The Color and Consistency of Steaks and Ground Beef Produced from Mature Bulls

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The Color and Consistency of Steaks and Ground Beef Produced from Mature Bulls
The Color and Consistency of Steaks and Ground Beef Produced from Mature Bulls

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Animal Science

by

Jace Hollenbeck
South Dakota State University
Bachelor of Science in Animal Science, 2011

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This thesis is approved for recommendation to the Graduate Council.

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ABSTRACT

Two experiments were conducted to compare the color and cooked attributes of steaks and ground beef produced from mature bulls. Beef from mature bulls was used to test the effects of lactic acid (LA) enhancement solution pH (2.5, 3.0, or 3.5; B25, B30, B35, respectively) on fresh (5 d of display) and cooked color and tenderness of strip loin steaks (Exp. 1) and the effect of high pH trim on precooked ground beef patties (Exp. 2). In experiment 1, mature bull strip steaks were enhanced to 111% with a LA, sodium bicarbonate, and tap water solution, in comparison to USDA Select strip loin steaks (Sel). On d 0 of display, Sel steaks were redder (higher a*) than B0 steaks, but, on d 4 and d 5, Sel steaks were less red than B0, B25, B30, and B35 (treatment × time, P < 0.01). Steaks from B0 were least (P < 0.05) yellow (lowest b*), and Sel steaks were more (P < 0.05) yellow than B25 and B30 steaks. Instrumental cooked color was similar (P ≤ 0.08) among the treatments; however, Sel and B35 steaks received greater (P < 0.05) visual cooked color scores than B0, whereas Sel, B25, and B35 were rated higher (P < 0.05) for internal doneness than B0. Sel steaks had lower (P < 0.05) WBSF, values than steaks from bull strip loins, regardless of LA enhancement solution pH. In experiment 2, ground beef patties were formulated from mature bull necks, USDA Select peeled knuckles, and 50:50 beef trimmings to a target lean to fat ratio 85:15. Internal cooked color was lighter (P < 0.001) in patties reheated on the charbroiler than in the microwave; otherwise, reheating method did not (P ≥ 0.406) affect the internal color of reheated patties. Conversely, internal color of reheated patties remained redder (greater a*values and lower HA) as the percentage of bull trim increased from 0 to 100% of the lean portion (linear, P < 0.001). Potentially, steaks or products formulated from mature bull beef could lead to consumer discrimination resulting from an undercooked appearance.
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DEDICATION

I would like to dedicate my Master’s Thesis to the late Pink Hollenbeck. My grandpa spent his entire life around cattle, from growing up on Snake Creek, loading bulls into railroad cars at the Sioux Falls Stockyards, or settling on the Pink Hollenbeck Ranch southwest of Mobridge, SD. Through all those years, he always dedicated himself to improving cattle, and that the end product wasn’t when the calves loaded onto the pot and drove away. He was a man truly ahead of his time. He taught me many things, and is a model of how I wish to live my life.
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CHAPTER I
INTRODUCTION AND REVIEW OF THE LITERATURE

Introduction

The subject of bull beef utilization has been a focus of research at the University of Arkansas since Brown et al. (1962, 1963) published work comparing the relationship of performance records, carcass cut-out data, and eating quality of bulls. Over the past 50 years, a plethora of research has compared the growth performance and beef quality attributes of bulls to steers. In 2012, bulls (551,300) represented 1.7% (USDA, 2013) of domestic beef slaughter; yet, beef production from intact males has encountered strong resistance from packers, in part because of the price difference between carcasses from bulls and steers. The price difference is a result of the lower USDA quality grade of bulls and the belief that beef from intact males has lower consumer acceptance at the retail level because of differences in color, texture, and fat distribution (Seideman et al., 1982).

Mature Bull Beef

Maturity plays a key role in the way bull beef can be utilized or improved. Arthaud et al. (1977) stated that beef from bulls generally had less marbling, coarser texture, darker color, and was less tender than beef from steers; however, a number of studies relating to palatability of beef from young bull carcasses indicated a reasonably high level of acceptability. It is well documented that beef from older cattle is less tender (Laakkonen et al., 1969; Romans et al., 1965; Smith et al., 1982; Tuma et al., 1962) and darker (Field, 1971; Romans et al., 1965; Tuma et al., 1962, 1963) than beef from young cattle; however, little work has been done to look at the effects of advanced carcass maturity in bull carcasses. When slaughtered between 300 to 399 d
of age, Field et al. (1966) failed to discern any differences between bulls, steers, and heifers for Warner-Bratzler shear force (WBSF) and sensory tenderness, whereas WBSF increased, and sensory tenderness scores decreased, with advancing chronological age in bulls.

**Ultimate pH & Color**

At a higher ultimate pH ($pH_u$), Ledward et al. (1992) reported that proteins were able to bind with water, creating less free water in the product. When proteins bind more water, the myofibrils become swollen, causing light to absorb deeply into the meat; therefore, meat that has a higher $pH_u$ will be darker in color because there is less free water to reflect light (Ledward et al., 1992). Moreover, at a higher $pH_u$, enzymes that use oxygen are more active, resulting in less oxygenation of the surface myoglobin and a darker color. Dark-cutting (DC) beef results from cattle with lower-than-normal muscle glycogen stores at the time of slaughter, which curtails lactic acid production after slaughter and, resulting in $pH_u$ of 6.0 or greater (Wulf et al., 2002). When muscle pH values remain elevated, mitochondrial respiration remains high, myoglobin is deoxygenated, and a dark red color results (Ashmore et al., 1973). Field (1971) theorized that because of their temperament, bulls may be stressed more than steers and, therefore, are likely candidates to become DC beef. Page et al. (2001) found that there was increase in muscle $pH_u$ and DC beef with increasing overall carcass maturity. In addition, Page et al. (2001) reported that bullock carcasses had greater $pH_u$, a greater incidence of DC discount, and lower $L^*$ values. Moreover, Kousgaard (1980) reported over 18% of young bulls had a 24-h pH value greater than 6.0, resulting in a darker-colored lean than steers. Conversely, Boccard et al. (1979) reported that the *semitendinosus* of bulls had greater pigment content than that of steers; otherwise, there were no further differences in myoglobin content observed in any other muscles between carcasses of bulls and steers. Additionally, DeVol et al. (1985) found that the *longissimus* muscle (LM) from
bull carcasses had greater myoglobin concentrations and lower visual color scores, indicating a
darker, less youthful color, even though 24-h LM pH did not differ between bulls and steers.

The cooked internal color of high pHu meat has been reported to have a persistent
undercooked, red-colored appearance at temperatures typically associated with internal browning
of normal pH meat (Mancini et al., 2005; Mendenhall, 1989). The persistent red internal cooked
color is caused by the high pHu protecting myoglobin from thermal denaturation during cooking
(Hunt et al., 1999; Trout, 1989). Hawrysh et al. (1985) found that semitendenosus roasts from
young bulls with a pHu of greater than 6.51 had lower internal cooked L* (lightness) values than
roasts from young bulls with a pHu less than 5.99, and internal cooked a* (redness) values were
greater in roasts with a pHu value greater than 6.51.

**Water-Holding Capacity**

Hamm (1960) defined water-holding capacity (WHC) as the ability to hold fast to its own
or added water during application of any force (pressing, heating, grinding, etc.). According to
Ledward et al. (1992), meat with a higher pHu (≥6.0) has a greater ability to bind water, creating
less free water in the product; thus, high pHu meat has been shown to positively affect WHC.
Miller et al. (1968) adjusted pH in ground beef to 5.5, 6.0, and 6.5, and found that ground beef
with pH 6.0 and 6.5 lost less moisture during centrifugation and cooking than pH 5.5 ground
beef. In addition, Bouton et al. (1971) reported a linear increase in WHC with increasing pH,
along with a linear decrease in cooking losses with increasing pH. Fortunately, beef from bulls
tends to have a high pHu (Dikeman et al., 1985, Page at al., 2001). Schön and Scheper (1960)
found a relationship between sex, species, and WHC, where WHC increased in pigs, calves,
cows, heifers, oxen, and bulls, in that order. Pulford et al. (2009) measured levels of purge and
cook loss from 22 h to 8 d postmortem in bull beef segregated into pHu groups of low (pHu <
5.7), intermediate (pH<sub>u</sub> < 6.3), and high (pH<sub>u</sub> > 6.3). They found that the difference in purge between low and high pH<sub>u</sub> bull beef was apparent as early as 2 d postmortem, whereas low pH<sub>u</sub> bull beef sustained increased levels of purge at 3 d postmortem compared to intermediate and high pH<sub>u</sub> bull beef. Moreover, greater cooking losses were observed in low pH<sub>u</sub> compared to high pH<sub>u</sub> bull beef (Pulford et al., 2009). Miller et al. (1968) found that bull beef, when used as the lean block in sausage-manufacture, had less moisture loss from both centrifugation and cooking, than cow beef, pork shoulders, and pork snouts. Conversely, Dikeman et al. (1986) reported that steaks from bull LM had greater cooking losses when compared to steaks from steers, and Forrest et al. (1975) found that rib roasts from bulls were less juicy than rib roasts from steers. In a review of several experiments, Field (1971) indicated there was no consensus in differences in juiciness ratings between beef from bulls and steers.

As previously stated, Page et al. (2001) found that with increased carcass maturity elicits an increase in muscle pH<sub>u</sub>. Smith et al. (1982) found that LM and semimembranosus (SM) steaks from A-maturity carcasses received greater sensory panel juiciness scores than steaks from E-maturity carcasses. When combining maturity and sex, however, Field et al. (1966) reported that juiciness scores were not affected by age of bulls, but that roasts from older bulls (> 599 d of age) were less juicy than roasts from steers and heifers, and tended to less juicier than bulls less than 599 d of age.

**Tenderness**

It is well understood that chronological and/or physiological age plays a major role in meat tenderness. Early work by Mackintosh et al. (1936b) reported that beef from young steers contained less collagen and was more tender than beef from mature steers. Hiner and Hankins (1950), Tuma et al. (1962), and Goll et al. (1963) also found that WBSF values increased with
increasing chronological age, and Tuma et al. (1962) reported that sensory tenderness decreased with advancing age. Goll et al. (1964) suggested that it was not the content of collagen from mature animals that created tenderness issues per se, rather it was the increased cross-linking, and subsequent decreased solubility, of the collagen fibers responsible for the toughening association with advancing age. Herring et al. (1967) found that the LM from A-, B-, and E-maturity carcasses contained similar quantities of collagen; however, the SM from E-maturity carcasses had more collagen than the SM from A- and B-maturity carcasses. Moreover, Herring et al. (1967) demonstrated that collagen solubility decreased in the LM from 10.48% in A-maturity muscles to 9.40 and 4.21% for B- and E-maturity muscles, respectively. Hill (1966) found that, during the cooking process, less collagen was solubilized in meat from older animals, and, consequently, an increased sensation of toughness was perceived during consumption of meat from older animals. Moreover, Field et al. (1966) reported no differences in WBSF values and sensory tenderness scores between rib roasts from bulls, steers, and heifers less than 500 d of age, roasts from bulls had greater WBSF values and lower tenderness scores than steers and heifers greater than 499 d of age. Furthermore, Hedrick et al. (1969) reported that WBSF values and sensory tenderness scores indicated that steaks from bulls less than 16 mo of age were comparable in tenderness to steaks from steers and heifers of comparable age; however, steaks from more mature bulls were less tender. Hunsley et al. (1971) also found that beef from bulls had lower tenderness scores than beef from steers. Boccard et al. (1979) found that regardless of animal age, collagen content of muscle was greater in bulls than in steers.

