DETERMINATION OF THE REPEATABILITY AND ACCURACY OF THE PRESSED JUICE PERCENTAGE (PJP) METHOD AT SORTING BEEF STRIP LOIN STEAKS INTO CATEGORIES OF KNOWN JUICINESS

by

KASSANDRA MCKILLIP

B.S., Texas Tech University, 2014

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Animal Science
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2016

Approved by:

Major Professor
Travis G. O'Quinn

Copyright

Abstract

The objectives of this study were to determine the effect of enhancement on consumer and trained beef palatability scores of three quality grades when cooked to three degrees of doneness (DOD) and to determine the accuracy and repeatability of the Pressed Juice Percentage (PJP). Striploins of USDA Prime, Low Choice, and Low Select quality grades were used in this study. To maximize variation in juiciness, steaks were either enhanced (formulated for 108% pump with a solution of water, salt, and alkaline phosphates) or non-enhanced, and cooked to three degree of doneness (Rare: 60°C, Medium: 71°C, or Very Well-Done: 82°C). All samples were evaluated for Warner-Bratzler shear force (WBSF), Slice Shear Force (SSF), PJP, and palatability traits by consumer and trained panelists. Consumer panelists rated all enhanced treatments similar ($P > 0.05$) to each other and greater ($P < 0.05$) for juiciness, tenderness, flavor liking, and overall liking than all non-enhanced treatments. Consumer ratings of juiciness, tenderness, and overall liking scores increased ($P < 0.05$) as DOD decreased. Consumer panelists rated all enhanced treatments similar ($P > 0.05$) and greater ($P < 0.05$) for the percentage of steaks classified as premium quality. For trained panel initial juiciness, all enhanced treatments and non-enhanced Prime samples were similar ($P > 0.05$) and greater ($P < 0.05$) than other treatments cooked to Medium and Very Well Done. Results indicated PJP had a relatively high repeatability coefficient (0.70), indicating that only 30% of the variation observed was due to sample measurement differences. The PJP threshold values evaluated accurately segregated steaks by the probability of a sample being rated “juicy” by consumers, with the actual percentage of “juicy” samples determined to be 41.67%, 72.31%, 89.33%, and 98.08% for the <50%, 50 – 75%, 75 – 90%, and >90% categories, respectively. Therefore, enhancement has a substantial, positive effect on beef palatability. Enhancing higher quality beef does not provide

an additional palatability benefit; hence the greatest economic advantage is in enhancing lower quality beef products. Results of this study indicate the PJP juiciness method is both repeatable and accurate at sorting steaks based on the likelihood of a steak being “juicy”.

Table of Contents

List of Figures

List of Tables

Acknowledgements

The first person I want to thank is my loving husband. Jacob, I cannot thank you enough for your never ending selflessness since I started my Master's degree. Without your love, encouragement, and support I wouldn't have had such a successful year and a half and be here today. I know the long nights and weekends gone have been hard on both of us, but we are getting one step closer to having the life we have dreamed of. I love you and I really appreciate all that you have done for me through this time and I cannot wait for the years we have ahead of us.

I would also like to thank my major advisor, Dr. Travis O'Quinn. From the time I started working with you, I have always admired the knowledge and skill you possess and confidence you exude. Through the last year and a half I have learned so much from you and have been pushed to be a better scientist and hardworking individual. I cannot thank you enough for all of the help you have been over the past year and a half and I am very proud that I have had the pleasure of having you as a mentor.

I would like to express my gratitude to my other committee members, Dr. John Gonzalez and Dr. John Unruh. I have great respect for each of you and am extremely honored to be able to receive advice and assistance from two wonderful meat scientists.

I have received needed assistance from my fellow graduate student Alaena Wilfong. Without Alaena's help in the preparation and execution of this project the outcome would not be as successful. Additionally, she has been one of the best friends I could ask for in this very stress filled time.

Lastly, on a personal note I cannot explain how much I appreciate all of the love and support my parents have given me over the years. Even though they do not always understand

why I want to take the path I do, they always immerse themselves in my choices and cheer me on without hesitation. For that, I will be forever grateful! My mom Candy, dad Mike, brothers Victor and Mikey Ognoskie, and my best friends Brittany Reid, Caitlin Quesenberry, and Mallory Maltsberger mean the world to me and to know they are always there for me has a calming effect and something I think about when the times have gotten crazy over the last year and a half. My grandma Marylynn Murphy has always offers her never failing love and support in all of my endeavors. I love you all so much!

Chapter 1 - Literature Review

Palatability Defined

Palatability is a measurement of overall eating satisfaction and can be evaluated by three important factors. Tenderness, juiciness, and flavor are the three attributes that have been identified as the largest contributors to overall eating satisfaction (Bratzler, 1971; Emerson, Woerner, Belk, & Tatum, 2013; Miller et al., 1995a; Platter et al., 2003). However, a product cannot only excel in a single trait and still be considered satisfactory by a consumer, as each of the traits interact to deliver perceived eating satisfaction (Aberle, Forrest, Gerrard, & Mills, 2001; Emerson et al., 2013; Savell & Cross, 1988). Tenderness has been long documented as having the largest influence on consumer palatability perception (Dikeman, 1987; Savell et al., 1987). Through the years studies have included a question asking what palatability trait was most important for consumers when eating beef. In the late 1990's and early 2000's studies reported that 51.0% (Huffman et al., 1996), 50.0% (Miller, Huffman, Gilbert, Hamman, & Ramsey, 1995b), and 51.6% (Platter et al., 2003) of consumers found "tenderness" to be the most important trait. This number has steadily declined over the past 20 years and has more recently been reported at 40.3% by Kerth, Braden, Cox, Kerth, and Rankins Jr (2007) and at 30.8% by Corbin et al. (2015). Conversely, the percentage of consumers who have identified "flavor" as the most important trait has increased over the same time period from 39.0% (Huffman et al., 1996), 40.0% (Miller et al., 1995b), and 37.6% (Platter et al., 2003) to 44.6% (Woolley, 2014). Additionally, "juiciness" has increased in importance to consumers from 10.0% (Huffman et al., 1996; Miller et al., 1995b; Platter et al., 2003) to 18.4% (Corbin et al., 2015). These data indicate the growing importance of flavor and juiciness to the overall consumer beef eating experience. This is potentially due to the large percentage of retail beef that is "tender" (Guelker et al., 2013), with today's consumers potentially not considering beef tenderness as big of a challenge as those from previous generations. With a more consistently tender beef supply, it appears today's consumers are putting a greater emphasis on other aspects of the beef eating experience.

