evaluated on an 8-point scale, and panelists were instructed to score patties to the nearest 0.5 visual color unit. The scale used for initial color was: 1 = bleached, pale red, 2 = slightly cherry red, 3 = moderately light cherry red, 4 = cherry red, 5 = slightly dark red, 6 = moderately dark red, 7 = dark red, and 8 = very dark red. Display visual color was scored on an 8-point scale to the nearest 0.5 unit according to the following scale: 1 = very bright red or pinkish red, 2 = bright red or pinkish red, 3 = dull red or pinkish red, 4 = slightly dark red or pinkish red, 5 = reddish tan or pinkish tan, 6 = moderately dark red or reddish tan or moderately dark

pinkish red or pinkish tan, 7 = tannish red or tannish pink, and 8 = tan to brown. Panelist considered a score of 5.5 to be borderline acceptable color.

2.6 Thiobarbituric acid reactive substances (TBARS) analysis

A modified procedure of Witte, Krause, and Bailey (1970) was used for thobarbituric acid reactive substances (**TBARS**) extraction and quantification. The TBARS samples were taken on d 0, 2 and 4 of display and pulverized in liquid nitrogen. Ten g of pulverized sample was combined with 10 ml of perchloric acid and 20 ml of cold distilled water. A Whatman No. 2 filter paper was used to filter the blended samples, and the TBARS reagent was added. Samples were stored at approximately 27 °C for 24 h. Absorbance was at 529.5 nm, and then a standard equation was used to determine TBARS concentration. The TBARS are reported at mg malonaldehyde per 1 g meat sample.

2.7 Metmyoglobin-reducing activity (MRA)

A modified procedure of Sammel, Hunt, Kropf, Hachmeister, and Johnson (2002b) was used to quantify metmyoglobin-reducing activity (**MRA**). A 2.54 cm x 2.54 cm x 1.5 cm section was taken from the center of each ground beef patty sampled on d 0, 2 and 4 of display. Samples were then submerged in a 0.3% $NaNO_3$ (Sodium nitrite, Sigma-Aldrich, St. Louis, MO) solution for 20 min to induce metmyoglobin (**MMb**) development. Samples were carefully removed from solution to prevent crumbling, lightly blotted, and vacuum packaged (3-mil, standard-barrier nylon/polyethylene, 0.6 cm^3 oxygen / 645.16 cm^2 / 24 h at 0 °C; Koch Supplies, Inc., Kansas City, MO). Immediately after vacuum packaging, samples were scanned twice using a HunterLab MiniScan™ XE Plus Spectrophotometer (Model 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer; Hunter Associates Laboratory, Inc., Reston, VA). Because the ground beef samples did not maintain a three-dimensional shape after packaging, the 2.54-cm aperture could be used. Samples were then incubated at 30 °C for 2 h (Thelco Model 4, Precision Scientific, Chicago, IL) to induce the reduction of MMb to deoxymyoglobin (**DMb**). Following incubation, samples were rescanned twice. Pre- and post-incubation MMb was calculated as a percentage using K/S ratios and

equations (AMSA, 1991). This equation was used to determine MRA: MRA = (Δ% surface MMb ÷ pre-incubation surface MMb) x 100.

2.8 Fatty acid analysis

A modified gas chromatography procedure of Sukhija and Palmquist (1988) was used for fatty acid analysis. Muscle samples for fatty acid analysis were pulverized in liquid nitrogen in order to facilitate fatty acid extraction and sample uniformity. Analysis was conducted using a gas chromatograph (Shimadzu model GC9-AM, Columbia, MD) with a flame ionization detector containing a Supelco column (SM 2560, 100 m x 0.25 mm x 0.2 µm; Supelco, Bellefonte, PA) was used. A 1-µl injection volume was used to determine a complete fatty acid profile of the muscle samples. Samples were injected and held for 15 min at 140 °C, and then increased to 240 °C at a rate of 4 °C per min. Total runtime was 45 min per sample.

2.9 Statistical analysis

The experiment had a split-split-plot design, with biological-type treatment being the whole-plot factor and fat source and lean point were the subplot factors (Figure 4.1). Data were analyzed with **MIXED** procedure of **SAS** (SAS Institute, Inc., Cary, NC). The model included the selected response and all possible interactions between cow type, fat type, lean point and day of display (day of display served as a repeated measure). When respective F-tests were significant ($P < 0.05$), pairwise comparisons of least squares means were used to determine significant differences ($P < 0.05$).

3. Results

3.1 pH

Ground DSM (pH 5.7) tended to have a higher ($P = 0.08$) pH than ground BSM (pH 5.5). However, when blended and fattened, the pH of treatments did not differ ($P > 0.10$).

3.2 Visual color

For initial color, a lean source x fat source x lean point ($P < 0.05$) was observed (Table 4.1). Initial visual color for each treatment is outlined in Figure 4.2. The trained color panel determined that 80/20 ground BSM regardless of fat source had the brightest-red ($P < 0.05$) initial color score (moderately light cherry red). The ground 90/10 DSM and ground 90/10 BSM + DSM had intermediately dark red initial color. The 90/10 ground DSM fattened with BCT had the darkest ($P < 0.05$) initial color score, described as moderately dark red.

A lean source x fat source x lean point x display day interaction ($P < 0.05$) was observed for visual display color (Table 4.2). At the start of display, ground DSM blended with YBT or BCT had the lowest visual display color scores. In general, ground DSM fattened with either YBT or BCT were scored darker at the beginning of display. The BSM + DSM fattened YBT or BCT were intermediately red at d 0 of display. The combination of DSM fattened with BCT yielded superior ($P < 0.001$) visual color score at d 4. This combination maintained a dull-red color through d 3 of display. The DSM fattened with YBT developed a tannish-red color by d 3 of display and had superior color compared with the remaining treatments containing BSM or BSM + DSM. Treatments containing only BSM discolored more rapidly, developing a tannish-red color by d 2 of display. The combination treatment of BSM + DSM yielded intermediate visual display color scores. The DSM with either fat source were the only treatments considered salable (visual color score < 5.5) at 4 d.

3.3 Instrumental color

A lean source x fat source x lean point x display day interaction ($P < 0.05$) was observed for instrumental color responses. As well, BSM beef fattened with YBT had higher ($P < 0.05$) L* values at d 4 of display than ground BSM with BCT, and a similar trend was observed in all lean-source treatment combinations (Table 4.3). Thus, the ground SM with YBT had a lighter, whiter color as expected, than those with BCT. The lightest ($P < 0.05$) color at d 4 of display was for ground BSM and BSM + DSM fattened with YBT. The initial (d 0) L* value for ground DSM and BSM + DSM fattened BCT was

lower ($P < 0.05$) than the other treatment combinations. For most lean source combinations, the 80/20 blends had higher ($P < 0.05$) L* values throughout display.