Additionally, bull beef is generally accepted to be tougher than beef from steers. In 7 studies reviewed by Field (1971), bull beef was found to be less tender than steer beef. Studies conducted by Albaugh et al. (1975), Arthaud et al. (1977), Glimp et al. (1971), and Ntunde et al.
(1977) noted that consumers rated bull beef acceptable for tenderness; however, the ratings were lower than those for beef from young steers. Even though, Landon et al. (1978) observed no differences in WBSF between sexes of cattle, Adams and Arthaud, (1963), Field et al. (1966), Hedrick et al. (1969), and Hunsley et al. (1971) concluded that sex and chronological age may combine to have a greater negative effect on the tenderness of bull beef, especially when compared to steer beef.

**Acid Marination**

As early as the 1930’s, Mackintosh and Hall (1936a) reported that DC beef was harshly discriminated against by the consumer and retailer. Moreover, Mackintosh and Hall (1936a) stated, “it has long been recognized that old cows and mature bulls tend to cut darker than normal beef, while vealers and calves produce a much lighter color.” Early experimental efforts to inhibit the DC condition included the use of tranquilizers and injection of the hormones hydrcortisone and insulin in attempts to counteract the effects of epinephrine release during stress (Ashmore et al. 1973); however, none were successful. More recent antemortem solutions include late feeding sugar (Fernandez et al., 1992) to boost glyoglytic potential and implant strategies (Scanga et al., 1998).

More recently, organic acids have been considered as a means of improving the fresh and cooked lean color of DC beef. Arganosa and Marriott (1989) observed that uncooked acid-treated beef had greater L* (lightness) values compared to untreated DC beef. Moiseev and Cornforth (1999) found that ground beef patties manufactured with DC beef and subsequently treated with lactic acid (LA) had fresh L* values comparable to patties formulated with normal pH beef. In contrast, Mikel et al. (1999) reported no improvement in Hunter color ‘L’ values between acid-sprayed beef strip loin steaks when compared to controls.
Hinkle et al. (2010) reported increased L* values of steaks from the *biceps femoris* (BF) when treated with low concentration (0.1 M) of acetic (AA), citric (CA), and LA over the course of 8 h. In addition, a* (redness) values of BF steaks decreased at low concentrations of AA, CA, and LA. There were few differences among treatments, or between low and high acid concentrations (0.1 vs. 0.5 M), except meat treated with AA tended to be darker and less red than CA-treated muscles. Meat treated with AA or LA had discoloration at the injection sites (observed subjectively), likely a pH effect, and the AA and CA treatments generally had the greatest reductions in overall redness over time compared to the LA treatment (Hinkle et al., 2010). Moreover, the authors further tested the effects of AA, CA, and LA at different low (0.75 M) and high (1.5 M) concentrations on fresh beef color of BF steaks, and reported that L* values decreased over 8 h, regardless of concentration of acid (Hinkle et al., 2010). Steaks became less red (lower a* values) over 8 h in low and high concentrations of both AA and LA. In addition, both AA- and LA-treated steaks had lower a* values compared to CA treated steaks at 1 and 8 h after enhancement.

Sawyer et al. (2009) looked at fresh beef quality characteristics of DC strip loins treated with 1 of 4 enhancement treatments of LA (0.25, 0.50, 0.75, or 1.00%) over 5 d of simulated retail display. They reported that DC control steaks were darker (lower L* values) when compared to normal pH and DC steaks treated with 0.25 to 0.75% LA. Furthermore, steaks from DC strip loins received the highest overall color scores each day of simulated display, indicative of dark red to extremely dark red color (Sawyer et al., 2009). In addition, they also reported that between d 1 and 2 of display, overall color scores decreased 1.5, 1.0, 0.8, and 2.0 units in DC steaks enhanced with 0.25, 0.50, 0.75, and 1.00% LA, respectively, indicating a shift from extremely dark red to a less dark, more bright red color in LA-enhanced steaks. However,
Sawyer et al. (2009) found that enhancement with 0.75 and 1.00% LA negatively affected fresh color, with panelists noting shades of gray to black, in addition to areas of surface oxidation.

From the same laboratory, Apple et al. (2011) reported 2 experiments testing the effects of LA enhancement of DC beef strip loin steaks with 0.15 and 0.35% LA (Experiment 1), and 0.35 and 0.50% LA (Experiment 2) solutions. In experiment 1, the authors reported increased L* values in 0.35% LA enhanced steaks compared to DC controls; however, L* values in 0.35% LA enhanced steaks were still lower than normal pH control steaks, indicating, that the 0.35% LA enhanced steaks still appeared darker than those from non-enhanced normal pH, strip loins. Moreover, in experiment 2, L* values were greater in 0.35 and 0.50% LA enhanced steaks than DC cutting controls; yet, were still lower, and subsequently darker than normal pH controls. In experiment 1, there was no adverse discoloration reported for steaks enhanced with LA; however, in experiment 2, in agreement with Sawyer et al. (2009), small to modest discoloration scores was reported for DC steaks enhanced with 0.50% LA solution.

A persistent red-colored, undercooked appearance at temperatures typically associated with internal browning of normal pH meat, can be found in high pH, DC beef (Hunt et al., 1999; Mancini et al., 2005; Mendenhall 1989; Trout 1989). Sawyer et al. (2009) reported sensory internal cooked color and internal degree of doneness scores were the lowest in non-enhanced DC steaks, indicating a pink, “medium rare” internal appearance, whereas DC steaks enhanced with 1.00% LA received the greatest sensory cooked color and internal degree of doneness scores, representative of gray-brown to brown, “well” to “very well done” internal appearance.

In experiment 2 of Apple et al. (2011), steaks, regardless of LA enhancement level, exhibited improved sensory cooked color and degree of doneness scores and lowered cooked hue angle (HA). Additionally, steaks enhanced with 0.50% LA had lower sensory cooked color
scores, as well as lower a* values and red-to-brown ratio (630/580 nm), compared to normal pH steaks. In addition, Arganosa and Marriott (1989) reported cooked, acid-treated samples had lower a* (redness) values, indicating a greater change from red to brown during the cooking process.

It is also widely accepted that bull beef tends to be tougher than beef from steers (Adams and Arthaud, 1963; Field et al., 1966, 1971; Hedrick et al., 1969; Hunsley et al., 1971). Efforts to improve bull beef tenderness have ranged from electrical stimulation (420 to 550 V); (Gariépy et al., 1992; Jeremiah et al., 1992; Shivas et al., 1985; Solomon et al., 1986; Stiffler et al., 1986; Vanderwert et al., 1986), hot-boning (Shivas et al., 1985; Wheeler et al., 1991), and antemortem enzyme injection (Smith et al., 1973). Jeremiah et al. (1992), Solomon et al. (1986), and Stiffler et al. (1986) all reported improvements in bull beef tenderness from electrical (470 to 550 V) stimulation, whereas Gariépy et al. (1992), Shivas et al. (1985), and Vanderwert et al. (1986), reported no improvements in bull beef tenderness due to electrical (420 to 550 V) stimulation. Moreover, Shivas et al. (1985) found no tenderness advantage in hot-boning bull beef when comparing to steers. Smith et al. (1973) demonstrated that sensory tenderness scores, but not WBSF values, were improved in beef from antemortem enzyme-treated bull carcasses comparable to beef from steers.

As with DC beef color, the improvement of meat tenderness with organic acids has been widely investigated. The effects on instrumental (Berge et al., 2001; Ertbjerg et al., 1999; Mikel et al., 1996) and sensory tenderness (Berge et al, 2001; Mikel et al., 1996), in addition to collagen solubility (Arganosa and Marriott, 1989; Berge et al., 2001; Chang et al., 2010), have been explored with various organic acid treatments. Berge et al. (2001) found that injecting pectoralis profundus (PP) from 3- to 4-yr-old cows with LA at 1 and 24 h postmortem decreased
shear force values both at 2 d postmortem, as well as at 14 d postmortem in PP injected at 24 h. Moreover, Berge et al. (2001) reported that sensory tenderness was rated higher in PP injected with LA. Ertbjerg et al. (1999) stated LA injection reduced WBSF in PP when compared to non-injected PP. Conversely, Mikel et al. (1996) reported no differences in WBSF values or sensory tenderness between beef strip loin steaks treated with AA or LA and control steaks. When it comes to collagen solubility, Arganosa and Marriot (1989) showed that collagen solubility was increased with AA, CA, and LA treatments when compared to controls. Berge et al. (2001) found that the insoluble collagen content decreased with LA injection, and Chang et al. (2010) reported that, although the ST treated with LA produced the least amount of insoluble collagen content, insoluble collagen content did not differ among control, AA-, or CA-marinated ST.

**Cooked Beef Characteristics**

Cookery methods used in meat research can vary widely, and the methods preferred by a particular institution may differ according to cost, space allowances, ease of use, and effectiveness in research (Yancey et al., 2011). Moreover, attempting to mimic at-home, consumer cookery methods has become increasingly important. The increase of 2 working-person households has increased the demand for foods that can be rapidly prepared (Boles and Parrish, 1990). Since the 1960’s, the use of microwave ovens to prepare food has rapidly increased (Baldwin, 1977). Today, microwave cooking has become popular because of its rapid speed of food preparation and amount of energy saved in homes, food processing, and food service operations (Jeong et al., 2004). In addition to microwave ovens, grilling has become common in households for preparation of steaks and hamburgers. Lorenzen et al. (1999) surveyed 4 major U.S. cities and found outdoor grilling (charbroiling) to be the most common (>40%) method of cookery for steaks in all cities. Furthermore, Yancey et al. (2011) evaluated
how counter-top griddles (another common household cookery method), affected cooking time, shear force, cooking loss, and internal cooked color. Clam-shell grills have become a very popular method for research cookery, as it is common in consumer households, and mimics the conductive heating of the belt-grill in repeatability, but is not near as expensive and demanding (Yancey et al., 2011).