Juiciness Defined

Boylston et al. (2012) defined juiciness as the moisture released from food during mastication. Additionally, Bratzler (1971) divided juiciness into two phases. The first phase, initial impression, is considered the first wetness produced by the rapid release of fluids from the first chews. The second phase, termed sustained juiciness, consists of a slow release of juice from the fat and enacts the salivary flow. The source of meat juiciness consists of water and intramuscular lipids; and when cooked, the water combines with the melted fat and creates juice that is dispersed during mastication (Aberle et al., 2001). Therefore, regardless of the other palatability characteristics, if meat is not juicy, the overall acceptability is limited (Aberle et al., 2001).

Enhancement effect on palatability traits

Enhancement could also be termed "deep basting" or "injection marination". Over the past few decades, enhancement technology has been studied and tested to help eliminate variation among products. The USDA Food Safety Inspection Service (FSIS) regulates the rules on enhanced meat and poultry. Currently "enhanced" or "marinated" red meat can contain no more than 10% solution (USDA-FSIS, 2013). Limiting the amount of solution that can be injected into a product will ensure that processors are not able to add large amounts of water to increase weight and sell at a higher price. The two most commonly used and extensively researched types of enhancement solutions contain either water and calcium chloride, or a solution consisting of water, salt, and alkaline phosphates.

One of the commonly used and extensively researched enhancement solutions is a combination of water, salt, and alkaline phosphates. Alkaline phosphates have been reported to interact with beef proteins, increasing their ability to hold moisture inside the products during cooking (Brooks, 2011). This occurs through phosphates binding to myofibrillar proteins, which results in an increase charge repulsion from the myofilaments (negative net charge effect). The protein expansion results in the muscle complex swelling, allowing greater water binding and holding capacity (Xiong, 2005). Additionally, an increase in pH is reported for solutions containing alkaline phosphates, which is due to the phosphate pH that are typically a pH of 7 or higher (Sebranek, 2015).

The addition of phosphates in enhancement solution is widely used; however, treatments containing alkaline phosphates have resulted in a considerable increase in pH ranging from 2.2% to 6.8% compared to non-enhanced control treatments (Baublits, Pohlman, Brown Jr, Yancey, & Johnson, 2006; Pietrasik & Janz, 2009; Robbins et al., 2002; Robbins et al., 2003b; Smith, Simmons, McKeith, Bechtel, & Brady, 1984; Stetzer, Tucker, McKeith, & Brewer, 2008; Wicklund et al., 2005). Additionally, enhancement solutions containing alkaline phosphates have also reported increased moisture content compared to control by 2.1% and 4.7% respectively (Baublits et al., 2006; Pietrasik & Janz, 2009).

Moreover, objective and subjective color readings can be altered by alkaline phosphates that are included in enhancement solutions. Previous studies show that steaks enhanced with alkaline phosphates have lower L*, a*, and b* values than non-enhanced steaks (Pietrasik & Janz, 2009; Robbins et al., 2003b; Wicklund et al., 2005). Robbins et al. (2003b) conducted a study that consisted of four different muscles and found all enhanced muscles to have L* values between 3.9 to 7.9% lower, a* values between 9.1 to 14.4% lower, and b* values between 5.7 to

11.2% lower than readings of the non-enhanced counterparts. Similarly, Wicklund et al. (2005) reported enhanced steaks had lower values of L* by 9.9%, a* by 9.7%, and b* by 17.4% than the control treatment. Also, Pietrasik and Janz (2009) evaluated two different levels of pump (12 and 25%) and different salt concentrations (0.5 or 1.5%). In that study, L* values decreased as salt concentration increased, with the L* values decreasing as the percentage pump decreased from 25% to 12% to control treatment. Additionally, the a* (7.3 to 19.7%) and b* (8.3 to 21.1%) values decreased compared to the non-enhanced control as percent pump and salt concentration increased (Pietrasik & Janz, 2009). Moreover, Baublits et al. (2006) tested a control treatment and four treatments that consisted of phosphates and differed in salt concentrations (0.0, 1.5, 1.0 or 1.5%). The L* values decreased from the control (4.2 to 17.1%) as the salt concentration increased from 0.0 to 1.5% (Baublits et al., 2006). Additionally, Stetzer et al. (2008) reported the enhanced longissimus dorsi (LD) decreased L* value by 7.1% compared to the control. Also, a study by Robbins et al. (2002) reported enhanced steaks had lower L*, a*, and b* values from day 0 to 4, which mirrored the trained panel visual color scores in that study.

Phosphates and salt have previously been reported to decrease purge and cook loss. Stetzer et al. (2008) reported enhanced steaks had a 1.4% lower purge loss than the non-enhanced treatment. Additionally, Pietrasik and Janz (2009) conducted a study with a control treatment, two pump levels (12 or 25%), and two salt concentration levels (0.5 or 1.5%). Percentage purge loss decreased as salt concentration increased regardless of percentage pump, and all enhanced treatments other than the 25% pump and 0.5% salt treatment had lower purge loss than the control treatment (Pietrasik & Janz, 2009). Additionally, Pietrasik and Janz (2009) reported that the percentage of cooking loss decreased as salt concentration increased from 0.5 to 1.5%, and all enhanced treatments had lower percentages of cook loss than the non-enhanced control. Similarly, a control treatment, and four treatments that had the same amount of phosphate and differed in salt concentration, (0.0, 0.5, 1.0, or 1.5%) were evaluated (Baublits et al., 2006). The treatments with salt decreased percentage of cook loss from 31.1 to 22.7% as salt content increased from 0.5 to 1.5%, all treatments with a salt content were between 2.5% and 11.0% lower than the control treatment. Furthermore, McGee, Henry, Brooks, Ray, and Morgan (2003) evaluated four different percent pumps (0, 5, 7, or 9%), and found treatments with 5, 7, or 9% pump had at least 7% lower cook loss than the control. Studies conducted by Stetzer et al. (2008) and Wicklund et al. (2005) both enhanced beef steaks to 108% pump, and reported enhanced treatment had a decrease in cooking loss by 11.3% and 3.3% respectively. Also, beef that was enhanced to 110% pump was reported to have lower percentages of cooking loss of 2.3 and 2.6 % respectively (Robbins et al., 2003a, 2003b).