The a* values over time for each treatment are summarized in Table 4.4. Ground DSM fattened with either YBT or BCT, had higher ($P < 0.05$) a* values throughout display than ground BSM fattened with either YBT or BCT. By day 4, a* values of ground DSM were superior ($P < 0.001$) to ground BSM. The combination treatment of BSM + DSM was intermediate to the DSM-only and BSM-only treatments after d 0.

The b* least squares means are reported in Table 4.5. Over the 4 d display period, b* values tended to decrease. By d 4, 90/10 BSM fattened with either BCT or YBT had the highest b* values.

Distinctive differences in a*/b* was observed during the display period (Table 4.6). At d 0, a*/b* for all treatments except BSM fattened with YBT did not differ ($P > 0.05$). By day 2, all DSM-only combinations and 90/10 BSM + DSM fattened with BCT had higher ($P < 0.05$) a*/b* ratios than the BSM-only treatments. Similar ratios were observed on d 4 of display.

Saturation indices of ground beef decreased ($P < 0.05$) for all blends of BSM, DSM, BCT and YBT from d 0 to d 4 (Table 4.7). By d 4, DSM formulated with BCT had the highest ($P < 0.05$) SI. The DSM formulated with YBT, and the BSM + DSM ground beef had the second most saturated color at d 4. The lowest SI values observed at d 4 was for ground beef made from BSM.

Hue angle data is presented in Table 4.8. Interestingly, HA for DSM formulated to either 80/20 or 90/10 with either YBT or BCT decreased over the display period, indicating a trend away from MMb. The lowest HA ($P < 0.05$) was at d 4 observed for DSM fattened with BCT. For BSM formulated to 90/10 or 80/20 with either YBT or BCT, HA increased throughout display. The HA increased ($P < 0.05$) from d 0 to d 2 for BSM formulated to 80/20 and 90/10 with YBT, but did not increase ($P > 0.05$) further from d 2 to d 4. Interestingly, HA 80/20 BSM + DSM formulated with BCT was highest ($P < 0.05$) at d 2, and then decreased ($P < 0.05$) from d 2 to d 4. In general, formulations containing BCT had lower HA values by d 4.

3.4 Fatty acid profile

Table 4.11 outlines the stearic acid (**C18:0**), total conjugated linoleic acid (**CLA**), saturated fatty acid (**SFA**), monounsaturated fatty acid (**MUFA**) and polyunsaturated fatty acid (**PUFA**) least squares means of ground beef evaluated in this experiment. As expected, all lean combinations fattened with YBT to 80% lean had higher ($P < 0.001$) concentrations of stearic acid than all lean combinations fattened with BCT to 90/10.

Rank ordering of 6 highest observed CLA concentrations was: BSM + DSM (80/20; BCT) > DSM (80/20; BCT) > DSM (90/10; BCT) > BSM + DSM (90/10; BCT) > BSM (90/10; BCT) > BSM + DSM (80/20; BSM). Thus, the incorporation of dairy cow lean may have a positive effect on ground beef CLA concentration. The BSM fattened to 80% with YBT had the least ($P < 0.05$) CLA.

Interestingly, total SFA was higher ($P < 0.05$) for ground BSM fattened to 90% than for ground BSM fattened to 80/20. Also, ground DSM and ground BSM + DSM generally had higher concentrations of MUFA than ground BSM without the addition of ground DSM.

3.5 Thiobarbituric acid reactive substances (TBARS)

For TBARS, interactions between lean source, fat source, lean point and display day were not observed ($P > 0.05$). The standard error of the means was at times nearly equal to the value of the mean itself. It is well established that lipid oxidation is clearly linked to perceived color and overall color stability. While the initial (d 0) TBARS values were not unacceptable, some very high TBARS values (> 2 mg malonaldehyde / g meat) were observed at d 0. For ground BSM, 80% lean samples had lower TBARS values than the 90% lean samples, which is an expected result since fatter blends should have relatively less unsaturated fat. In agreement with the color data, the lipid oxidation data indicate that the DSM-only treatments fattened with BCT had the lowest d 4 TBARS values.

3.6 Metmyoglobin-reducing activity (MRA)

In general, BCT substantially increased MRA of ground beef blends, and ground beef formulated with YBT had less MRA than did ground formulated with BCT. The

reasons for this are not fully apparent, but they are interesting and indicate potential for blending operations using cow lean and/or fat.

Ground DSM reduced significantly greater amounts of MMb ($P < 0.05$) than all other treatments throughout the display period. However, by d 4 of display, the percentage of MMb reduced in the ground BSM and ground BSM + ground DSM was nominal.

4. Discussion

Both DSM and BCT have a positive effect on the color life of ground beef when packaged in HiO_2 MAP. Case-ready MAP packaging is occupying more retail meat display case space than ever (Eilert, 2005; Mize & Kelly, 2004). Using DSM and/or BCT may help prolong the display life of ground beef compared to the use of BSM and/or YBT.

Before differences in ground beef color found in this study can be further discussed, it must be reaffirmed that classification as beef-type or dairy-type was determined by packing plant personnel. Other unknowns about the cattle source of the lean used in this study include fed versus non-fed, and if fed, the diet fed, animal age, among others. Similar uncertainties exist for the BCT trim used in this experiment. Although BCT was obtained from different combos of Beef 50's, further information about the source of the trim is unknown and might potentially offer further explanations about why BCT had heightened color advantages to the overall color life of ground beef versus the seemingly deleterious effects of YBT. The only raw material for which its production history in terms of management and age is likely better understood is YBT. The YBT was obtained from a commercial beef packing plant that harvests primarily young, fed beef. Another fundamental difference between beef cow management versus dairy cow management is the administration of recombinant bovine somatotropin to dairy cows, and its affect on meat color has not been determined. Because of these unknown factors, plausible explanations for differences observed in this study shall be discussed.

Display color life is conceptually different than display color. Display meat color life refers to the length of time a meat product can remain in display without developing objective discoloration. Display color, on the other hand, refers to the apparent color at a given point in time. According to the visual panel, ground DSM appeared darker at the onset of display, which may be less-than-desirable to consumers. This differs from the information provided in the literature. Stelzleni et al. (2007) stated that dairy cow lean does not differ in color than beef cow lean. However, this was determined based upon intact muscle measurements of *longissimus*, a high color stability muscle. Neither grinding nor packaging in HiO_2 MAP was considered.