**Cooked Color**

There are 2 issues pertaining to cooked meat color, premature browning and persistent redness (PR). The former is of utmost importance as it is now generally accepted that the visual appearance of cooked meats does not necessarily indicate that a microbiologically safe cooking temperature has been achieved (King and Whyte, 2006), whereas the latter pertains mostly, not to meat safety, but rather palatability. Ralston et al. (2002) reported that the percent of respondents serving hamburgers rare, medium-rare, or medium-pink at home declined from 25% in 1988 to 17% in 1998; however, citing palatability preferences, about 5% of respondents reported switched from cooking hamburgers medium-well, or more, in 1991 to cooking hamburgers medium-rare or less in 1996. These findings suggest more and more consumers are properly preparing ground beef; however, PR may be a cause for overcooking ground beef, resulting in a negative eating experience and, thusly, returning to overall unsafe meat cooking. Mendenhall (1989) reported substantial consumers complain when ground beef patties were cooked to 71°C, which are normally grey inside, retain a red, pink raw color after cooking. Additional cooking removed the red, pink color but not without a concurrent loss of quality, particularly texture and juiciness (Mendenhall, 1989).

Persistent red color in ground beef cooked beyond 71°C has been attributed to high pHu (Berry, 1998; Mendenhall, 1989; Trout, 1989; van Laack et al., 1996a, b, 1997). Berry (1998)
obtained beef with pH > 6.0 from USDA-Utility grade carcasses, van Laack et al. (1996a) cooked cow beef patties with pH > 6.0, and Mendenhall (1989) used bull meat as the lean source for high pH patties, indicating carcass maturity and sex may play a pivotal role in PR ground beef. Conversely, Hague et al. (1994) found no relationship between carcass maturity and PR. The authors reported premature browning in ground beef patties formulated from advanced, E-maturity carcasses; however, it is important to note that pH of the patties formulated from E-maturity beef (pH = 5.56) was in the range of what is considered ‘normal.’

Attempts to control PR from high-pH beef have ranged from acid marination (Apple et al., 2011; Arganosa and Marriott, 1989; Sawyer et al., 2008, 2009), altering fat content (Berry, 1998; Troutt et al., 1992a, b), addition of lean, finely textured beef (van Laack et al., 1997), and cooking from differing storage conditions (i.e., frozen vs. thawed); (Berry, 1998; van Laack et al., 1996a). Apple et al. (2011), Arganosa and Marriott (1989), and Sawyer et al. (2008, 2009) were able to improve internal cooked color of high-pH steaks treated with organic acids. Berry (1998) reported that HA of cooked ground beef patties increased (indicative of more “well-done” appearance) with more fat content; however, there were no differences in a* (redness) values or sensory degree of doneness, indicating that increasing the fat content of high-pH patties did not alleviate the issue of PR. van Laack et al. (1997) found that a greater inclusion of lean, finely texture beef in ground beef patties resulted in lower a* values, greater HA, and a more “well-done” visual appearance.

Storage conditions seem to show promise when attempting to overcome PR. In experiment 1 of van Laack et al. (1996a), thawing resulted in a more “well-done” appearance in ground beef patties formulated from cow beef. Additionally, some patties were refrozen after 55 h, of thawing and then cooked from the frozen state, and the color of these patties was similar to
that of patties that were cooked after 18 or 24 h of thawing. This suggests that the effect of thawing on cooked color is not due to the cooking process. Possibly, the thawing process induces changes that influence myoglobin denaturation and cooked color that cannot be reversed by refreezing. Berry (1998) reported no differences in cooked ground beef color whether patties were cooked from a frozen or thawed state. Moreover, Hunt et al. (1999) reported that in addition to cooking from a thawed or frozen state, the state of myoglobin (deoxymyoglobin, oxymyoglobin, and metmyoglobin) had an effect on final cooked color and PR. Hunt et al. (1999) reported that if patties contained predominantly metmyoglobin or oxymyoglobin, a brown, more well-done appearance would develop, whereas when patties contained deoxymyoglobin, an undercooked appearance would develop.

**Cooking Yield**

Microwave cookery has been shown to increase cooking losses (Baldwin, 1977; Gibson and Jeremiah, 1988), whereas Wheeler et al. (1998) reported greater cooking yields in steaks cooked on a belt grill vs. an electric broiler. Yancey et al. (2011) reported no differences among 5 different cookery methods in cooking loss percentage; however, the authors did report increased cooking loss with increased end-point cooking temperature. Cross et al. (1976) also reported that cooking losses increased with increasing internal endpoint temperatures as well. Jeong et al. (2004) reported that cooking losses increased with increased fat content, confirming earlier work done by Berry (1998) and Troutt et al. (1992b). According to Ledward et al. (1992), meat with a higher pH_u is better able to bind with water, and, as one would expect, a high-meat pH improves cooking yield (Apple et al., 2011; Bouton et al., 1971; Miller et al., 1968; Pulford et al., 2009; Sawyer et al., 2008, 2009).
**Tenderness**

While it is well accepted that increasing internal temperature will result in decreased tenderness (Cross et al., 1976; Parrish, Jr. et al., 1973; Yancey et al., 2011), factors such as cookery method remain up in the air. Wheeler et al. (1998) reported that steaks cooked on a belt grill had higher WBSF values than steaks cooked on an electric broiler; however, Yancey et al. (2011) found no difference in WBSF values of LM steaks cooked in clam-shell griddles, counter-top griddles and gas-fired char broiler. The authors did report that steaks cooked on clam-shell and counter-top griddles (methods of conduction heat transfer) were tougher than steaks cooked in forced-air, impingement and convection ovens (methods of convection heat transfer), suggesting that the effects on tenderness may arise from the method of heat transfer rather than cookery method. The theory of heat transfer and difference in tenderness has been demonstrated by McKenna et al. (2003) and Wheeler et al. (1998); however, both Kerth et al. (2003) and Lawrence et al. (2001) found no differences in tenderness when comparing the 2 primary heat transfer methods.

**Conclusions**

With advanced maturity, bull beef will generally develop a pH greater than 6.0, responsible for its high WHC and dark-appearing lean. The dark appearance is due to the ability of light to penetrate deeply into the muscle, and limit light reflection, as well as, a higher concentration of myoglobin. Moreover, with advancing chronological age, bull beef will have increased collagen cross-linking, which in part decreases tenderness.

A number of factors affect cooked beef attributes, especially cooked beef color. Because of an increased pH and myoglobin concentration, mature bull beef appears red and undercooked
when cooked to a suitable internal temperature indicative of medium doneness. Therefore, research is needed to alleviate persistent redness in mature bull beef, as well as tenderness issues.


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CHAPTER II

EFFECT OF LACTIC ACID ENHANCEMENT pH ON BEEF QUALITY ATTRIBUTES OF MATURE BULL STRIP LOINS


Introduction

Bull beef improvement has been a topic of concern for the past 50 years. However, very little research has focused on the color and tenderness of mature bull beef. Field (1971) theorized that because of their temperament, bulls may be stressed more than steers and, therefore, are likely candidates to produce dark-cutting (DC) beef. In a 2001 survey of beef muscle color and pH, Page et al. (2001) found that carcasses with increased overall maturity had an increased postmortem muscle pH and an increase in DC discount.

It is well reported that there is an increase in muscle myoglobin content with advancing animal age (Lawrie, 1950). Boccard et al. (1979) presented that there was a systematic increase in the muscle pigment in all muscles with advancing age of bulls, whereas DeVol et al. (1985) indicated that the darker colored lean from bull is due in part to an increase in pigment concentration.

The relationship between beef tenderness and animal age has been extensively researched, and is generally accepted that there is a decrease in tenderness (Boccard et al., 1979; Goll et al., 1963; Hiner and Hankins, 1950; Field et al., 1966; Laakkonen et al., 1969; Mackintosh et al., 1936; Romans et al., 1965; Shorthose and Harris, 1990; Smith et al., 1982; Tuma et al., 1962, 1963) with increased animal age; however, bull beef tenderness is understood to a lesser extent. Field et al. (1966) and Hedrick et al. (1969) reported young bull tenderness was comparable to tenderness scores from heifers and steers of comparable ages; yet, Field et al.
(1966) reported that mature bulls had greater shear force values than heifers and steers of similar age, but, for the most part, bull beef tends to be tougher than beef from steers (Adams and Arthaud, 1963; Field et al., 1971; Hunsley et al., 1971).

Recent research has shown that enhancing postrigor muscle with organic acids could reduce muscle pH and improve meat color and tenderness, but most organic acid enhancement research relates to young maturity, normal pH beef (Berge et al., 2001; Ertbjerg et al., 1999; Hinkle et al., 2010). Others have focused on improving DC beef with organic acid enhancement (Apple et al., 2011, Sawyer et al., 2008, 2009). Therefore, the objective of this study was to test the effects of lactic acid enhancement of mature bull beef on fresh color during 5 d of simulated retail display, cooked beef color, and cooked beef tenderness.

Materials and Methods

Institutional Animal Care and Use Committee approval was not obtained for this experiment because no live animals were used.

Strip Loin Selection and Enhancement Treatments

Mature bull (C-, D-, and E-maturity; n = 8) beef strip loins (NAMP #180) were selected based on physiological skeletal ossification, identified, and collected during fabrication at a commercial slaughter facility (San Angelo Packing Co., San Angelo, TX). Vacuum-packaged strip loins were transported to the University of Arkansas Red Meat Abattoir and allowed to age 12 d at 2°C. Additionally, USDA Select (n = 4) beef strip loins (IMPS #180) were purchased from a commercial meat processor (Cargill Meat Solutions, Wichita, KS), and shipped to the University of Arkansas Red Meat Abattoir, where they were aged 12 d from box date at 2°C. After the aging period, strip loins were removed from their packaging, and all subcutaneous fat
and heavy connective tissue were removed. Each strip loin was then transversely sectioned into 2 equal length (n = 24) sections, and were allotted randomly to 1 of 5 treatments: 1) a non-enhanced USDA Select (Sel, n = 8) control; 2) a non-enhanced bull (B0; n = 4) control; 3) a 2.5-pH enhancement solution (B25; n = 4) treatment; 4) a 3.0-pH enhancement solution (B30; n = 4) treatment; and 5) a 3.5 pH enhancement solution (B35; n = 4) treatment. The average pre-enhancement pH was determined using a spear-tip probe and meter (model 205; Testo Inc., Sparta, NJ) of B0, B25, B30, B35, and Sel strip loin sections was 6.09 ± 0.58, 6.32 ± 0.46, 6.10 ± 0.73, 5.70 ± 0.10, and 5.62 ± 0.04, respectively.

Enhancement solution was prepared by buffering lactic acid; (PURAC® FCC 88, Purac America, Lincolnshire, IL) into a sodium bicarbonate (Newly Weds Foods, Inc., Chicago, IL) and 4°C tap water solution with a hand-held drill driver with an agitator attachment. Each strip loin section was weighed, and B25, B30, and B35 treatments were injected to a target 111% their individual green-weight with the assigned LA enhancement solution via a multi-needle injector (Fomaco 20/40, Resier Inc., Canton, MA). Enhanced bull strip loin sections were placed into a vacuum tumbler (model TM-300; Promarks Inc., Claremont, CA) immediately after injection, tumbled at 35 rpm under 100 kPa of vacuum for 10 min, removed, and allowed to drip on racks for 15 min before remeasuring pH and reweighing to calculate post-enhancement yield (difference between pre- and post-enhancement weights divided by the pre-enhancement weight multiplied by 100). All strip loin sections were vacuum-packaged and held overnight at 2°C.