Enhancement technology has been utilized for years in the poultry and pork industry to increase consistency and improve palatability traits of multiple different cuts (Prestat, Jensen, McKeith, & Brewer, 2002; Sheard & Tali, 2004; Sutton, Brewer, & McKeith, 1997). Increases in pork pH due to inclusion of alkaline phosphates have been previously reported (Sheard & Tali, 2004; Smith, Simmons, McKeith, Bechtel, & Brady, 1984). A study conducted by Sheard and Tali (2004) tested eight different enhancement solutions. The treatment that contained alkaline phosphates and salt reported a pH increase of 8.3% from the control treatment (Sheard & Tali, 2004). Similarly, Smith et al. (1984) reported the enhanced treatment had an 8.2% increase in pH from control. Also, a 3.7% pH increase was reported by Sutton et al. (1997) for the treatment with 0.4% sodium tripolyphosphate compared to the control.

Moreover, color differences were seen in previous pork research. Decreases in values of L* (4.9%) and b* (3.3%) were reported for the enhanced treatment compared to control (Prestat et al., 2002). In addition, Sutton et al. (1997) enhanced sections of pork loin with different levels of sodium tripolyphosphate (0.0, 0.2, or 0.4%), and instrumental color measurements were taken on raw pork samples that showed the L* values decreased by 3.7% as the level of sodium tripolyphosphates increased from 0.0% to 0.4%.

Furthermore, decreases were observed in shear force values in research conducted by Smith et al. (1984) and Sheard and Tali (2004). A 51.0% decrease in Warner-Bratzler shear force values (WBSF) values were reported for enhanced samples (Smith et al., 1984). Also, Sheard and Tali (2004) reported the treatment of alkaline phosphates and salt had a 41.7% lower Volodkevich shear value (technique used to emulate the biting action of the front incisors) than the control. Therefore, mechanical tenderness was shown to be lower for enhanced pork than the non-enhanced control treatment.

Enhanced pork also results in a more tender and juicy product when rated by trained panelists (Prestat et al., 2002; Smith et al., 1984; Sutton et al., 1997). Research by Smith et al. (1984) and Prestat et al. (2002) demonstrated enhanced pork resulted in a 27.2% and a 30.8% increase in tenderness ratings from the control respectively. Smith et al. (1984) also reported enhanced pork had a 40.0% increase in juiciness ratings from the control. Additionally, Sutton et al. (1997) reported both an increase in juiciness (26.4%) and tenderness (19.0%) over the control treatment as percentage of sodium tripolyphosphates increased from 0.0% to 0.4%.

The effects of enhancement on lower quality beef cuts has been previously researched. Enhancement is utilized to improve palatability traits. Enhancing beef with the solution of water, salt, and alkaline phosphates has shown enhanced steaks result in increased consumer palatability traits of tenderness, juiciness, flavor liking, and overall liking (Brooks et al., 2010; McGee et al., 2003). Similarly, enhanced roasts were reported to be more tender and juicy, as well as have greater beef flavor, more salty flavor, and a higher overall acceptability rating than the non-enhanced roasts (Robbins et al., 2003a). Bagley, Nicholson, Pfeiffer, and Savell (2010) evaluated three cooking methods which were grilling, cooking in the oven, and cooking in a skillet. Enhanced steaks were reported as more tender and juicy when cooked on the grill and in the oven, but when cooked in the skillet enhanced steaks were found to only be more tender (Bagley et al., 2010). Moreover, Igo et al. (2015) reported consumers found enhanced steaks to be more tender, and flavorful than the non-enhanced counterparts collected from grocery stores in four major metropolitan areas. Two prior studies evaluated different percent pumps (McGee et al., 2003; Pietrasik & Janz, 2009). McGee et al. (2003) evaluated enhancing product with the same solution to 5, 7, or 9% pump, and no differences were observed among the different pump rates for any of the palatability traits. Furthermore, Pietrasik and Janz (2009) tested solutions that differed in salt concentration (0.5 or 1.5%) and percentage pump (12 or 25%) where all enhanced treatments were reported more tender than the control; however, no differences were found among percent pump and enhancement levels for tenderness. All enhanced treatments were also found to be juicier than the control, but the ratings for juiciness were higher for the enhanced treatments with 1.5% salt (Pietrasik & Janz, 2009). As expected, all enhanced treatments were reported more salty than the control, and consumers found the treatments with 1.5% salt the most salty (Pietrasik & Janz, 2009).

Previous studies reported trained panelists also rated enhanced samples more tender, juicy, and saltier than non-enhanced samples (Robbins et al., 2002; Robbins et al., 2003b; Wicklund et al., 2005). Stetzer et al. (2008) reported similar increased tenderness and juiciness ratings for enhanced steaks, as well as increased beef flavor than non-enhanced steaks. Furthermore, Baublits et al. (2006) evaluated four enhancement solutions that were constant in the percentage pump (12%) and the amount of sodium tripolyphosphate (0.4%), however the percentage of salt in the solution (0.0, 0.5, 1.0, 1.5%) differed. All treatments with salt in the solution resulted in an increase in myofibrillar tenderness, connective tissue amount, and overall tenderness compared to the phosphate only and control treatment (Baublits et al., 2006). Also, the LD was shown to be juicier as the salt concentration increased among treatments (Baublits et al., 2006). Moreover, Vote et al. (2000) evaluated different percent pumps (7.5, 10.0, 12.5, or 15.0%) with the same enhancement solution, and enhanced treatments were reported as more tender, juicy, flavorful, and saltier with no differences detected among percent pump treatments.