Generally, diary cows are housed in confinement whereas beef cows are loosely housed. Because of this, one may expect color differences. Theoretically, dairy cows muscle should be more oxidative in nature than beef cow muscle, which should be more anaerobic. Accordingly, dairy cows should have a higher proportion of red muscle fibers than beef cows, and dairy cows should have a higher proportion of white muscle fibers. This may explain differences in the initial color differences observed by the panel. Moreover, it has been suggested that increased exercise, as would be typical of beef cows, results increased oxygen species in muscle and therefore, be conducive to accelerated lipid oxidation and meat discoloration (Dunne et al., 2005). The results of this study reaffirm the findings of Dunne et al. (2005).

Shorthose and Harris (1991) suggested that pasture-managed cattle possess more myoglobin in muscle tissue than confinement-managed cattle due to differences in physical activity. The data in this study, presuming the dairy cows were confinement-managed and beef cows were pasture-managed, may be supportive of this considering that HiO_2 MAP was used. Packaging in an 80% O_2 atmosphere likely would have resulted in a greater amount of OMb to form, which explains the brighter red initial color of BSM ground beef.

The suggested differences in the prevalence of red versus white fiber types of DSM versus BSM, however, may not agree with the findings of Renerre and Labas (1987) who found that meat with greater amounts of red fibers metabolize more oxygen and discolor faster. These results only *may* disagree because once again, packaging in

high-oxygen MAP was not a technology available or widely considered at the time of that research.

While differences in animal age for diary cows versus beef cows may offer insight to the observed color differences in this study, the otherwise intuitively developed explanations for color differences due to age are not supported by this research. More intensive dairy production has resulted in dairy cows being culled at younger ages than what would be 'typical' for beef cows. Sawyer, Mathis and Davis (2004) observed that lean color tends ($P = 0.11$) to darken as cattle age. However, if the dairy cattle in this study were younger than the beef cattle, then one would expect that DSM would be brighter than BSM. This was not observed in this study. Granted, actual age of the animals from which lean was sourced in this study was not known.

Further, the conformation of dairy cows differ from that of beef cows in that beef cows are generally heavier muscled. Considering this, it is possible that *M. semimembranosus* of dairy cows may more efficiently chill than *M. semimembranosus* of beef cow. Sammel, Hunt, Kropf, Hachmeister, Kastner and Johnson (2002a) reported that *M. semimembranosus* MRA is sensitive to a pH x temperature decline interaction. At the time of ground beef manufacture, muscle dimensions or potential within-muscle color variation was not noted. This may also help explain the positive color traits of DSM compared to BSM.

The MRA data indicate that DSM possessed either a greater amount of and/or more active MMb reductase enzymes than BSM. The MRA data presented in this study (% MMb reduced) are markedly lower than that reported by Seyfert, Mancini, Hunt, Tang and Faustman (2005) who used the same MRA procedure. Although the atmosphere in which meat was packaged was different ($LowO_2$ versus HiO_2), the more likely explanation is that the procedure was used on ground beef in this study and not intact muscle like the procedure was used in theirs. Increased porosity of ground beef would have allowed for greater saturation of $NaNO_2$, and thus oxidized the sample throughout rather than just superficially. Even so, the MRA data and differences within obtained in this study support the instrumental and visual color data for the same samples. Thus, DSM offered greater MRA than BSM.

The use of BCT versus YBT presents another series of questions. The BSM, DSM, and BCT were sourced from the same plant (a plant harvesting primarily mature cows) on the same harvest day. The YBT was obtained from a different plant (a plant harvesting primarily young, fed beef), and this may explain the some differences in the visual and instrumental color data. Although one may suspect differences in the oxidative age of the different lean sources and/or fat sources, sufficient mixtures of YBT, BCT, DSM and BSM were formulated to refute this. Even so, at the time of ground beef manufacture, YBT had higher TBARS values (0.74 ± 0.2 mg malonaldehyde / kg meat) than BCT (0.69 ± 0.2 mg malonaldehyde / kg meat). The observed differences in TBARS may be attributed to differences in MRA myoglobin chemistry, and possible interactions thereof.

5. Summary

Ground DSM originating from muscles of intermediate color stability has a display color life equal to or better than ground BSM of the same muscle type. In addition, use of BCT for a fat source also improved the color stability of ground beef. Ground DSM has better color stability than ground BSM providing the DSM is from reasonably color stable muscle. Dairy cow lean is more color stable than more color stable than beef cow lean obtained from cattle raised under their respective management strategies. Even so, this research also supports the need for further investigations into the causes of the apparent color differences.

6. Conclusions

1) Ground dairy-type cow inside round has greater color stability than ground beef-type cow inside round.

2) Ground dairy-type cow inside round will appear darker than ground beef-type cow inside round at the onset of display.

3) Display color of ground beef fattened with beef cow trim will not be worse than display color of ground beef fattened with young beef trim.

7. Implications

Opportunities to use lower-cost yet readily available lean and fat sources for ground beef production exist. Centrally processed and packaged ground beef in HiO_2 MAP can have longer display color life by using dairy cow lean in ground beef, particularly when display case turnover is slow. Addition of one display day to color ground beef color life, especially considering that the one day of added color life is from less-valuable cattle, offers opportunity for increased profits and reduced product loss due to premature discoloration.

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Figure 4.1 Simplified experimental design and project flow diagram