Steak Fabrication and Simulated Retail Display

All strip loin sections were removed from their packaging and cut into 2.54-cm-thick steaks: 2 steaks were vacuum packaged and immediately frozen at -20°C; 1 steak for cooked
color and Warner-Bratzler shear force (WBSF); and a forth steak for myofibril fragmentation index (MFI) determination. An additional steak was weighed and placed in a foam tray with soaker pad’ and overwrapped with polyvinyl chloride film (O₂ transmission rate = 14,000 mL O₂/24 h/atm; Koch Supplies Inc., Kansas City, MO). Steaks were then placed into coffin-style display cases (model LMG12; Tyler Refrigeration Corp., Niles, MI) for 5 d under 1,600 lx of continuous deluxe warm-white fluorescent lighting (40-W bulb, type F40T12; Phillips Inc., Somerset, NJ) at 2°C.

On each day of simulated retail display, steaks from each strip loin section had instrumental color [L* (lightness), a* (redness), b* (yellowness), and visible spectrum reflectance (400-700 nm)] values for each steak were determined immediately from a mean of 3 random readings made with a Hunter MiniScan XE spectrophotometer (Hunter Associates Laboratory, Reston, VA), using illuminant A and a 25-mm aperture. The spectrophotometer was calibrated each day before data collection with a standard white tile and standardized with a black glass. The hue angle (representing an angular position between the true red X-axis and true yellow Y-axis) was calculated as tan⁻¹(b*/a*), whereas chroma (C*; representing the total color, or vividness), was calculated as √(a*² + b*²).

**Cooked Color and WBSF Determination**

Steaks were thawed for approximately 16 h at 2°C and weighed before being cooked to an internal end-point temperature of 71°C on electric counter-top griddles (model 07047; National Presto Industries Inc., Eau Claire, WI). Internal temperature was monitored with a hand-held thermometer (model KM28; Comark Instruments Inc., Beaverton, OR). Steaks were flipped every 2 min during cooking. When the internal end-point temperature was reached,
steaks were immediately removed from the griddle, placed into Ziploc freezer bags, and submerged in ice-water to stop the cooking process.

Approximately 10 min after ice-water submersion, steaks were reweighed to calculate cooking yield (difference between pre- and post-cook weights divided by the pre-cook weight multiplied by 100). Steaks were then cut into 2 portions, and, within 20 s of cutting, the internal cooked color was evaluated by a 3-person trained visual color panel. Each steak was scored to the nearest 0.5 point for internal cooked color (1 = very red to 7 = brown; AMSA, 1991) and internal doneness (1 = very rare; 2 = rare; 3 = medium rare; 4 = medium; 5 = well done; and 6 = very well; AMSA, 1991). Immediately after visual color determination, steaks were wrapped in polyvinyl chloride film, and instrumental cooked color was then measured from the mean of 3 readings on the cut surface using a Hunter MiniScan XE Plus spectrophotometer (Hunter Associates Laboratory, Reston, VA) using illuminant A and a 1.27-cm aperture. The spectrophotometer was calibrated and standardized daily, as described previously, and C* and hue angle were calculated according to the equations described previously. In addition, the reflectance ratio of 630 to 580 nm was calculated as an estimate of the cooked color change from red to brown.

After cooked color data collection, six 1.27-cm-diameter cores were removed parallel to the muscle fiber orientation from the LM of each steak, between the 2 halves. Each core was then sheared through the center with the WBSF attachment on an Instron Universal Testing Machine (model 4466, Instron Corp., Canton, MA), equipped with a 55-kg load cell and a crosshead speed of 250 mm/min. Peak shear force values of the 6 cores were averaged for statistical analysis. Steaks for MFI determination were thawed for approximately 16 h at 2°C according to the protocol of Culler et al. (1978) (Appendix I).
Statistical Analysis

Data were analyzed as a completely randomized design, with strip loin section as the experimental unit. Analysis of variance was conducted using the mixed models procedure of SAS (SAS Inst. Inc., Cary, NC). Color data were analyzed as a repeated measures, with day of display the repeated subject. Least squares means were separated statistically with the PDIFF option of SAS.

Results and Discussion

Enhancement Changes

Non-enhanced Sel strip loin sections had lower ($P < 0.05$) pre-enhancement pH values than did non-enhanced mature bull strip loin sections (Table 2.1). Enhancement at solution pH 2.5 and 3.5 lowered ($P = 0.05$) post-enhancement pH values to values comparable of non-enhanced Sel strip loin sections. Even though post-enhancement pH values did not ($P \geq 0.05$) differ between B30 and B0 strip loins, pH values were reduced to less than 6.0, and an average of 0.27 units less than B0. The pH results of high postmortem muscle pH, mature bull steaks with LA in the current experiment are in agreement with previous research showing that injecting higher than normal pH beef, with organic acids can reduce post-enhancement muscle pH values (Apple et al., 2011; Sawyer et al., 2008, 2009). Specifically, Sawyer et al. (2008) reported that LA concentration (0.5%) reduced pH values to levels generally recognized as normal.
**Instrumental Fresh Beef Color**

There were \( P < 0.003 \) interactive effects of LA solution pH and retail display duration for \( a^* \) (redness), and hue angle (Figure 1). Generally, \( a^* \) values increased between d 0 and 1, before declining on d 2 and 3. In addition, \( a^* \) values in B0, B30, and B35, for the most part, leveled off on d 4 and 5, whereas \( a^* \) values continued to decline in both B25 and Sel steaks. Finally, \( a^* \) values were lowest in Sel steaks on d 4 and 5, indicative of beef discoloration (Figure 1A). Moreover, hue angle (HA) did not differ between treatments from d 0 to 2; yet, on d 3, HA of Sel steaks began to increase (closer to the true yellow axis), and HA values for Sel steaks were greater than all other treatments on d 4 and 5 of simulated retail display (Figure 1B). During display, none of the mature bull treatments had an average hue angle of above 45°. The combination of the least \( a^* \) values and the greatest hue angle on d 4 and 5 indicated that Sel steaks were the least color stability steaks among treatments towards the end of display.

Furthermore, steaks from B0, B25, and B30 were darker (lesser \( L^* \) values, linear, \( P < 0.002 \)) and was less yellow (lesser \( b^* \) values, linear, \( P < 0.002 \)) than Sel and B35 strip steaks (Table 2.2). Also, strip steaks were the lighter \( (P < 0.05) \) on d 0, 2, and 3, and more yellow \( (P < 0.05) \) and displayed more total color (greater \( C^* \) values, \( P < 0.05 \)) on d 1 (Table 2.2). It is generally accepted that mature beef is darker (Field, 1971; Romans et al., 1965; Tuma et al., 1962, 1963) than young maturity beef. Results of the present study agree with these findings as fresh, instrumental color for non-enhanced mature bull steaks was darker than normal pH, young maturity Sel steaks. Redness of mature bull strip steaks, including B0, remained more stable d 3-5, compared to Sel steaks, which decreased in fresh, instrumental \( a^* \) values and increased its hue angle. There was an effect of enhancement solution pH on fresh reflectance values within the red spectra (600 to 700 nm). Reflectance values were lowest \( (P < 0.05) \) in B0 and B30 steaks at 600
to 620 nm, and 660 to 700 nm (Figure 2). Moreover, B30 had the lowest ($P < 0.05$) reflectance values within the red spectra between 630 and 650 nm (Figure 2).

**Cooking Yields and Cooked Beef Color**

Cooking losses were lowest ($P<0.05$) for B0, which compared to B30, and Sel steaks (Table 2.4). According to Ledward et al. (1992), meat with a higher pH ($\geq 6.0$) has a greater ability to bind water, creating less free water in the product; thus, a high pH of meat has been shown to positively affect WHC. Pulford et al. (2009) measured levels of cooking loss in bull beef segregated into pH groups of low (pH $< 5.7$), intermediate (pH $< 6.3$), and high (pH $> 6.3$), where greater cooking losses were observed in low pH compared to high pH bull beef.

Surprisingly, there were no ($P \geq 0.44$) main effect for instrumental $a^*$, $b^*$, or $C^*$ (Table 2.3). Internal cooked color of mature bull steaks had a redder appearance, as evidenced by greater ($P < 0.05$) 630:580 nm than Sel steaks. Internal cooked $L^*$ values tended to be greater (lighter, $P < 0.08$) in Sel strip steaks than B0, B25, and B30 steaks. Moreover, internal cooked HA tended to be lower ($P = 0.10$) in B0 steaks than B25 and B35. Within the red spectra, reflectance values were less ($P < 0.05$) in B0, B25, and B30 than Sel steaks between 600 and 660 nm, whereas all mature bull steaks had lower ($P < 0.05$) reflectance values within the red spectra from 670 to 700 nm than Sel (Figure 3).

As expected, non-enhanced mature bull steaks received the lowest ($P < 0.05$) sensory cooked color and degree of doneness scores indicative of a very red, “very rare” internal appearance, whereas Sel steaks received the highest ($P<0.05$) cooked color and degree of doneness scores; however, Sel steaks were still rated as having a pink, “medium-rare” internal appearance (Table 2.3). Mature bull steaks enhanced at solution pH of 2.5 and 3.0 were
comparable in sensory cooked color scores to that of B0 steaks, whereas B35 steaks were similar to Sel steaks. Internal degree of doneness scores of B30 steaks were similar to B0 steaks, but B25 and B35 steaks had individual degree of doneness scores comparable to Sel steaks. Sawyer et al. (2008, 2009) reported that non-enhanced DC steaks received the lowest scores of cooked color and degree of doneness scores, but LA-enhancement improved both cooked color and degree of doneness scores to that of non-enhanced Sel steaks. Both DC beef and mature bull beef are associated with higher than normal ($\geq$6.0) pH values, that when cooked to an internal temperature typically associated with medium doneness, results in a undercooked appearing cooked beef color.