Furthermore, steaks enhanced with alkaline phosphates and salt have reported decreased (11.3 - 48.7%) WBSF values compared to non-enhanced steaks (Bagley et al., 2010; Baublits et al., 2006; Brooks et al., 2010; Igo et al., 2015; McGee et al., 2003; Pietrasik & Janz, 2009; Robbins et al., 2002; Robbins et al., 2003a, 2003b; Stetzer et al., 2008; Vote et al., 2000; Wicklund et al., 2005; Woolley, 2014). Within the study by Bagley et al. (2010), the steaks were additionally enhanced with liquid papain. Papain is a proteolytic enzyme which is isolated from papaya which is used in meat tenderization (Aberle et al., 2001). Therefore, Bagley et al. (2010) reported a 34.2% decrease in WBSF values which indicates supplementary tenderness improvement rather than that of just the salt and phosphates. The study conducted by Baublits et al. (2006) had enhanced treatments which differed in salt concentration (0.0, 0.5, 1.0, or 1.5%). Among the treatments with salt in the solution, as the salt concentration increased from 0.5% to 1.5%, WBSF values decreased from 17.2 to 38.2% from the control treatment (Baublits et al., 2006). Also, McGee et al. (2003) and Vote et al. (2000) enhanced steaks with salt, phosphates, and sodium lactate to three (5, 7, 9%) and four (7.5, 10.0, 12.5, or 15.0%) different injection levels respectively. Values of WBSF for all injection levels were similar and lower than the non-enhanced treatment (McGee et al., 2003; Vote et al., 2000). Furthermore, when a combination of salt concentrations (0.5 or 1.5%) and percent pump (12 or 25%) were tested, all enhanced treatments evaluated were similar and 25.5 - 33.9 % lower than the control treatment (Pietrasik & Janz, 2009). Therefore, the percent enhancement did not change mechanical tenderness values (Pietrasik & Janz, 2009). Additionally, Igo et al. (2015) evaluated both WBSF and slice shear force (SSF) values, and reported enhanced steaks had 32.3% lower WBSF values and 24.6% lower SSF values over the non-enhanced steaks, indicating enhancement has a similar effect on both WBSF and SSF values. Additionally, Woolley (2014) determined both the Select high enhanced (26.4%) and Select low enhanced (24.6%) treatments had lower SSF values than the non-enhanced Select treatment.

Solutions of water and calcium chloride ($CaCl_2$) have also been heavily researched over the past two decades. Many studies have tested concentrations of $CaCl_2$ (200 mM or 250 mM) at 5% pump. Tenderness has been shown to have a strong relationship calcium, and all research on $CaCl_2$ solutions report the tenderization effects are calcium dependent (Beekman, 1994). Calcium chloride enhancement of steaks results in an increase in consumer palatability traits (Carr, Crockett, Ramsey, & Miller, 2004; Hoover et al., 1995; Miller et al., 1995b). Miller et al. (1995b) and Carr et al. (2004) reported consumers rated calcium chloride enhanced beef greater for tenderness, juiciness, flavor, and overall palatability than non-enhanced beef steaks. Additionally, Hoover et al. (1995) reported consumer palatability traits of tenderness and flavor intensity were greater for calcium chloride enhanced strip loin steaks. When consumers were asked how much they were willing to pay for each steak after sampling, consumers were willing to pay $0.95/kg more for steaks enhanced with calcium chloride (Carr et al., 2004).

Trained panels conducted with steaks enhanced with calcium chloride solutions have also shown increased palatability traits over control steaks. Rodas-Gonzalez et al. (2011) reported an increase in beef flavor and flavor intensity compared to non-enhanced steaks. Similarly, enhanced steaks were also found to have an increased sustained juiciness, beef flavor, and overall mouthfeel over non-enhanced steaks (Carr et al., 2004). Moreover, a study conducted by Lansdell, Miller, Wheeler, Koohmaraie, and Ramsey (1995) demonstrated that steaks enhanced with $CaCl_2$ resulted in more juicy and tender steaks with a higher ease of fragmentation. Additionally, Kerth, Miller, and Ramsey (1995) tested enhancement solutions with two different concentrations of calcium chloride (200 mM or 250 mM). In that study, trained panelists rated the 200 mM concentration enhanced steaks greater in initial juiciness, sustained juiciness, and flavor intensity when compared to the control non-enhanced treatment (Kerth et al., 1995). Also, the steaks enhanced with 250 mM solution resulted in increased initial tenderness, sustained tenderness, beef flavor, and flavor intensity (Kerth et al., 1995).

Moreover, beef enhanced with calcium chloride results in 13.3 - 33.2% decreased WBSF values compared to the non-enhanced treatments (Carr et al., 2004; Lansdell et al., 1995; Rodas-Gonzalez et al., 2011). As the concentration of calcium increased from 200 mM to 250 mM, the WBSF values decreased 16.1% to 21.4% lower than the non-enhanced control (Kerth et al., 1995). Moreover, enhanced steaks had 14.3% decreased SSF values from non-enhanced controls, which was a similar decrease as found with WBSF (13.3%; Rodas-Gonzalez et al., 2011).

Marbling effects on palatability traits

USDA quality grades are important to assure eating quality (Aberle et al., 2001). Different levels of marbling equate to different USDA quality grade carcasses for similar maturity. Many studies have reported that as quality grades increases, chemical fat percentage also increase; USDA Standard (1.3 - 2.5%), Select (2.5 - 4.5%), Low Choice (4.5 – 5.8%), Top

Choice (6.0 – 9.0%), and Prime (10.4 - 14.7%) (Corbin et al., 2015; Dow, Wiegand, Ellersieck, & Lorenzen, 2011; Emerson et al., 2013; Gilpin, Batcher, & Deary, 1965; Hunt et al., 2014; Legako et al., 2015; Luchak et al., 1998; O'Quinn et al., 2012; Parrish, Olson, Miner, & Rust, 1973; Savell, Cross, & Smith, 1986; Woolley, 2014). Additionally, as quality grade increases the percentage of moisture decreases; USDA Standard (72.2 - 74.3%), Select (71.3 - 71.9%), Low Choice (69.3 – 72.4%), Top Choice (66.8 - 69.1%), and Prime (62.9 - 67.1%) (Corbin et al., 2015; Gilpin et al., 1965; Hunt et al., 2014; Legako et al., 2015; Luchak et al., 1998; O'Quinn et al., 2012; Parrish et al., 1973; Savell et al., 1986).