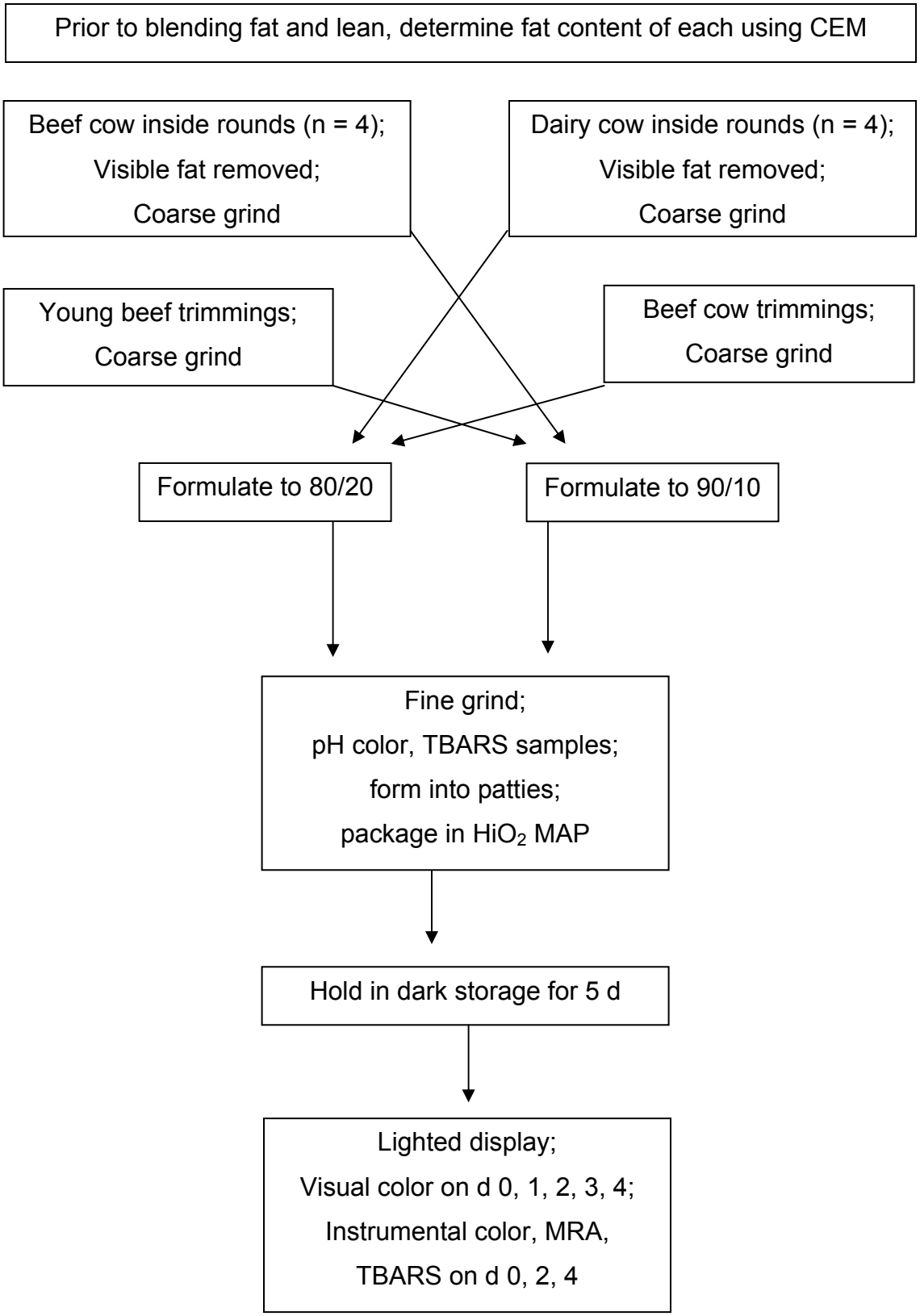
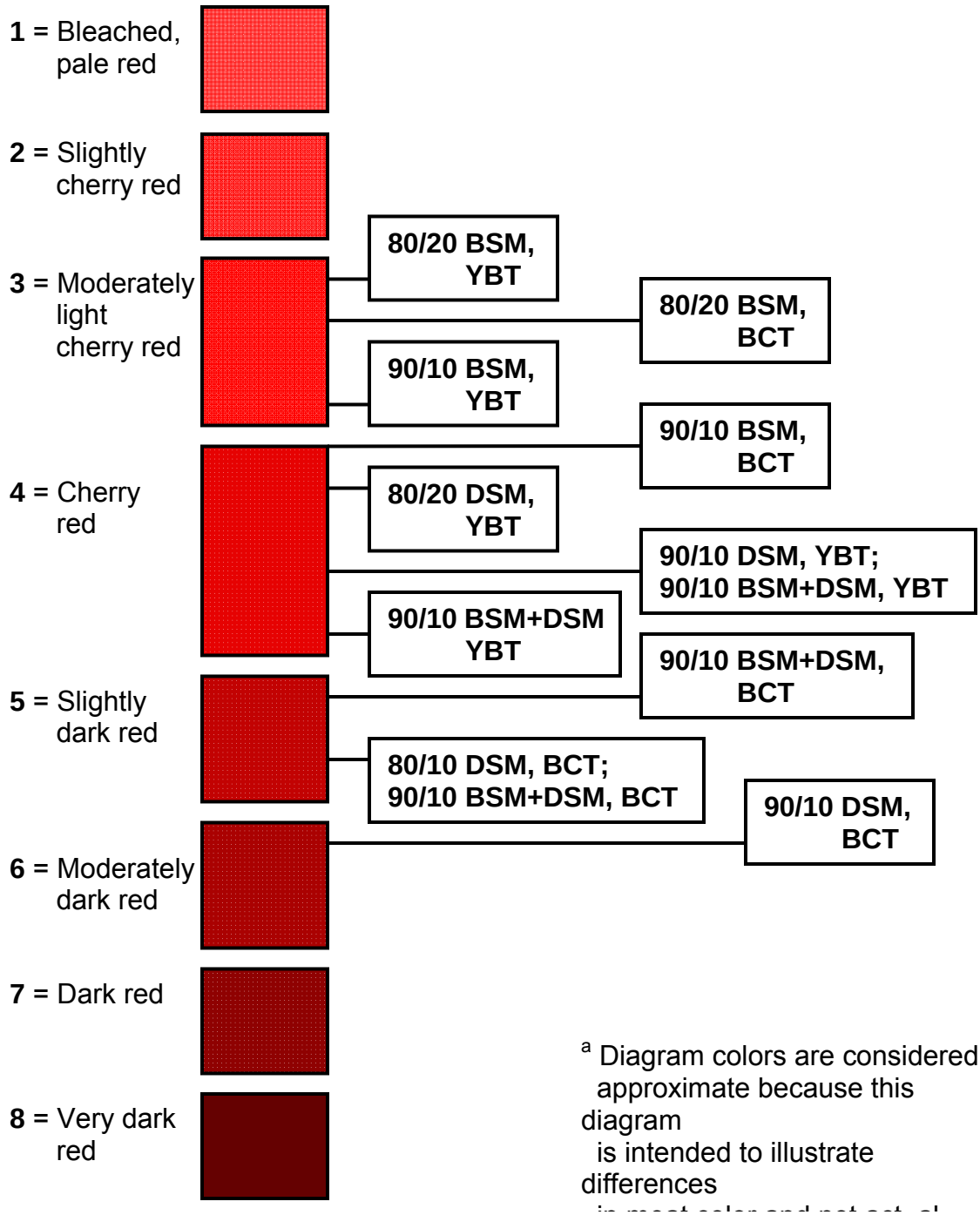