**WBSF and MFI**

Not surprising, MFI values were greater ($P<0.05$) for Sel steaks compared to mature bull strip loins (Table 2.4). Myofibril fragmentation index is used to eliminate any doubt about changes in tenderness due to post-mortem proteolytic degradation. The difference in MFI may be due to lower levels of $\mu$-calpain, the primary proteolytic enzyme in postmortem protein degradation, in mature animals. Studies have indicated that $\mu$-calpain activity declines with increasing animal age (Ou and Forsberg 1991; Veiseth et al., 2004); however, little is understood of $\mu$-calpain activity in advanced maturity meat animals. Also, Ou and Forsberg (1991) found that calpastatin activity decreased with advancing age. As stated previously, bull beef tends to be tougher than beef from steers (Adams and Arthaud, 1963; Field et al., 1971; Hunsley et al., 1971). It was of no surprise then, after analyzing MFI results, that WBSF values were lower ($P > 0.05$) among all mature bull strip loins, when compared to Sel steak WBSF values (Table 2.4).
Conclusions

Results from this study indicate that the addition of LA to mature bull strip loins will lower postmortem muscle pH. In addition, fresh beef color of mature bull strip steaks, regardless of LA enhancement or not, has a redder, more stable color towards the end of 5 d of simulated retail display. Moreover, LA enhancement at solution pH 3.5 improved visual cooked beef color to that of normal pH beef, whereas enhancement with pH 2.5 and 3.5 LA solutions improving visual degree of doneness similarly to that of USDA Select. However, enhancing mature bull strip loins with LA solution did not alter cooked shear force values to that of USDA Select. Therefore, further research is needed to investigate the impact of acidic marination on beef quality attributes of mature bull beef.
Literature Cited


Table 2.1 Main effect of lactic acid enhancement on weight and pH of mature bull strip loin sections

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>B0</th>
<th>B25</th>
<th>B30</th>
<th>B35</th>
<th>Sel</th>
<th>SEM</th>
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<td>4</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Green weight, kg</td>
<td>3.18b</td>
<td>3.30b</td>
<td>3.81b</td>
<td>3.40b</td>
<td>5.34a</td>
<td>0.280</td>
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<tr>
<td>Post-injection weight, kg</td>
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<td>0.550</td>
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<td>Post-injection pH</td>
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a–c, Within a row, least squares means lacking common superscripts differ, $P < 0.05$
Table 2.2 Main effect of lactic acid enhancement and day on fresh beef color of mature bull strip steaks

<table>
<thead>
<tr>
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<th>B0</th>
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<th>B30</th>
<th>B35</th>
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<th>SEM</th>
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<td>4</td>
<td>4</td>
<td>8</td>
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<tr>
<td>L*</td>
<td>29.41&lt;sup&gt;c&lt;/sup&gt;</td>
<td>34.58&lt;sup&gt;b&lt;/sup&gt;</td>
<td>28.10&lt;sup&gt;c&lt;/sup&gt;</td>
<td>36.90&lt;sup&gt;ab&lt;/sup&gt;</td>
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<tr>
<td>b*</td>
<td>15.48&lt;sup&gt;c&lt;/sup&gt;</td>
<td>17.49&lt;sup&gt;b&lt;/sup&gt;</td>
<td>17.07&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>C*</td>
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<td>L*</td>
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<td>35.41&lt;sup&gt;ab&lt;/sup&gt;</td>
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<td>26.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.61&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.13&lt;sup&gt;c&lt;/sup&gt;</td>
<td>13.17&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
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<td>0.677</td>
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<sup>a–c</sup> Within a row, least squares means lacking common superscripts differ, *P* < 0.05

<sup>1</sup>L* = measure of darkness to lightness (larger value indicates a lighter color); and *b* = measure of yellowness (larger value indicates a more yellow color). Chroma (C*) represents the total color of the sample (larger value indicates a more vivid color).
Table 2.3 Main effect of lactic acid enhancement on cooked beef color of mature bull strip steaks

<table>
<thead>
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<tr>
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<td>4</td>
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<td>a*</td>
<td>25.21</td>
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<tr>
<td>b*</td>
<td>20.80</td>
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</tr>
<tr>
<td>C*</td>
<td>32.71</td>
<td>32.94</td>
<td>33.63</td>
</tr>
<tr>
<td>Hue angle</td>
<td>39.32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>42.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40.58&lt;sup&gt;ab&lt;/sup&gt;</td>
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<tr>
<td>630-580 nm</td>
<td>29.70&lt;sup&gt;b&lt;/sup&gt;</td>
<td>27.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>29.00&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Cooked Color Scores&lt;sup&gt;2&lt;/sup&gt;</td>
<td>1.88&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.42&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>2.12&lt;sup&gt;bc&lt;/sup&gt;</td>
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<tr>
<td>Degree of Doneness&lt;sup&gt;3&lt;/sup&gt;</td>
<td>1.92&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.71&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>2.42&lt;sup&gt;bc&lt;/sup&gt;</td>
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<sup>a-c</sup> Within a row, least squares means lacking common superscripts differ, P < 0.05

<sup>1</sup>L* = measure of darkness to lightness (larger value indicates a lighter color); a* = measure of redness (larger value indicates a more intense red color); and b* = measure of yellowness (larger value indicates a more yellow color). Chroma (C*) represents the total color of the sample (larger value indicates a more vivid color); hue angle represents the change from the true red axis (larger value indicates a shift from red to yellow); 630-580 nm reflectance ratio (estimate of the cooked color change from red to brown).

<sup>2</sup>Score 1 = very red; 2 = medium red; 3 = pink; 4 = slightly pink; 5 = pinkish gray; 6 = gray brown; and 7 = brown

<sup>3</sup>Score 1 = very rare; 2 = rare; 3 = medium rare; 4 = medium; 5 = well done; and 6 = very well
Table 2.4 Main effects of lactic acid enhancement on cooked beef attributes and MFI of mature bull strip steaks

<table>
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<th>Characteristic</th>
<th>B0</th>
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<th>B35</th>
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<th>SEM</th>
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<td>19.50&lt;sup&gt;ab&lt;/sup&gt;</td>
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<td>0.017</td>
<td>0.0075</td>
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<sup>a,b</sup>Within a row, least squares means lacking common superscripts differ, *P* < 0.05

<sup>1</sup>540 nm absorbance × 200

<sup>2</sup>Cook loss = (Pre-cook steak weight – post-cook steak weight/pre-cook steak weight) × 100
**Figure 1.** Interactive effects of lactic acid enhancement and duration of simulated retail display (*P* < 0.0029) on A) redness (a*) values, and B) hue angle. Bars for non-enhanced, mature bull, negative controls (B0); mature bull strip loin sections enhanced with solution pH 2.5, 3.0, and 3.5, and non-enhanced, USDA Select, positive controls (Sel) represent the mean of 4, 4, 4, 4, and 8 steaks, respectively. Bars lacking common letters (a-h) differ, *P* < 0.05.
Figure 2. Main effect of lactic acid enhancement on fresh reflectance values of mature bull strip loin sections (P < 0.05). Lines for non-enhanced, mature bull, negative controls (B0); mature bull strip loin sections enhanced with solution pH 2.5, 3.0, and 3.5, and non-enhanced, USDA Select, positive controls (Sel) represent the mean of 4, 4, 4, 4, and 8 steaks, respectively. Lines lacking common letters (a-d) differ, P < 0.05.
Figure 3. Main effect of lactic acid enhancement on cooked reflectance values of mature bull strip loin sections ($P < 0.05$). Lines for non-enhanced, mature bull, negative controls (B0); mature bull strip loin sections enhanced with solution pH 2.5, 3.0, and 3.5, and non-enhanced, USDA Select, positive controls (Sel) represent the mean of 4, 4, 4, 4, and 8 steaks, respectively. Lines lacking common letters (a, b) differ, $P < 0.05$. 

1 = Bull 0.0, B0$^b$, B25$^b$, B30$^b$, B35$^{ab}$, Sel$^a$
2 = Bull 2.5, B0$^b$, B25$^b$, B30$^b$, B35$^b$, Sel$^a$.
APPENDIX I

Myofibril Fragmentation Index

Extraction

1. Sample extraction should be done in duplicate.

2. In a cold room (2°C), scissor mince 4 grams of muscle. Minced sample should be free of fat and connective tissue.

3. Put sample in a 50 mL centrifuge tube with 40 mL cold (2°C) MFI buffer. Using a homogenizer, homogenize on high for 30 seconds

4. Centrifuge at 1,000 x g for 15 minutes (2°C).

5. Discard the supernatant. If there is a fat cap (layer of fat, connective tissue, and myofibrils) above the supernatant, save the fat cap with the pellet.

6. Using a glass stir rod, resuspend the pellet (and fat cap) in 40 ml cold (2°C) MFI buffer. (DO NOT USE A VORTEX MIXER).

7. Centrifuge at 1,000 x g for 15 minutes (2°C).

8. Discard the supernatant and fat cap.

9. Resuspend the pellet in 10 ml cold (2°C) MFI buffer and mix well by using a Vortex Mixer.

10. To remove connective tissue, pour the sample through a fine mesh tea strainer.

11. Rinse the centrifuge tube with an additional 10 ml cold (2°C) MFI buffer and pour through the tea strainer.
Protein Assay

Refer to Bausch and Lomb Spectronic 20 Setup before being this assay

1. Protein assay should be conducted in duplicate for each sample suspension.
2. Place 0.25 mL of each sample into 13x100 mm glass tubes.
3. Add 0.75 mL MFI buffer.
4. Add 4 mL Biuret reagent and mix on a vortex mixer.
5. Incubate for 30 minutes at room temperature and in the dark.
6. Simultaneously, Bovine Serum Albumin (BSA) standards should be run to establish a standard curve used in determining protein concentration. The following concentrations are preferred: 0 (blank), 2.5, 5.0, 7.5, and 10.0 mg/mL.
7. To these 1 ml standards, add 4 mL Biuret reagent and incubate for 30 minutes.
8. Standards should be run in duplicate.
9. Read the absorbance at 540 nm using a Bausch and Lomb Spectronic 20 Spectrophotometer with a large slit with (20 nm). If the spectrophotometer is properly calibrated, the absorbance of the standards should be approximately 0, 0.15, 0.30, 0.45 and 0.60 for the 0, 2.5, 5.0, 7.5, and 10.0 mg/mL BSA standards, respectively.
MFI Measurement

Refer to Bausch and Lomb Spectronic 20 Setup before being this assay

1. MFI should be measured in duplicate for each sample suspension.
2. In a 13x100 mm glass tube, dilute an aliquot of the sample suspension to equal 0.5 mg/ml protein in 8 ml MFI buffer.
3. Cap tube and mix sample immediately before reading the absorbance (540 nm) on the Spectronic 20 spectrophotometer. Use MFI buffer for the blank.
4. Multiply the absorbance reading by 200 to obtain the Myofibril Fragmentation Index.

Bausch and Lomb Spectronic 20 Setup

1. Startup Spectronic 20 15 minutes prior to use.
2. Set wavelength to 540 nm.
3. Ensure cuvette cell is empty and door is shut. Using left dial, set to 0% transmittance.
4. Place blank in the cuvette cell (Protein Assay = 0 mg/mL BSA; MFI Measurement = MFI buffer) and using the right dial, set to 100% transmittance.
MFI BUFFER (2 LITERS), pH 7.0

You will need 250 mL MFI buffer per sample.