Consumer panels conducted with a range of muscles and quality grades have reported increases in palatability ratings with higher marbling levels. Behrends et al. (2005) evaluated Top Choice and High Select semimembranosus (SM) steaks and consumers determined Top Choice steaks rated higher for tenderness, juiciness, flavor liking, and overall liking. Studies by Corbin et al. (2015), Woolley (2014), and O'Quinn et al. (2012) reported the longissimus lumborum (LL) increased in consumer ratings of tenderness, juiciness, flavor liking, and overall liking as quality grade increased from Standard to Prime. Hunt et al. (2014) evaluated steaks from four muscles, the LL, gluteus medius (GM), serratus ventralis (SV), and SM, of Top Choice and Select quality grades. Top Choice steaks were reported to have higher ratings for juiciness, flavor, and overall liking for the LL, GM, and SV while no differences of tenderness, juiciness, flavor or overall liking were found among quality grades for the SM (Hunt et al., 2014). Similarly, Legako et al. (2015) also tested four muscles; the LL, psoas major (PM), SM, and GM with quality grades of Standard, Select, Low Choice, Top Choice, and Prime. The LL was the only muscle that showed a linear decrease in rankings of juiciness, flavor liking, and overall liking as quality grade decreased (Legako et al., 2015). Additionally, the Low Choice treatment had the lowest rating for juiciness, flavor liking, and overall liking for the PM and SM, with mixed results for the GM (Legako et al., 2015). Moreover, Breidenstein, Cooper, Cassens, Evans, and Bray (1968) evaluated the LD and SM muscles of Select, Top Choice, Low Prime, and High Prime quality grades and determined that as quality grade increased from Select to High Prime, ratings of juiciness, flavor, and overall liking increased for the LD, while the SM increased in juiciness and flavor ratings. Additionally, Guelker et al. (2013) evaluated three different muscles (LD, GM, and LL) at various quality grades (Ungraded, Select, Low Choice, Top Choice, and Prime). Increases in tenderness liking and intensity as well as juiciness liking were found as quality grade increased in the LD (Guelker et al., 2013). The Ungraded quality grade was found to be the highest rated for juiciness liking, flavor liking, and overall liking for the GM, and no differences in consumer ratings were seen in the LL (Guelker et al., 2013). Therefore, quality grade effect is muscle dependent. Conversely, a study by McKenna et al. (2004) evaluated the LD at quality grades of Low Choice, High Select and Low Select and reported no differences in consumer palatability ratings. Also, no differences in palatability traits were observed when the GM was evaluated of Low Choice, High Select, and Low Select quality grades (Neely et al., 1998). O'Quinn, Brooks, and Miller (2015) tested the PM at Choice, High Select, and Select quality grades and found no differences for the palatability traits of tenderness, juiciness, flavor, and overall liking. Within the studies by O'Quinn et al. (2015), McKenna et al. (2004), and Parrish et al. (1973) steaks of varying quality grades were cooked to multiple degrees of doneness (DOD), no quality grade by DOD interaction was reported in any of the studies. Therefore, all marbling results were pooled across the DOD levels, likely contributing to the reported results. Additionally, this lack of significant DOD × marbling level interaction indicates the effect of quality grade in each study was consistent for each DOD evaluated.

Additionally, as quality grade increases the percentage of samples rated “Premium quality” increased from USDA Standard (1.9 - 6.7%) to Prime (17.4 - 35.8%) while the opposite was seen as quality grade decreased from Prime (4.2 - 6.7%) to Standard (18.3 - 40.0%) for the percentage of samples rated “Unsatisfactory quality” increased (Corbin et al., 2015; Hunt et al., 2014; O'Quinn et al., 2012; Woolley, 2014). Moreover, intramuscular fat content has been strongly linked with consumer sensory panel ratings. Corbin et al. (2015) reported strong consumer correlations of percentage fat with tenderness (r = 0.81), juiciness (r = 0.88), flavor liking (r = 0.74), and overall liking (r = 0.79). Furthermore, O'Quinn et al. (2012) and Hunt et al. (2014) found similar consumer correlations for intramuscular fat percentage with tenderness (r = 0.31, 0.32), juiciness (r = 0.37, 0.29), flavor liking (r = 0.25, 0.37), and overall liking (r = 0.28, 0.42) respectively. Breidenstein et al. (1968) also reported consumer correlations of fat percentage with tenderness (r = 0.30), juiciness (r = 0.62), flavor (r = 0.62), and overall opinion (r = 0.39).

Moreover, trained panelist ratings have been reported to have positive relationships with marbling. When evaluating the LL of multiple quality grades from USDA Standard to Prime, ratings for tenderness, juiciness, and flavor increase linearly as quality grade increases (Emerson et al., 2013; Savell et al., 1987; Smith et al., 1985; Woolley, 2014). A study by Tatum et al. (1980) evaluated the LD that ranged in quality grades from Standard to Top Choice. In that study trained panelists determined that as quality grade increased the palatability traits of juiciness, myofibrillar tenderness, and flavor also increased. Additionally, Acheson, Woerner, and Tatum (2014) and Miller et al. (1997) reported increased ratings of tenderness, juiciness, and beef flavor of Choice quality graded LL over Select quality grade. Whereas, when Select and Choice LL were evaluated by Vote et al. (2000), only increased ratings of tenderness and cooked beef flavor were reported for the Choice quality grade. Furthermore, Gilpin et al. (1965) demonstrated Prime and Top Choice grades result in more tender, juicy, and flavorful ratings for the LD and SM. Luchak et al. (1998) evaluated four different muscles, Longissimus thoracis (LT), LL, semitendinosus (ST), and GM of Select and Choice quality grades, and the only differences found in palatability traits were in the LD, where Choice was greater for muscle fiber tenderness, and overall tenderness. Similarly, multiple muscles (LL, GM, and SM) at multiple quality grades (Low Select, High Select, Low Choice, and Top Choice) were tested and the LL resulted in a linear increase in muscle fiber tenderness, juiciness, and cooked beef flavor as quality grade increased (Lorenzen et al., 2003). An increase was also observed for flavor when the quality grade increased for the GM, whereas for the SM, increases in flavor and juiciness were found with increased quality grade (Lorenzen et al., 2003). Additionally, strong trained panel correlations have been reported with marbling and tenderness (r = 0.63), juiciness (r = 0.67), buttery/ beef fat flavor (r = 0.84), and overall sensory experience (r = 0.78; Emerson et al., 2013).