Figure 4.2 Map of approximated[a] initial visual color of ground beef patties formulated with beef cow lean (BSM), dairy cow lean (DSM), young beef trim (YBT), and beef cow trim (BCT) to 80/20 and 90/10 lean points



[a] Diagram colors are considered approximate because this diagram is intended to illustrate differences

Table 4.1 Initial color (d 0) score[a] least squares means (SE = 0.2-0.3) for ground beef patties made from beef-type cow inside round (BSM) and dairy-type cow inside round (DSM) formulated to 80% and 90% lean points with young beef trim (YBT) or beef cow trim (BCT)

Lean & fat combination		***Lean point***	
Lean source	**Fat source**	**80/20**	**90/10**
BSM	**YBT**	3.2[b]	3.8[c]
BSM	**BCT**	3.4[b]	4.0[c]
DSM	**YBT**	4.2[cd]	4.6[d]
DSM	**BCT**	5.7[f]	6.2[g]
BSM + DSM	**YBT**	4.6[d]	4.9[de]
BSM + DSM	**BCT**	5.2[e]	5.7[f]

[a] 1 = bleached, pale red, 2 = slightly cherry red, 3 = moderately light cherry red, 4 = cherry red, 5 = slightly dark red, 6 = moderately dark red, 7 = dark red, 8 = very dark red

[b-g] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 4.2 Display color score[a] least squares means (SE = 0.3-0.4) for ground beef patties made from beef-type cow inside round (BSM) and dairy-type cow inside round (DSM) formulated to 80% and 90% lean points with young beef trim (YBT) or beef cow trim (BCT) displayed for 4 d in high oxygen MAP

Lean & fat combination		*Lean point within day of display*									
Lean source	**Fat source**	**d 0**		**d 1**		**d 2**		**d 3**		**d 4**	
		80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
BSM	**YBT**	1.8^{b}	2.2^{b}	3.8^{de}	3.6^{d}	5.8^{g}	6.0^{g}	6.6^{h}	6.3^{gh}	7.7^{ii}	7.2^{hi}
BSM	**BCT**	2.1^{b}	2.0^{b}	3.5^{d}	3.7^{d}	5.1^{f}	5.0^{f}	5.3^{f}	5.5^{fg}	6.8^{h}	6.7^{h}
DSM	**YBT**	3.2^{c}	3.4^{cd}	3.3^{c}	3.5^{d}	3.2^{c}	3.4^{cd}	5.4^{f}	4.9^{f}	5.3^{f}	5.0^{f}
DSM	**BCT**	3.6^{d}	3.3^{cd}	3.0^{c}	3.3^{c}	3.0^{c}	3.1^{c}	3.7^{d}	3.7^{d}	4.6^{e}	4.4^{e}
BSM + DSM	**YBT**	2.9^{c}	3.0^{c}	3.6^{d}	3.8^{de}	4.2^{e}	4.4^{e}	5.8	5.7^{g}	6.2^{gh}	6.3^{gh}
BSM + DSM	**BCT**	3.3^{cd}	3.5^{d}	3.4^{cd}	3.2^{c}	3.6^{d}	3.6^{d}	4.0^{e}	4.2^{e}	5.5^{fg}	5.7^{g}

[a]1 = very bright red or pinkish red, 2 = bright red or pinkish red, 3 = dull red or pinkish red, 4 = slightly dark red or pinkish red, 5 = reddish tan or pinkish tan, 6 = moderately dark red or reddish tan or moderately dark pinkish red or pinkish tan, 7 = tannish red or tannish pink, and 8 = tan to brown

[b-k] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 4.3 L* value least square means (SE = 1.1-1.3) for ground beef patties made from beef-type cow inside round (BSM) and dairy-type cow inside round (DSM) formulated to 80% and 90% lean points with young beef trim (YBT) or beef cow trim (BCT) displayed for 4 d in high oxygen MAP

Lean & fat combination		***Lean point within day of display***					
Lean source	**Fat source**	**d 0**		**d 2**		**d4**	
		80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
BSM	**YBT**	53.1^{a}	47.8^{bc}	50.8^{ab}	47.4^{b}	48.6^{b}	45.4^{bc}
BSM	**BCT**	50.6^{ab}	46.3^{bc}	48.2^{b}	42.7^{c}	42.3^{c}	38.2^{d}
DSM	**YBT**	49.6^{ab}	43.1^{c}	47.6^{bc}	41.5^{cd}	45.7^{bc}	40.9^{d}
DSM	**BCT**	48.5^{b}	43.1^{c}	44.8^{c}	40.2^{d}	43.2^{c}	39.3^{d}
BSM + DSM	**YBT**	49.9^{ab}	46.0^{bc}	48.3^{b}	42.2^{c}	48.2^{b}	40.0^{d}
BSM + DSM	**BCT**	48.8^{b}	46.3^{b}	47.0^{b}	42.7^{c}	43.2^{c}	39.8^{d}

$^{a-d}$ In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 4.4 a* value least squares means (SE = 0.8-1.1) for ground beef patties made from beef-type cow inside round (BSM) and dairy-type cow inside round (DSM) formulated to 80% and 90% lean points with young beef trim (YBT) or beef cow trim (BCT) displayed for 4 d in high oxygen MAP

Lean & fat combination		***Lean point within day of display***					
Lean source	**Fat source**	**d 0**		**d 2**		**d4**	
		80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
BSM	**YBT**	27.3^{b}	25.4^{bc}	13.6^{g}	11.8^{h}	10.5^{i}	10.2^{i}
BSM	**BCT**	28.0^{b}	27.7^{b}	17.6^{f}	16.7^{f}	12.6^{g}	13.3^{g}
DSM	**YBT**	29.6^{a}	29.4^{a}	23.4^{d}	25.4^{c}	18.3^{ef}	20.0^{e}
DSM	**BCT**	30.3^{a}	29.9^{a}	27.3^{b}	26.3^{bc}	24.6^{cd}	26.3^{c}
BSM + DSM	**YBT**	29.4^{a}	28.2^{ab}	18.6	20.2^{e}	14.8^{g}	17.8^{f}
BSM + DSM	**BCT**	29.1^{a}	29.2^{a}	22.0^{d}	23.8^{d}	18.9^{ef}	20.2^{e}