100 mM KCl, 20 mM potassium phosphate, 1 mM EGTA, 1 mM MgCl₂, 1 mM NaN₃

KCl 14.91 g
KH₂PO₄ 2.72 g
K₂HPO₄ 3.50 g
EGTA 0.76 g
MgCl₂ 0.41 g
NaN₃ 0.13 g

Dissolve in distilled deionized water. Adjust pH to 7.0 with NaOH. Bring to a final volume of 2 liters. Store at 4°C. Do not use anhydrous magnesium chloride, as this chemical causes a yellow tint.

BIURET REAGENT

You will need 16 mL Biuret reagent per sample.

Dissolve 1.5 g Cupric Sulfate (CuSO₄•5H₂O) and 6 g sodium potassium tartrate (NaKC₄H₄O₆•4H₂O) in about 500 ml distilled deionized water in a 1000 mL volumetric flask. With constant stirring, add 300 mL of freshly prepared, carbonate free 10% NaOH. Bring up to 1 liter with distilled deionized water and store in a brown polyethylene bottle. Store at room temperature. Discard if a black or red precipitate appears.

REFERENCE

December 4, 2013

To Whom It May Concern:

This letter is confirmation that Mr. Jace J. Hollenbeck is the primary author of this manuscript/chapter entitled: “Effect of Lactic Acid Enhancement pH on Beef Quality Attributes of Mature Bull Strip Loin.” In addition, as his major advisor, I certify that Jace completed more than the required 51% of the research and writing of this particular paper. If any questions remain, please feel free to contact me at your convenience and I will be more than happy to address any concerns.

Sincerely,

Jason K. Apple, Ph.D.
Professor
CHAPTER III
COOKED COLOR OF PRECOOKED GROUND BEEF PATTIES FORMULATED WITH MATURE BULL TRIM

J.J. Hollenbeck, J.K. Apple, J.W.S. Yancey, K.N. Kerns, and A.N. Young

Introduction

Ground beef is the most common way beef is purchased in the U.S., and is the most common consumed form of beef at home as well as away from the home. Precooked ground beef patties are an emerging market because precooked patties are convenient for quick, in-home meals, and are a perceived safer product for foodservice outlets. In addition, due to many food-borne outbreaks linked to undercooked ground beef, many of today’s consumers associate a red internal cooked color with questionable wholesomeness.

Field (1971) theorized that because of their temperament, bulls may be stressed more than steers and, therefore, are likely candidates to become dark-cutting beef, beef with a higher than normal, postmortem pH (≥ 6.0) and have a dark red to black appearance. In addition, studies have shown that there is an increase in muscle myoglobin content with advancing animal age (Boccard et al., 1979; DeVol et al., 1985; Lawrie 1950). DeVol et al. (1985) indicated that the darker-colored lean from bull is due in part to an increase in pigment concentration. Moreover, it has been reported that undenatured myoglobin may cause a persistent red color in high pH (≥ 6.0) meat cooked to 71°C (Berry, 1998; Mendenhall, 1989; Trout, 1989; van Laack et al., 1996a, b, 1997). Additional cooking will remove the red, pink color but not without a concurrent loss of quality, particularly texture and juiciness (Mendenhall, 1989). Therefore, the objective of this study was to characterize cooked color of reheated, precooked ground beef patties formulated with various levels of mature bull beef.
Materials and Methods

Institutional Animal Care and Use Committee approval was not obtained for this experiment because no live animals were used.

Bull Beef Selection and Batch Formulation

Mature bull (C-, D-, and E-maturity) beef necks were selected based on physiological skeletal ossification, identified, and collected during fabrication at a commercial slaughter facility (Lone Star Beef Processors, San Angelo, TX). Vacuum-packaged beef necks were transported to the University of Arkansas Red Meat Abattoir and stored for 2 d at 2°C. In addition, A-maturity, USDA Select peeled beef knuckles (IMPS #167a) and 50:50 beef trimmings were purchased from a commercial meat processor (Cargill Meat Solutions, Wichita, KS), and were shipped to the University of Arkansas Red Meat Abattoir, and stored for 2 d at 2°C. After 2 d, necks and knuckles were removed from their packaging, and trimmed, cubed, and, along with the 50:50 beef trimmings, coarse ground through a 1.59-cm grinder plate and placed into 18.1-kg capacity lugs. Random grab samples from each lug’s contents were analyzed for fat content (model HFT 2000; Data Support Co., Inc., Encino, CA) and then combined appropriately to formulate 25, 13.6-kg batches of 85% lean ground beef. The lean portion consisted of 0, 25, 50, 75, or 100% ground mature bull trimmings (MBT). The remainder of the lean portion was composed with the ground knuckles (Table 3.1), whereas 50:50 beef trimmings were used as the “fat” portion of the ground beef blend. Rosemary extract (Newly Weds Foods Inc., Chicago, IL) was added to each batch at 0.035% of total weight, whereas tap water was included at 5%. Batches were then ground through a 0.95-cm grinder plate, and 151-g patties
were formed using a commercial patty forming machine (Hollymatic Corp., Countryside, IL). Six random patties from each batch were selected for raw pH and fat analysis.

Twelve random patties from each batch were allowed to bloom for 30 min before raw instrumental color (L*, a*, b*, and visible spectrum reflectance (400 to 700 nm)) for each patty was determined immediately from a mean of 3 random readings made with a Hunter MiniScan EZ spectrophotometer (model 4500L; Hunter Associates Laboratory, Reston, VA), using illuminant A and a 2.54-cm aperture. Then, these patties were segregated and maintained for following through the cooking process. The spectrophotometer was calibrated before data collection with a standard white tile and standardized with a black glass. The hue angle (HA; representing an angular position between the true red X-axis and true yellow Y-axis) was calculated as \( \tan^{-1}(b*/a*) \), whereas chroma (\( C^* \); representing the total color, or vividness) was calculated as \( \sqrt{(a^{*2} + b^{*2})} \).

**Initial Cooked Color and Cooking Yields**

All patties were held overnight at 2°C. The 12 segregated patties used to measure raw instrumental color, were weighed, traced (planar area), and measured for thickness. Then all patties were cooked to an internal end-point temperature of 71°C in a gas-fired, forced-air, impingement oven (model 1116-080-A; Lincoln Foodservice Products Inc., Fort Wayne, IN) set at 204.4°C with a belt speed to 10.5 min. Patties were placed on the conveyor chain and internal temperature was checked with a hand-held thermometer (model KM28; Comark Instruments Inc., Beaverton, OR), and patties that had not reached the correct temperature were pushed back into the oven until the specified end-point temperature was reached.
After cooking, the 12 segregated patties were placed into Ziploc freezer bags and submerged in ice water to stop the cooking process. Approximately 10 min after being placed in the ice bath patties were reweighed to calculate cooking yield (difference between pre- and post-cook weights divided by the pre-cook weight, multiplied by 100), retraced to calculate planar area change (difference between pre- and post-cook planar areas), and measured again for thickness to calculate thickness change (difference between pre- and post-cook thickness). The L*, a*, b*, and visible spectrum reflectance values were then measured, both externally and internally, from the mean of 3 readings using a Hunter MiniScan EZ spectrophotometer (Hunter Associates Laboratory, Reston, VA) with illuminant A and a 2.54-cm aperture. The spectrophotometer was calibrated and standardized before use, as described previously, and C* and HA were calculated according to the equations described previously. Additionally, the reflectance ratio of 630 nm and 580 nm was calculated as an estimate of the cooked color change from red to brown for internal color. Three random patties were removed from each batch for initial cook pH, whereas the remaining patties were frozen overnight at -20°C, and then loosely bagged and stored at -20°C.

Reheated Color and Cooking Yields

Twenty-four random patties from each batch were weighed, traced, and thickness measured as described previously. Patties were split into 1 of 2 reheating methods, a gas-fired, open-hearth charbroiler (model 6148RCBD; Star Manufacturing International, Inc., Smithville, TN) set at medium-high heat, turned every 2 min to an end-point internal temperature of 71°C monitored by a hand-held thermometer (model KM28; Comark Instruments Inc., Beaverton, OR), or an 1100-W microwave oven (model WES1450; General Electric Co., Louisville, KY) for 2 min.
After reheating, patties were placed into Ziploc freezer bags and submerged in ice water to stop the cooking process. Approximately 10 min after being placed in the ice bath patties were reweighed to calculate cooking yield, retraced to calculate planar area change, and patty thickness was measured to calculate thickness change, as described previously. The L*, a*, b*, and visible spectrum reflectance values were then measured, both externally and internally, from the mean of 3 readings using a Hunter MiniScan EZ spectrophotometer (Hunter Associates Laboratory, Reston, VA) with illuminant A and a 2.54-cm aperture. The spectrophotometer was calibrated and standardized before data collection, as described previously and C*, hue angle, and 630:580 ratio were calculated as described previously. Moreover, an additional 3 random patties were reheated using each method for reheated pH determination.

**Statistical Analysis**

All data were analyzed as a completely randomized design with batch (n=5/formulation) as the experimental unit. The analysis of variance was carried out using the mixed models procedure of SAS (SAS Inst., Inc., Cary, NC), with the proportion of MBT, as well as reheating method, as fixed effects and batch as the lone random effect. Least squares means were separated statistically with the PDIFF option of SAS. In addition, linear and quadratic contrasts were used to discern the effects of MBT level in patty formulation on color and dimensions of cooked and reheated patties.

**Results and Discussion**

**Batch Composition**

Within each production step (raw, initial cook, and reheat) pH was greater ($P<0.05$) with increasing percentages of MBT (MBT × Production Step, $P < 0.0001$; Figure 1). Moreover, pH
decreased after initial cook and then again during the reheating step within each MBT treatment. Moiseev and Cornforth (1999) presented contradictory findings, reporting meat pH increased after cooking in ground beef patties formulated with normal pH beef compared to dark-cutting beef.

**Raw Ground Beef Patty Color**

At a higher postmortem pH, Ledward et al. (1992) reported that proteins were better able to bind with water, creating less free water in the product and causing light to absorb deeply into the meat, giving meat a darker color. The results of the present study indicated that lightness (L*) values tended to decrease (linear, \( P = 0.079 \)) with increasing levels of MBT (Table 3.2). Otherwise, there were no (\( P \geq 0.622 \)) main effects of MBT level on instrumental color for a* (redness), b* (yellowness), C*, and HA of raw ground beef patties (Table 3.2). Raw reflectance values within the red spectra (600 to 700 nm) were lower (\( P < 0.05 \)) in 100% and 75% MBT patties at 600 to 620 nm, and again at 660 to 700 nm (Figure 2).

**Initial Cooked Ground Beef Patty Color and Cooking Yields**

There was no main effect (\( P = 0.283 \)) of MBT on external cooked a* (redness) values (Table 3.3). External cooked color of patties formulated with 100 and 75% MBT had lesser L* (darker; linear, \( P < 0.0001 \)) values, and lower HA (closer to the true red axis, linear, \( P < 0.0001 \)), than patties formulated with 50, 25, and 0% MBT (Table 3.3). Patties formulated with 25 and 0% MBT were more yellow (greater b* values; linear, \( P < 0.0001 \)) and displayed more total color (greater C* values; linear, \( P < 0.0001 \)) than all other treatments (Table 3.3).