Mechanical measurements of tenderness have been reported to have an inverse relationship with marbling level. Multiple studies have tested the LL ranging in quality grade from Prime to Standard, and have reported a 20.5 - 32.3% decrease in WBSF values as quality grade increased from Select to Prime (Savell et al., 1987; Smith et al., 1985; Tatum et al., 1980). Moreover, the longissimus muscle (LM) from Select to Choice quality grades have been evaluated, with the Choice grade resulting in a 11.7 - 15.4% decrease in WBSF value (Jennings, Berry, & Joseph, 1978; McKenna et al., 2004; Vote et al., 2000). Hunt et al. (2014) evaluated four muscles (LL, GM, SM, and SV) of two quality grades (Select or Top Choice), and found Top Choice LL and SV resulted in 23.9% and 19.0% lower WBSF values, respectively, compared to Select, while no differences were found between the quality grades for the GM and

SM. Lorenzen et al. (2003) reported Top Choice and Low Choice LL were similar in WBSF values but 7.1% more tender than High and Low Select steaks. Also, Luchak et al. (1998) determined the LL and LD had 5.3% and 11.1% lower WBSF values for the Choice treatment than Select, whereas no WBSF differences were reported for the GM steaks or ST steaks and roasts. When evaluating SM and LD of Top Choice and Select for Kramer Shear force, Top Choice steaks had a 16.7% and 2.8% lower shear value for each muscle, seen respectively (Gilpin et al., 1965). Additionally, Emerson et al. (2013) and Acheson et al. (2014) both reported WBSF and SSF values of the LL on a range of quality grades from Select to Top Choice. Acheson et al. (2014) reported that as quality grade increased, values of WBSF and SSF of Top Choice grade decreased by 17.6% and 13.4% compared to Select, respectively. Emerson et al. (2013) similarly determined WBSF and SSF values of Top Choice graded LL steaks decreased 35.0% and 35.2% compared to Select respectively. Conversely, a study conducted by Breidenstein et al. (1968) showed the LD and SM of varied quality grades from Select to Prime had no differences in WBSF values. Similarly, Parrish et al. (1973) reported no differences in shear force among the quality range of Select to Prime LD steaks. Moreover, Jennings et al. (1978), Hunt et al. (2014), Emerson et al. (2013), and Breidenstein et al. (1968) all reported marbling to be correlated with WBSF (r = -0.32, -0.72, -0.48, -0.14), respectively. Emerson et al. (2013) also reported marbling was correlated with SSF (r = -0.45).

Degree of doneness effects on palatability traits

When meat is cooked to a higher endpoint temperature, cooking losses simultaneously increase. Aberle et al. (2001) stated cooking loss and juiciness have an inverse relationship, and that protein hardening also increases with higher DOD, which has an inverse relationship with tenderness. Previous studies reported as DOD increases, so does the percentage of cooking loss (Cross, Stanfield, & Koch, 1976; Gilpin et al., 1965; Gomes, Pflanzer, Cruz, de Felício, &

Bolini, 2014; Lorenzen, Davuluri, Adhikari, & Grün, 2005; Luchak et al., 1998; O'Quinn et al., 2015; Parrish et al., 1973; Wheeler, Shackelford, & Koohmaraie, 1999). The study conducted by Cross et al. (1976) evaluated the LM cooked to four different internal temperatures (60, 70, 80 or 90°C) and determined as temperature increased from 60 - 90°C there was a 14.7% increase in cooking loss. Similarly, the LM was cooked to three DOD (60, 70 or 80°C) and as the internal temperature increased from 60°C to 80°C, there was a 9.7% and 10.1% increase in cooking loss respectively (Parrish et al., 1973; Wheeler et al., 1999). Lorenzen et al. (2005) cooked the LM to multiple DOD (55, 60, 63, 71, 77 and 82°C) and determined there was a 19.6% increase in cooking loss as the DOD increased from 55°C to 82°C. Moreover, the LD and SM were cooked to three DOD (60, 71 or 82°C) and a 12.0 - 15.8% and 10.1 - 13.5% increase in cooking loss was seen for the LD and SM respectively as DOD increased from 60°C to 82°C (Gilpin et al., 1965). Luchak et al. (1998) also evaluated four different muscles (LL, LD, GM, and ST), with a 11.3% and 16.4% increase in cooking loss reported for the LL and GM respectively as DOD increased from 57°C to 74°C. The LD and ST also increased 6.3 - 10.0% in cooking loss as DOD increased from 57°C to 68°C (Luchak et al., 1998). O'Quinn et al. (2015) determined that as the DOD increased from 55°C to 77°C, cooking loss for the PM increased by 13.3%. The study by Gomes et al. (2014) evaluated two different cooking methods (oven or griddle) cooked to three internal temperatures (65, 71, or 77°C) and found cooking loss increased as the internal temperature increased by 11.9% and 7.3% for the oven and griddle respectively. Cox, Thompson, Cunial, Winter, and Gordon (1997) reported consumers find DOD a very important aspect of overall eating experience. After consuming a beef steak at one of nine restaurants, consumers were asked what DOD was ordered and how it was perceived when delivered; meals were also scored on tenderness, taste, overall satisfaction, and value for money (Cox, et al., 1997). When the consumers were served a different DOD than what was ordered, ratings of tenderness and overall satisfaction decreased, with ratings declining more when steaks were overcooked one or two DOD rather than undercooked (Cox et al., 1997).