$^{a-d}$ In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 4.5 b* value least squares means (SE =1.3-1.5) for ground beef patties made from beef-type cow inside round (BSM) and dairy-type cow inside round (DSM) formulated to 80% and 90% lean points with young beef trim (YBT) or beef cow trim (BCT) displayed for 4 d in high oxygen MAP

Lean & fat combination		***Lean point within day of display***					
Lean source	**Fat source**	**d 0**		**d 2**		**d4**	
		80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
BSM	**YBT**	22.5^{a}	21.0^{a}	16.6^{bc}	16.3^{bc}	13.7^{d}	13.2^{d}
BSM	**BCT**	22.4^{a}	20.5^{a}	17.6^{bc}	16.1^{bc}	13.2^{d}	12.8^{d}
DSM	**YBT**	21.5^{a}	20.4^{ab}	18.9^{b}	19.1^{b}	14.3^{cd}	13.9^{d}
DSM	**BCT**	23.1^{a}	22.4^{a}	21.1^{a}	18.9^{b}	14.6^{c}	14.1^{d}
BSM + DSM	**YBT**	23.2^{a}	21.3^{a}	17.1^{bc}	17.4^{bc}	13.6^{d}	13.2^{d}
BSM + DSM	**BCT**	21.6^{a}	22.4^{a}	18.7^{b}	18.4^{b}	13.9^{d}	13.3^{d}

$^{a-d}$ In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 4.6 a*/b* value least squares means (SE = 1.3-1.5) for ground beef patties made from beef-type cow inside round (BSM) and dairy-type cow inside round (DSM) formulated to 80% and 90% lean points with young beef trim (YBT) or beef cow trim (BCT) displayed for 4 d in high oxygen MAP

Lean & fat combination		***Lean point within day of display***					
Lean source	**Fat source**	**d 0**		**d 2**		**d4**	
		80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
BSM	**YBT**	1.22^{b}	1.23^{b}	0.80^{e}	0.75^{e}	0.55^{f}	0.52^{f}
BSM	**BCT**	1.28^{a}	1.30^{a}	1.03^{c}	1.05^{c}	0.68^{ef}	0.72^{e}
DSM	**YBT**	1.28^{a}	1.35^{a}	1.19^{b}	1.33^{a}	1.03^{c}	1.12^{bc}
DSM	**BCT**	1.30^{a}	1.25^{ab}	1.29^{a}	1.27^{a}	1.14^{b}	1.18^{b}
BSM + DSM	**YBT**	1.28^{a}	1.32^{a}	0.98^{cd}	1.25^{ab}	0.88^{d}	1.00^{cd}
BSM + DSM	**BCT**	1.30^{a}	1.33^{a}	1.20^{b}	1.29^{a}	1.02^{c}	0.99^{cd}

$^{a-d}$ Means lacking a common superscript letter differ ($P < 0.05$)

Table 4.7 Saturation index[1] least squares means (SE = 0.46-0.58) for ground beef patties made from beef-type cow inside round (BSM) and dairy-type cow inside round (DSM) formulated to 80% and 90% lean points with young beef trim (YBT) or beef cow trim (BCT) displayed for 4 d in high oxygen MAP

Lean & fat combination		***Lean point within day of display***					
Lean source	**Fat source**	**d 0**		**d 2**		**d4**	
		80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
BSM	**YBT**	35.4^{ab}	33.0^{b}	21.5^{d}	20.1^{de}	17.3^{ef}	16.7^{f}
BSM	**BCT**	35.9^{ab}	34.5^{b}	24.9^{d}	23.2^{d}	18.2^{e}	18.5^{d}
DSM	**YBT**	36.6^{ab}	35.8^{ab}	30.1^{c}	31.8^{c}	23.2^{d}	24.4^{d}
DSM	**BCT**	38.1^{a}	37.4^{a}	34.5^{b}	32.4^{bc}	28.6^{cd}	29.8^{c}
BSM + DSM	**YBT**	37.5^{a}	35.3^{b}	25.3^{d}	26.7^{d}	20.1^{de}	22.2^{d}
BSM + DSM	**BCT**	36.2^{ab}	36.8^{ab}	28.9^{c}	30.1^{c}	23.5^{d}	24.2^{d}

[1] Saturation index: $SI = (a^{*2}+b^{*2})^{1/2}$

[a-f] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 4.8 Hue angle[1] least squares means (SE = 1.7-1.8) for ground beef patties made from beef-type cow inside round (BSM) and dairy-type cow inside round (DSM) formulated to 80% and 90% lean points with young beef trim (YBT) or beef cow trim (BCT) displayed for 4 d in high oxygen MAP

Lean & fat combination		***Lean point within day of display***					
Lean source	**Fat source**	**d 0**		**d 2**		**d4**	
		80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
BSM	**YBT**	39.5^{c}	39.6^{c}	50.7^{e}	50.1^{e}	52.5^{e}	52.9^{e}
BSM	**BCT**	38.7^{bc}	36.5^{bc}	45.0^{d}	44.0^{d}	46.3^{d}	43.9^{d}
DSM	**YBT**	36.0^{bc}	34.8^{b}	38.9^{bc}	36.9^{bc}	38.0^{b}	34.8^{b}
DSM	**BCT**	37.6^{bc}	36.8^{bc}	37.7^{bc}	35.7^{b}	30.7^{a}	28.2^{a}
BSM + DSM	**YBT**	38.3^{c}	37.1^{bc}	47.4^{de}	40.7^{c}	42.6^{d}	36.6^{bc}
BSM + DSM	**BCT**	36.6b^{c}	37.5^{bc}	49.6^{de}	37.7^{ab}	36.3^{ab}	33.4^{a}

[1] Hue angle: HA = tan-1 (*b*/a*)
[a-e] In any row or column, means lacking a common superscript letter differ ($P < 0.05$)

Table 4.9 Observed TBARS (SE = 0.78-1.88) for ground beef patties made from beef-type cow inside round (BSM) and dairy-type cow inside round (DSM) formulated to 80% and 90% lean points with young beef trim (YBT) or beef cow trim (BCT) displayed for 4 d in high oxygen MAP

Lean & fat combination		***Lean point within day of display***					
Lean source	**Fat source**	**d 0**		**d 2**		**d4**	
		80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
BSM	**YBT**	1.00	2.74	3.63	3.63	7.00	6.78
BSM	**BCT**	1.91	2.67	4.88	4.56	5.77	6.30
DSM	**YBT**	1.60	1.46	2.27	2.79	1.92	2.39
DSM	**BCT**	0.83	0.84	2.35	2.16	1.68	1.92
BSM + DSM	**YBT**	2.12	2.50	3.63	2.50	4.93	7.10
BSM + DSM	**BCT**	1.48	2.08	2.08	4.56	6.86	4.71