Occurrence of products with persistently red internal color after cooking has been reported previously (Cornforth et al., 1991; van Laack et al., 1996b). Mendenhall (1989) and
Trout (1989) reported that undenatured myoglobin occurred in meat cooked to 71°C if pH was greater than 6.0. Both authors also suggested that myoglobin denaturation was related to myoglobin concentration. Both these parameters fit well with ground beef patties formulated with MBT, as bull beef is associated with both a high concentration of myoglobin (Boccard et al., 1979; DeVol et al., 1985) and a high postmortem muscle pH (Kousgaard, 1980; Page et al., 2001). However, there were no main effects ($P \geq 0.2025$) for internal cooked $a^*$, $C^*$, HA, or 630nm to 580 nm reflectance ratios (Table 3.3). Patties formulated with 25% MBT were lightest (greater L* values; linear, $P < 0.002$) internally, whereas 100 and 75% MBT patties were darkest (lower L* values; linear, $P < 0.002$) among treatments (Figure 3). Moreover, 25 and 0% MBT patties were less yellow (lower b* values, linear, $P < 0.0001$) internally compared to 100-50% MBT patties (Figure 3). It is important to note that, during the initial cooking process, expressed juices from 100% MBT patties were visually red, whereas expressed juices from 0% MBT patties were visually clear. In addition, differences within the red spectra only existed at the 690 and 700 nm wavelengths, where 100 and 75% MBT patties presented lower ($P < 0.05$) reflectance values (Figure 4).

It has been reported that ground beef patties formulated with dark-cutting beef have higher cooking yields (Moiseev and Cornforth, 1999). Unexpectedly, patties formulated with 100% MBT expressed greater (linear, $P < 0.0001$) cooking losses than all other batch formulations (Table 3.4). Moiseev and Cornforth (1999) also reported no effects of dark-cutting beef on patty thickness or diameter shrinkage. However, patty thickness increased an average of 0.48 mm in patties formulated with 0% MBT, whereas, all batches formulated with MBT exhibited an average reduction (linear, $P < 0.0001$) in patty thickness of 1.50, 1.16, 0.12, and 0.23 mm, as MBT decreased from 100-25%, respectively (Table 3.4). In addition, patty area
decreased (quadratic, $P < 0.0001$) in all treatments (Table 3.4), with the greatest reduction in patty area in those formulated with 50% MBT and the least change in 0% MBT patties.

**Reheated Ground Beef Patty Color and Cooking Yields**

The external surface of patties reheated on the charbroiler were darker (lower L* values; $P < 0.05$), less red (lower a* values; $P < 0.05$), less yellow (lower b* values; $P < 0.05$), displayed less total color (lower C* values; $P < 0.05$), and a lower HA (this would indicate a redder color; $P < 0.05$) than the surface of patties reheated in the microwave (Table 3.5). This is to be expected as charbroiling patties resulted in a charred, “blackened” external appearance. Furthermore, 0% MBT patties displayed greater external L* (linear, $P < 0.004$) values than patties formulated with 50 to 100% MBT (Table 3.5). In addition, external b* and C* values, as well as HA, increased ($P < 0.0001$) as MBT decreased in the patty formulation.

As previously stated, meat with a postmortem pH greater than 6.0 has been associated with persistent redness when cooked to 71°C. The reheated internal color findings of this study coincide with these ideas as patties formulated with 100 and 75% MBT presented greater internal a* (linear, $P < 0.0001$) values (Figure 5), greater internal C* (linear, $P < 0.0001$) values (Table 3.6), lower internal hue angle (linear, $P < 0.0001$) (Figure 3), and greater internal 630:580 nm reflectance ratio (linear, $P < 0.0001$) calculations, compared to 50-0% MBT patties (Table 3.6). Moreover, 100% MBT patties were the most yellow (quadratic, $P < 0.0001$) internally of all treatments, whereas, 50 and 25% patties were the least yellow (Figure 5). Also, patties reheated on the charbroiler exhibited greater internal L* values ($P < 0.05$), whereas patties formulated with 100% MBT tended to be darker ($P = 0.069$) than 25% MBT patties (Table 3.6). Furthermore, patties formulated from 100 and 75% MBT had greater ($P < 0.05$) reflectance values at 630, 670,
690, and 700 nm when compared to 0% MBT patties (Figure 6). In addition, 100 and 75% MBT patties had greater ($P < 0.05$) red spectra reflectance values at 640 to 660, and 680 nm than 50% MBT patties. Moreover, patties reheated on the charbroiler had greater ($P < 0.05$) reflectance values across the entire visual color spectra (400 to 700 nm) than those reheated in microwaves, indicative of differences in lightness.

When reheated, patties formulated with 100, 75, and 0% MBT exhibited less cooking losses ($P < 0.05$) than 25% MBT patties (Table 3.4). Interestingly, when reheated on the charbroiler, patty thickness increased ($P < 0.05$), or “plumped,” an average of 2.4 mm, whereas thickness of patties reheated in the microwave oven decreased ($P < 0.05$) 0.8 mm (Table 3.4). Furthermore, regardless of the proportion of MBT, patty area decreased ($P < 0.05$) when reheated on the charbroiler compared to ground beef patties reheated in microwave ovens (Figure 8). Moreover, when reheated in the microwave oven 50 and 0% MBT patties had the greatest decrease in planar area, whereas patty area decreased the least when 0% MBT patties were reheated on the (MBT × cookery method, $P < 0.0001$, Figure 8).

Conclusions

Within each step of production, pH increased with increasing MBT, with 100% MBT patties maintaining a pH greater than 5.9 throughout production. In addition, patties made with 100 and 75% MBT maintained a red cooked internal color after being cooked and reheated to 71°C. Moreover, upon reheating, patties formulated with 100 and 75%, and surprisingly 0% MBT, had the least amount of loss when heated, regardless of reheating method.
Literature Cited


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Table 3.2 Main effects of %MBT inclusion on raw ground beef patty color

| Characteristic | Mature Bull Trimmings, % | | | | | | SEM | P > F |
|---------------|-------------------------|---|---|---|---|---|---|---|---|
| No. of patties| 60                      | 60 | 60 | 60 | 60 | - | - | - | - |
| L*            | 52.04<sup>c</sup>       | 52.73<sup>bc</sup> | 54.04<sup>abc</sup> | 55.05<sup>bc</sup> | 55.78<sup>a</sup> | 0.996 | 0.080 |
| a*            | 27.25                   | 26.81 | 25.64 | 24.66 | 23.67 | 2.091 | 0.735 |
| b*            | 23.31                   | 23.36 | 23.08 | 22.87 | 22.67 | 0.706 | 0.950 |
| C*            | 35.91                   | 35.60 | 34.55 | 33.70 | 32.85 | 2.000 | 0.799 |
| Hue angle     | 40.96                   | 41.39 | 42.36 | 43.25 | 44.16 | 1.610 | 0.622 |

<sup>a-c</sup>Within a row, least squares means lacking common superscripts tend to differ, P = 0.0798

<sup>1</sup>L* = measure of darkness to lightness (larger value indicates a lighter color); a* = measure of redness (larger value indicates a more intense red color); and b* = measure of yellowness (larger value indicates a more yellow color). Chroma (C*) represents the total color of the sample (larger value indicates a more vivid color); hue angle represents the change from the true red axis (larger value indicates a shift from red to yellow).
Table 3.3 Main effects of %MBT on initial, internal and external, cooked ground beef patty color

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mature Bull Trimmings, %</th>
<th></th>
<th></th>
<th></th>
<th>SEM</th>
<th></th>
<th>P &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>75</td>
<td>50</td>
<td>25</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of patties</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>48</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L*</td>
<td>39.86&lt;sup&gt;c&lt;/sup&gt;</td>
<td>40.69&lt;sup&gt;c&lt;/sup&gt;</td>
<td>41.94&lt;sup&gt;b&lt;/sup&gt;</td>
<td>42.72&lt;sup&gt;b&lt;/sup&gt;</td>
<td>44.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.292</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>a*</td>
<td>14.37</td>
<td>14.44</td>
<td>14.44</td>
<td>14.57</td>
<td>14.70</td>
<td>0.110</td>
<td>0.283</td>
</tr>
<tr>
<td>b*</td>
<td>19.08&lt;sup&gt;c&lt;/sup&gt;</td>
<td>19.55&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>20.05&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20.83&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.221</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>C*</td>
<td>23.90&lt;sup&gt;c&lt;/sup&gt;</td>
<td>24.32&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>24.72&lt;sup&gt;b&lt;/sup&gt;</td>
<td>25.43&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.91&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.230</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Hue angle</td>
<td>52.97&lt;sup&gt;c&lt;/sup&gt;</td>
<td>53.51&lt;sup&gt;c&lt;/sup&gt;</td>
<td>54.16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>54.94&lt;sup&gt;a&lt;/sup&gt;</td>
<td>55.35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.212</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of patties</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>48</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a*</td>
<td>17.54</td>
<td>18.57</td>
<td>17.81</td>
<td>17.52</td>
<td>17.16</td>
<td>0.570</td>
<td>0.499</td>
</tr>
<tr>
<td>C*</td>
<td>26.35</td>
<td>26.93</td>
<td>26.35</td>
<td>25.77</td>
<td>25.46</td>
<td>0.447</td>
<td>0.203</td>
</tr>
<tr>
<td>Hue angle</td>
<td>48.48</td>
<td>46.51</td>
<td>47.57</td>
<td>47.26</td>
<td>47.73</td>
<td>0.842</td>
<td>0.583</td>
</tr>
<tr>
<td>630:580 nm</td>
<td>2.07</td>
<td>2.23</td>
<td>2.10</td>
<td>2.09</td>
<td>2.04</td>
<td>0.090</td>
<td>0.595</td>
</tr>
</tbody>
</table>

<sup>a-c</sup>Within a row, least squares means lacking common superscripts differ, *P* < 0.05

<sup>1</sup>L* = measure of darkness to lightness (larger value indicates a lighter color); a* = measure of redness (larger value indicates a more intense red color); and b* = measure of yellowness (larger value indicates a more yellow color). Chroma (C*) represents the total color of the sample (larger value indicates a more vivid color); hue angle represents the change from the true red axis (larger value indicates a shift from red to yellow); 630:580 nm is an estimate of the cooked color change from red to brown.
Table 3.4 Main effects of %MBT on initial cooking loss and dimension change, and %MBT and reheating method on reheated cooking loss and dimension change of cooked ground beef patties