Increases in DOD have been reported to have an inverse relationship to consumer palatability traits. Aberle et al. (2001) stated the greater the DOD, the less juicy a meat cut will be. Parrish et al. (1973) evaluated the LM at three DOD (60, 70 or 80°C) and determined ratings of tenderness, juiciness, flavor, and overall liking decreased as internal temperature increased linearly. As DOD increased (63°C to 77°C), the LL and GM decreased in ratings of tenderness and juiciness respectively (Lorenzen et al., 2005; Savell et al., 1999). The study conducted by O'Quinn et al. (2015) reported as DOD increased from 55°C to 77°C, ratings of the PM decreased in tenderness and juiciness. Also, Behrends et al. (2005) tested consumers in two different cities (Chicago and Philadelphia) and cooked SM steaks to two different DOD (71°C or 74°C), and found differences between the cities. Consumers in Chicago found steaks cooked to 74°C were more tender, flavorful, and had a higher overall liking, whereas consumers in Philadelphia reported steaks cooked to 71°C were juicier (Behrends et al., 2005). Many cooking methods were evaluated by McKenna et al. (2004) and the ratings of tenderness, juiciness, flavor, and overall satisfaction increased when steaks were cooked from 63°C to 70°C and then decreased when the LD was cooked to 77°C.

Trained panel palatability scores mimic those reported in consumer panels. When LL steaks were cooked to 66°C and 77°C, the steaks cooked to the lower DOD resulted in higher ratings of tenderness and juiciness (Vote et al., 2000). A study that tested a range of DOD (55, 60, 63, 71, 77 or 82°C) demonstrated that when the DOD of the LM increased, so did the roasted beef flavor, however ratings of tenderness and juiciness decreased (Lorenzen et al., 2005).

Similarly, Cross et al. (1976) reported when the LM was cooked to a range of DOD (60, 70, 80, or 90°C) ratings of initial and overall tenderness, and juiciness decreased as DOD increased. Moreover, Luchak et al. (1998) evaluated four different muscles (LL, LD, GM or ST) and found the ratings of muscle fiber tenderness, overall tenderness, and juiciness decreased for the LL and LD as the DOD increased from 57°C to 74°C. Also, the GM had decreased ratings of muscle fiber tenderness, overall tenderness, juiciness, and flavor intensity as DOD increased (Luchak et al., 1998). As the LD and SM were cooked from 60°C to 82°C, ratings of tenderness, juiciness, and flavor decreased (Gilpin et al., 1965). Additionally, Wulf, Morgan, Tatum, and Smith (1996) reported ratings of tenderness and juiciness decreased as DOD increased from 63°C to 77°C for the LL, GM and SM. Moreover, when cooking methods of the oven and griddle were evaluated, Gomes et al. (2014) determined that as the internal temperature of LL steaks increased from 65°C to 77°C, ratings of roast beef aroma and flavor increased and ratings of juiciness and tenderness decreased.

Changes induced by increased endpoint temperature can cause coagulation and protein hardening and result in decreased instrumental meat tenderness. WBSF has been reported to increase 9.3 - 57.4% concurrently with degree of doneness (Gomes et al., 2014; Lorenzen et al., 2005; Luchak et al., 1998; Vote et al., 2000; Wulf et al., 1996). Similarly, Gilpin et al. (1965) reported Kramer shear force also increased 14.9% and 2.9% for the LD and SM respectively as degree of doneness increased. A range of DOD (55, 60, 63, 71, 77 or 82°C) was evaluated by Lorenzen et al. (2005) and it was determined as DOD increased WBSF increased by 28.3%. Additionally, Wulf et al. (1996) reported the LL, SM, and GM had a decrease of 37.0%, 25.5% and 57.4% in WBSF values as DOD decreased from 77°C to 63°C. Similarly, Luchak et al. (1998) found as the DOD increased from 57°C to 74°C the WBSF values for the LL and GM increased by 23.8% and 17.0% respectively, and as the DOD increased from 57°C to 68°C the LD also increased in WBSF values by 9.3%. The LM was reported to have a much larger increase in WBSF values (23.8%) when there was a 20°C difference in endpoint temperatures, versus the 9.3% increase when only cooked to 10°C higher (Luchak et al., 1998).

Objective measures of beef tenderness

The two methods of measuring objective beef tenderness currently being used within the beef industry are WBSF and SSF (Derington et al., 2011). The WBSF method was developed by Bratzler (1932). The method is conducted on a samples that have been cooled overnight. Four to eight 1.3-cm cores are removed parallel to muscle fiber orientation, and each is sheared perpendicular to the muscle fiber using a v-shaped Warner-Bratzler shear blade with a half-round beveled cutting edge. Conversely, the SSF method is performed on a warm sample, immediately after cooking. The SSF method was designed to be conducted during the carcass grading process in large scale operations to allow for an objective measure of tenderness at the time of grading. To accomplish this, the measurement would need to match grading chain speeds of 400 head per hour. With the time constraints, the evaluation would need to be done on hot samples, and with the difficulties associated with core removal, it was decided to instead remove a single rectangular slice from the steak (Shackelford & Wheeler, 2009). Shackelford, Wheeler, and Koohmaraie (1999b) described the sample used for SSF as a 1-cm thick and 5-cm long piece removed with a double bladed knife at a 45° angle from the steak parallel to the muscle fiber orientation. The slice is then sheared perpendicular to the muscle fibers with a SSF blade, a flat blunt-end blade which is the same thickness and degree of bevel (half-round) on the shearing edge similar to the Warner-Bratzler shear blade (Shackelford, Wheeler, & Koohmaraie, 1999a). However to date, SSF has not been widely adopted as most packing facilities are not willing to sacrifice the 2.54-cm portion of the loin from each animal to obtain a tenderness measurement.

The current global standard within the meat industry and the most familiar and recognizable method is WBSF.