Table 4.10 Metmyoglobin reducing activity (MRA[a]) least squares means (SE = 2.07-2.31) for ground beef patties made from beef-type cow inside round (BSM) and dairy-type cow inside round (DSM) formulated to 80% and 90% lean points with young beef trim (YBT) or beef cow trim (BCT) displayed for 4 d in high oxygen MAP

Lean & fat combination		***Lean point within day of display***					
Lean source	**Fat source**	**d 0**		**d 2**		**d4**	
		80/20	**90/10**	**80/20**	**90/10**	**80/20**	**90/10**
BSM	**YBT**	15.7^{cd}	16.8^{cd}	7.8^{f}	8.2^{ef}	4.1^{gh}	3.3^{h}
BSM	**BCT**	20.3^{c}	19.9^{c}	9.7^{ef}	11.3^{e}	5.4^{g}	6.7^{fg}
DSM	**YBT**	28.6^{b}	31.4^{b}	25.8^{b}	26.9^{b}	11.8^{e}	10.4^{e}
DSM	**BCT**	38.6^{a}	39.7^{a}	31.4^{b}	28.4^{b}	15.6^{d}	16.7^{d}
BSM + DSM	**YBT**	18.6^{c}	19.6^{c}	12.7^{de}	11.9^{e}	7.4^{f}	7.6^{f}
BSM + DSM	**BCT**	20.5^{c}	20.1^{c}	15.6^{cd}	14.7^{d}	7.9^{f}	9.7^{ef}

[a] MRA = (∆% surface MMb ÷ pre-incubation surface MMb) x 100
[b-h] Means in any column or row with a common superscript letter do not differ (P >.05)

Table 4.11 Stearic acid (C18:0), conjugated linoleic acid (CLA), and total saturated fatty acid (SFA), monounsaturated fatty acid (MUFA), and polyunsaturated acid (PUFA) least squares means for ground beef patties made from beef-type cow inside round (BSM) and dairy-type cow inside round (DSM) formulated to 80% and 90% lean points with young beef trim (YBT) or beef cow trim (BCT)

Lean & fat combination			C18:0	CLA	SFA	MUFA	PUFA
Lean Source	Fat Source	Lean Point					
BSM	**YBT**	**80**	2.282^{a}	0.043^{e}	3.629^{e}	4.212^{d}	0.465^{e}
BSM	**YBT**	**90**	1.456^{d}	0.061^{d}	5.081^{c}	4.622^{d}	0.509^{d}
BSM	**BCT**	**80**	1.875^{bc}	0.061^{d}	3.525^{e}	4.337^{d}	0.518^{d}
BSM	**BCT**	**90**	0.885^{e}	0.084^{bc}	5.579^{c}	7.603^{bc}	0.599^{d}
DSM	**YBT**	**80**	2.016^{b}	0.095^{ab}	6.883^{b}	8.128^{ab}	0.692^{ab}
DSM	**YBT**	**90**	1.267^{d}	0.092^{b}	6.216^{b}	7.865^{b}	0.698^{ab}
DSM	**BCT**	**80**	1.310^{d}	0.074^{c}	5.105^{c}	6.767^{c}	0.641^{bc}
DSM	**BCT**	**90**	1.490^{cd}	0.065^{d}	4.128^{d}	4.654^{d}	0.602^{c}
BSM + DSM	**YBT**	**80**	2.231^{ab}	0.082^{bc}	7.807^{ab}	8.664^{a}	0.670^{b}
BSM + DSM	**YBT**	**90**	1.931^{b}	0.091^{b}	6.193^{b}	7.706^{bc}	0.643^{bc}
BSM + DSM	**BCT**	**80**	1.676^{c}	0.107^{a}	8.575^{a}	8.941^{a}	0.744^{a}
BSM + DSM	**BCT**	**90**	1.435^{d}	0.069^{d}	5.765^{c}	6.244^{c}	0.556^{d}
Standard Error			0.050	0.007	0.317	0.041	0.014

$^{a-e}$ Within column, means lacking a common superscript letter differ ($P < 0.05$)

Chapter V

Intrinsic factors affecting ground beef color stability: *Summary of Conclusions*

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1. Conclusions from this Dissertation

1) Neither administering implants nor feeding Optaflexx® during the finishing period affects ground beef color stability.

2) Cow chronological ages does not affect ground beef color stability when cattle are fed for 60 d immediately before slaughter.

3) At the beginning of display, ground beef redness (a*) will not differ between steers and fed cows.

4) Ground beef sourced from fed cows is darker appearing and redder than ground beef from similarly managed steers.

5) Cow ground beef exhibits better color stability than steer ground beef.

6) Using ≥ 25% low color stability muscle in ground beef formulations shortens ground beef color life.

7) Ground beef color life is optimized when ≥ 50% of the lean is from high color stability muscle.

8) Ground dairy-type cow inside round has greater color stability than ground beef-type cow inside round.

9) Ground dairy-type cow inside round will appear darker than ground beef-type cow inside round at the onset of display.

10) Display color of ground beef fattened with beef cow trim will not be worse than display color of ground beef fattened with young beef trim.

Appendix A

Visual color evaluation scales for ground beef

Initial color score*:

1 = bleached, pale red

2 = slightly cherry red

3 = moderately light cherry red

4 = cherry red

5 = slightly dark red

6 = moderately dark red

7 = dark red

8 = very dark red

* determined by panelists at time 0

Display color score†:

1 = very bright red or pinkish-red

2 = bright red or pinkish-red

3 = dull red or pinkish-red

4 = slightly dark red or pinkish-red

5 = reddish-tan or pinkish-tan

6 = moderately dark red or reddish-tan, or moderately dark-pinkish red or pinkish-tan

7 = tannish-red or tannish-pink

8 = tan to brown

†determined by panelists at time 0 and throughout the display period

Appendix B

Determination of TBARS

Adapted from: Witte, V. C., Krause, G. J., & Bailey, M. E. (1970). A new extraction method for determining 2-thiobarbituric acid values of pork and beef during storage. Journal of Food Science, 35, 582-585.