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mature Bull Trimmings, %</th>
<th>Reheating Method</th>
<th>SEM</th>
<th>P &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 75 50 25 0</td>
<td>Charbroiler</td>
<td>Microwave Oven</td>
<td></td>
</tr>
<tr>
<td>No. of patties</td>
<td>60 60 60 48 60</td>
<td>288</td>
<td>288</td>
<td></td>
</tr>
<tr>
<td>Initial cook loss(^1), %</td>
<td>38.6(^a) 36.0(^b) 35.9(^b) 34.6(^c) 31.7(^d)</td>
<td>17.4</td>
<td>18.3</td>
<td>0.008</td>
</tr>
<tr>
<td>Reheat loss(^2), %</td>
<td>16.4(^b) 15.3(^b) 19.1(^ab) 21.3(^a) 17.0(^b)</td>
<td>2.43(^a)</td>
<td>-0.77(^b)</td>
<td>0.120</td>
</tr>
<tr>
<td>Initial Cook ΔThickness(^3), mm</td>
<td>-1.50(^c) -1.16(^c) -0.12(^b) -0.23(^b) 0.49(^a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reheat ΔThickness(^4), mm</td>
<td>0.55 0.71 0.90 1.19 0.80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Cook ΔArea(^5), cm(^2)</td>
<td>-27.78(^b) -28.72(^b) -32.73(^d) -30.11(^c) -23.15(^a)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Within a row, least squares means lacking common superscripts differ, \(P < 0.05\)
\(^1\)Initial cook loss = (Raw patty weight – cooked patty weight/raw patty weight) × 100
\(^2\)Reheat loss = (Frozen cooked patty weight – reheated patty weight/frozen cooked patty weight) × 100
\(^3\)Initial Cook ΔThickness = Raw patty thickness – cooked patty thickness
\(^4\)Reheat ΔThickness = Frozen patty thickness – reheated patty thickness
\(^5\)Initial Cook ΔArea = Raw planar patty area – cooked planar patty area
Table 3.5 Main effects of %MBT, and reheating method on reheated external instrumental cooked ground beef patty color

<table>
<thead>
<tr>
<th>Characteristic^1</th>
<th>Mature Bull Trimmings, %</th>
<th>SEM</th>
<th>P &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>No. of patties</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>L*</td>
<td>34.49^b</td>
<td>35.27^b</td>
<td>34.67^b</td>
</tr>
<tr>
<td>a*</td>
<td>12.33</td>
<td>12.37</td>
<td>12.53</td>
</tr>
<tr>
<td>b*</td>
<td>16.46^c</td>
<td>16.67^bc</td>
<td>17.20^b</td>
</tr>
<tr>
<td>C*</td>
<td>20.58^b</td>
<td>20.79^b</td>
<td>21.31^b</td>
</tr>
<tr>
<td>Hue Angle</td>
<td>52.85^b</td>
<td>53.07^b</td>
<td>53.57^b</td>
</tr>
</tbody>
</table>

Reheating Method

<table>
<thead>
<tr>
<th></th>
<th>Charbroiler</th>
<th>Microwave Oven</th>
<th>SEM</th>
<th>P &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patties</td>
<td>288</td>
<td>288</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>L*</td>
<td>31.45^b</td>
<td>39.32^a</td>
<td>0.327</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>a*</td>
<td>11.84^b</td>
<td>13.21^a</td>
<td>0.080</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>b*</td>
<td>15.25^b</td>
<td>19.44^a</td>
<td>0.161</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>C*</td>
<td>19.33^b</td>
<td>23.53^a</td>
<td>0.170</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Hue Angle</td>
<td>51.88^b</td>
<td>55.68^a</td>
<td>0.164</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

^a-c: Within a row, least squares means lacking common superscripts differ, P < 0.05
^1L* = measure of darkness to lightness (larger value indicates a lighter color); a* = measure of redness (larger value indicates a more intense red color); and b* = measure of yellowness (larger value indicates a more yellow color). Chroma (C*) represents the total color of the sample (larger value indicates a more vivid color); and hue angle represents the change from the true red axis (larger value indicates a shift from red to yellow).
Table 3.6 Main effects of %MBT, and reheating method on reheated internal instrumental cooked ground beef patty color

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mature Bull Trimmings, %</th>
<th>SEM</th>
<th>P &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patties</td>
<td>60 60 60 48 60</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>L*</td>
<td>61.75&lt;sup&gt;b&lt;/sup&gt; 62.50&lt;sup&gt;ab&lt;/sup&gt; 62.40&lt;sup&gt;ab&lt;/sup&gt; 63.08&lt;sup&gt;a&lt;/sup&gt; 62.32&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.327</td>
<td>0.070</td>
</tr>
<tr>
<td>b*</td>
<td>18.81&lt;sup&gt;a&lt;/sup&gt; 18.45&lt;sup&gt;b&lt;/sup&gt; 18.10&lt;sup&gt;c&lt;/sup&gt; 18.13&lt;sup&gt;b&lt;/sup&gt; 18.22&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.095</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>C*</td>
<td>23.57&lt;sup&gt;a&lt;/sup&gt; 23.14&lt;sup&gt;a&lt;/sup&gt; 21.67&lt;sup&gt;b&lt;/sup&gt; 21.50&lt;sup&gt;b&lt;/sup&gt; 21.54&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.264</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>630:580 nm</td>
<td>1.70&lt;sup&gt;a&lt;/sup&gt; 1.68&lt;sup&gt;a&lt;/sup&gt; 1.44&lt;sup&gt;b&lt;/sup&gt; 1.40&lt;sup&gt;b&lt;/sup&gt; 1.37&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.048</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reheating Method</th>
<th>Charbroiler</th>
<th>Microwave Oven</th>
<th>SEM</th>
<th>P &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patties</td>
<td>288</td>
<td>288</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>L*</td>
<td>62.99&lt;sup&gt;a&lt;/sup&gt; 61.82&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.190</td>
<td>&lt; 0.0001</td>
<td></td>
</tr>
<tr>
<td>a*</td>
<td>12.63</td>
<td>12.47</td>
<td>0.234</td>
<td>0.613</td>
</tr>
<tr>
<td>b*</td>
<td>18.31</td>
<td>18.37</td>
<td>0.055</td>
<td>0.410</td>
</tr>
<tr>
<td>C*</td>
<td>22.31</td>
<td>22.27</td>
<td>0.153</td>
<td>0.870</td>
</tr>
<tr>
<td>Hue Angle</td>
<td>55.64</td>
<td>56.13</td>
<td>0.466</td>
<td>0.460</td>
</tr>
<tr>
<td>630:580 nm</td>
<td>1.53</td>
<td>1.50</td>
<td>0.030</td>
<td>0.430</td>
</tr>
</tbody>
</table>

<sup>a-c</sup>Within a row, least squares means lacking common superscripts differ, P < 0.05

<sup>1</sup>L* = measure of darkness to lightness (larger value indicates a lighter color); a* = measure of redness (larger value indicates a more intense red color); and b* = measure of yellowness (larger value indicates a more yellow color). Chroma (C*) represents the total color of the sample (larger value indicates a more vivid color); hue angle represents the change from the true red axis (larger value indicates a shift from red to yellow); and 630:580 nm reflectance ratio (estimate of the cooked color change from red to brown).
**Figure 1.** Interactive effect of %MBT and production step ($P < 0.0001$) on pH. Bars for 100, 75, 50, 25, and 0% MBT represent the mean of 6 (Raw), 3 (Initial), and 3 (Reheat) patties per treatment, respectively. Bars lacking common letters (a-m) differ, $P < 0.05$. 
Figure 2. Main effect of %MBT inclusion on raw reflectance values of ground beef patty color ($P < 0.05$). Lines for 100, 75, 50, 25, and 0% MBT represent the mean of 60, 60, 60, 60, and 60 patties, respectively. Lines lacking common letters (a-d) differ, $P < 0.05$. 
Figure 3. Main effects of %MBT inclusion of internal instrumental initial cook ground beef patty color (linear, $P < 0.0018$) on A) lightness ($L^*$) values, and B) yellowness ($b^*$) values. Bars for 100, 75, 50, 25, and 0% MBT represent the mean of 60, 60, 60, 48, and 60 patties, respectively. Bars lacking common letters (a-c) differ, $P < 0.05$. 
Figure 4. Main effect of %MBT inclusion on initial cooked reflectance values of ground beef patty color ($P < 0.05$). Lines for 100, 75, 50, 25, and 0% MBT represent the mean of 60, 60, 60, 60, and 60 patties, respectively. Lines lacking common letters (a-d) differ, $P < 0.05$. 
Figure 5. Main effects of %MBT inclusion of internal instrumental reheated ground beef patty color (linear, \( P < 0.0001 \)) on A) redness (a*) values, and B) hue angle. Bars for 100, 75, 50, 25, and 0% MBT represent the mean of 60, 60, 60, 48, and 60 patties, respectively. Bars lacking common letters (a, b) differ, \( P < 0.05 \).
Figure 6. Main effect of %MBT inclusion on reheated reflectance values of ground beef patty color ($P < 0.05$). Lines for 100, 75, 50, 25, and 0% MBT represent the mean of 60, 60, 60, 48, and 60 patties, respectively. Lines lacking common letters (a-d) differ, $P < 0.05$. 
Figure 7. Main effect of reheating method on reheated reflectance values of ground beef patty color (P < 0.05). Lines for charbroiler and microwave oven represent the mean of 288, and 288 patties, respectively. Lines lacking common letters (a, b) differ, P < 0.05.
Figure 8. Interactive effect of %MBT and reheating method ($P < 0.0001$) on $\Delta$Area. Bars for 100, 75, 50, 25, and 0% MBT represent the mean of 60, 60, 60, 48, and 60 patties, respectively. Bars lacking common letters (a-e) differ, $P < 0.05$.)
December 4, 2013

To Whom It May Concern:

This letter is conformation that Mr. Jace J. Hollenbeck is the primary author of this manuscript/chapter entitled: “Cooked Color of Precooked Ground Beef Patties Formulated with Mature Bull Trim.” In addition, as his major advisor, I certify that Jace completed more than the required 51% of the research and writing of this particular paper. If any questions remain, please feel free to contact me at your convenience and I will be more than happy to address any concerns.

Sincerely,

Jason K. Apple, Ph.D.
Professor
CHAPTER IV

OVERALL CONCLUSIONS

Based on the results of the previous research and the current study, there is still much to learn on mature bull beef color. Because of its high pH and concentration of myoglobin, it appears mature bull beef displays a stable red color throughout simulated retail display. In addition, mature bull beef exhibits a persistent red color after fully cooking, and even reheating. Moreover, ground beef is the most common way beef is purchased in the U.S., and is the most common consumed form of beef at home as well as away from the home. The majority of mature bull beef is entering this sector of the market. The way in which mature bull beef is being utilized will need to be monitored, as many food-borne outbreaks have been linked to undercooked ground beef, and many of today’s consumers associate a red internal cooked color with questionable wholesomeness.

Therefore, because of the looming drought, and high cattle prices, mature cattle are being marketed more than ever. Moreover, the growing world population, mature beef offers an available and affordable red meat protein source for the developing middle class. Continued research will be needed to innovate and optimize new and better ways to utilize and market mature beef.