SOLUTIONS NEEDED:

① **9% PERCHLORIC ACID**

- → Prepare under fume hood
- → Fill 2 L volumetric flask with ~1500 ml of distilled-deionized H_20 (**DD H_2O**), then slowly add 259 ml of 70% perchloric acid. Bring to volume with distilled-deionized H_20
- → Store refrigerated

② **DISTILLED WATER**

③ **0.02 M 2-THIOBARBITURIC ACID (TBA)** SOLUTION

- → 1.4415 g 2-thiobarbituric acid / 500 ml
- → Dilute to volume with DD H_2O, use magnetic stir bar to dissolve TBA
- → Prepare immediately before use

④ **TETRAETHOXYPROPANE (TEP)** STOCK SOLUTION: (1,1,3,3 TEP)

- → Take 0.44 g TEP to 100 ml volume with DDI H_2O [2 x 10^{-5} mol / ml]
- → Pipette 0.5 into 500 ml volumetric flask, take volume with DD H_2O (This is the working stock solution) [2 x 10^{-8} mol / ml]
- → Store refrigerated; bring to room temperature before use

⑤ **TEP STANDARDS**

- → Dilute the TEP working stock solution [2 x 10^{-8} mol / ml] by taking the following mls of to 50 ml in a volumetric flask with DD H_2O

mls Working TEP stock solution	Resulting [mol / 5 ml]
1	0.2 x 10^{-8}
2	0.4 x 10^{-8}
4	0.8 x 10^{-8}
5	1.0 x 10^{-8}
10	2.0 x 10^{-8}
20	4.0 x 10^{-8}
30	6.0 x 10^{-8}
40	8.0 x 10^{-8}

TBARS PROCEDURE:

SAMPLE PULVERATION, PREPARATION

1. Cut meat sample into small cubes, regardless if intact muscle or ground muscle
2. Submerge cubed sample in liquid N_2 until liquid N_2 ceases boiling
3. Chill blender cup by pouring a small amount of N_2 into blender cup; Run blender for 2 – 3 s to complete cup chilling
4. Add frozen sample to blender cup; run blender for ~20 s to pulverize sample or until sample is completely pulverized / powdered
5. Package labeled sample, removing as much air as possible
6. Store sample at -80 °C until ready to use

EXTRACTION & ABSORBANCE READING

1. Weigh 10 g of sample in duplicate into small blender cup
2. Add 25 ml chilled DD H_2O to blender cup
3. Add 15 ml chilled 9% perchloric acid to blender cup
4. Blend for 15 s
5. Pour contents of blender cup into filter-lined funnel (se a Whatman #2 filter paper)
6. Collect filtrate in 25 x 150 mm test tube
7. Pipette 5 ml of filtrate from tube into 18 x 150 mm test tube
8. Add 5 ml TBA solution to filtrate in the 18 x 150 mm test tube
9. Vortex filtrate + TBA
10. Store in the dark at room temperature for 24 h to allow color reaction to develop
11. Develop standard curve using TEP Standards
    a. Use 0, 0.2 x 10^{-8}, 0.4 x 10^{-8}, 0.8 x 10^{-8}, 1.0 x 10^{-8}, 2.0 x 10^{-8} / ml TEP
    b. Pipette 5 ml of standard into 18 x 150 mm test tube, add 5 ml of TBA solution, vortex, and store as for test samples
12. Transfer developed solution to 13 x 100 mm test tube and measure spectral absorbance at 530 nm. Blank the spectrophotometer with a mixture of 5 ml DD H_2O and 5 ml of TBA solution
13. Calculate TEP concentration in samples based on standard curve. Multiply by 0.72 to convert from TEP to TBA reactive substances (TBARS) values.
14. Report results as mg of malonaldehye / kg muscle tissue

Appendix C

Determination of MRA for Ground Beef

Adapted*[†] *from: Sammel, L.M, Hunt, M. C., Kropf, D. H, Hachmeister, K. A., and Johnson, D. E. (2002). Comparison of assays for metmyoglobin reducing ability in beef inside and outside *semimembranosus* muscle. *Journal of Food Science*, *67*, 978-984.

[†]The procedure was originally developed for intact muscle samples. This method has been slightly modified for use in determining MRA of ground beef.

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1. From a ground beef patty (1.5 cm-thick), remove the center 2.54 x 2.54 x 1.5 cm portion
2. Submerge the ground beef portion in 0.3% $NaNO_2$ solution for 20 min to induce MMb development
3. Carefully remove ground beef, so as to prevent crumbling, from $NaNO_2$ solution
4. Lightly blot surface using an absorbent paper tissue. Blot all 6 sides of the ground beef sample, and allow any excesses / absorbed $NaNO_3$ to drain from the sample for ~1 min
   → In this study, KimWipes™ (Kimberly-Clark, Milwaukee, WI) were used
5. Keeping the ground beef sample in its 3-dimensional shape, carefully place it in a vacuum pouch.
   → In this study, laminated nylon pouches were used (3-mil, standard-barrier nylon/polyethelene, 0.6cm^3 oxygen / 645.15 cm^2 / 24 h at 0 °C; Koch Supplies, Inc., Kansas City, MO)
6. Vacuum package the bagged sample. When positioning the pouch in the packager, ensure that the seal is formed such that the vacuumed portion is square in shape – the ground beef will lose its 3-dimensional shape when a vacuum is pulled.
7. Immediately after vacuum packaging, measure spectral reflectance in triplicate using a HunterLab MiniScan XE, Illuminant A. (This is will be used to calculate pre-incubation MMb.)
8. Incubate the sample at 30 °C for 2 h to induce MMb reduction to DMb.
9. After incubation, re-scan the samples as done in step 7.
10. Calculate MRA[a]: MRA = (Δ% surface MMb ÷ pre-incubation surface MMb) x 100.
11. MRA is reported as % MMb reduced.

[a] AMSA. (1991). Guidelines for Meat Color Evaluation. *Proceedings of the 44th Reciprocal Meat Conference*, 1-17.

Appendix D

Initial[a] Fat Composition and TBARS Values of Beef Trim Sources

CHAPTER III

Beef Trim (Beef 50's)

% Fat[b]	Age (h)	TBARS
61 ± 2	~ 48	0.66 ± 0.4

CHAPTER IV

Young Beef Trim (Beef 50's)

% Fat[b]	Age (h)	TBARS
60 ± 3	~ 48	0.74 ± 0.2

Beef Cow Trim (Cow 50's)

% Fat[b]	Age (h)	TBARS
58 ± 2	~ 48	0.69 ± 0.2

[a] Evaluated at the time of ground beef manufacture

[b] Determined using the CEM method (AOAC 98515)