Relationships among objective measurements of tenderness

Strong correlations have been reported between consumer and trained panel tenderness scores with objective measures of tenderness such as WBSF or SSF. Hunt et al. (2014) reported consumer panel tenderness rating was correlated to WBSF values (r = -0.21). Also, consumer panel tenderness ratings (1 = like extremely, 9 = dislike extremely) were correlated (r = 0.63) to WBSF values (Platter et al., 2003). Lorenzen et al. (2003) reported the consumer panel tenderness score of the LL, GM, and SM was correlated with WBSF (r = -0.26, -0.22, -0.16, respectively). Published literature often report higher correlations of trained panel scores with instrumental tenderness than consumer panel tenderness scores. This is due to the reduced amount of variation in trained panel scores as trained panelists are considered precise human instruments. Trained panel tenderness ratings are negatively correlated (r = -0.54) with WBSF values (Emerson et al., 2013). Moreover, high correlations were found by Woolley (2014) for consumer and trained initial and sustained tenderness ratings and SSF (r = -0.50, -0.60, -0.61 respectively). Emerson et al. (2013) also reported trained panel tenderness and SSF were negatively correlated (r = -0.65). Furthermore, Derington et al. (2011), Shackelford, Wheeler, and Koohmaraie (1999a), and Emerson et al. (2013) reported values of SSF and WBSF to be closely related (r = 0.71, 0.80, 0.48, respectively). The correlations of these two methods explain how closely the two mechanical measures of tenderness are and how closely each method is associated with sensory panel scores.

Objective measures of beef juiciness

Juiciness is a measure that indicates the moisture content within the product. Over the past 82 years techniques, methods, and equipment used for objective measures of juiciness have progressed and changed. Water holding capacity (WHC) has been reported as one of the most important factors affecting juiciness of meat during mastication (Boylston et al., 2012). Many methods focus on measuring the WHC of the product to get the best determination of predicted sensory juiciness ratings. Measures of water holding capacity all have a similar goal, to measure the amount of unbound or loosely bound water within the muscle.

Centrifugation is one such method commonly used to measure WHC. The two types of centrifugation methods are separated into either low or high speed methods. For each method, the WHC is determined by the water the tissue did not lose during centrifugation (Boylston et al., 2012). Bouton, Harris, and Shorthose (1971) conducted low speed centrifugation to determine the WHC of mutton. The process utilized 1.5 to 2.5 g of sample placed in cellulose nitrite tubes and centrifuged at 200 – 800 × *g* for 60 min. Following centrifuging the sample was reweighed to determine moisture loss. A positive correlation (r = 0.95) of centrifugally expressed juice was found with organoleptic juiciness (Bouton et al., 1971). Similarly, Shults, Russell, and Wierbicki (1972) evaluated the SM, LM, and biceps femoris (BF) by centrifuging heated meat samples at 900 *g* for 15 min, with the amount of juice lost expressed as a percent of the sample. Certain methods of centrifugation include putting filter paper at the end of the tube or other material to absorb moisture that is lost during the rotations (Jauregui et al., 1981; Trout, 1988). High speed centrifugation methods have used 3 to 4 g of sample placed in polypropylene tubes and centrifuged at 5,000 to 40,000 g for 30 to 60 minutes (Bouton et al., 1971). Moisture loss is measured in the same manner as low speed centrifugation methods. However, a limitation of both low and high speed centrifugation is the length of time it takes to perform. Additionally, centrifuging can result in microstructural changes which do not give a true indication of the WHC of the samples as the microstructure is highly related to the WHC of the sample.

Various press methods are the most extensively researched type of WHC measurement and are described as the amount of water that can be squeezed or pressed out of a sample (Kauffman, Eikelenboom, van der Wal, Merkus, & Zaar, 1986). The expressible juice attained from a beef sample is dependent on sample size, amount of force applied, and the test duration. The first documented press method used to determine WHC was conducted by Childs and Baldelli (1934), with a machine named the “pressometer”. Research was conducted to determine the most accurate way to collect the fluids exerted from the sample and the optimal pressure and time (Childs & Baldelli, 1934). Within the study, three 1.3-cm cores were taken from a cooked roast and wrapped in a filter cloth which was pressed for 10 min at a pressure of 113.4 kg (Childs & Baldelli, 1934). Two muscles (PM and BF) were evaluated for press fluid and no differences were found between the muscles. Also the percentage moisture was recorded when pressed for 5 min and 20 min and no difference in pressed juice was found between press times (Childs & Baldelli, 1934). The percentage of press fluid was determined by dividing the weight of the pressed fluid by the weight of the muscle before pressing (Childs & Baldelli, 1934). Moreover, Wierbicki and Deatherage (1958) designed a similar machine that encompassed a hydraulic jack and pressure gauge that pressed a 400 mg to 600 mg sample of beef SM or pork LD. Research was conducted on pressure and pressing time, which determined as pressure increased from 100 to 1000 psi, the free water area increased concurrently (Wierbicki & Deatherage, 1958). The pressure of 500 psi and a duration of 1 min were determined as the standardized operating conditions, as it was reported as the most reproducible (Wierbicki & Deatherage, 1958).

The equation used to determine the moisture loss from each sample is: (sample weight before press - sample weight after press) / sample weight before press. The Carver press is another machine developed in the 1950’s to assess moisture content of frankfurters, beef, pork, and shrimp. Van Oeckel, Warnants, and Boucqué (1999) conducted a study evaluating three methods of water holding capacity. Drip loss, filter paper method, and the filter paper press method in which samples were pressed at 1 kg of force for 5 min. The filter paper press method was found to be the highest correlated (r = 0.27) with trained panel juiciness (Van Oeckel, Warnants, & Boucqué, 1999). Sanderson and Vail (1963) utilized the beef SM and BF for the Carver press method with 0.5 g samples pressed at a pressure of 907.2 kg and compared 1 or 15 min press time. The authors reported that between 1 or 15 min duration, the 1 min press time was more consistent in the percent of pressed fluids (Sanderson & Vail, 1963). Furthermore, another study evaluating the Carver press was conducted by Baker, Darfler, and Bourne (1968) where chicken frankfurters were evlauated for percentage expressible fluids by pressing the sample at 181.4 kg for 2 min and for trained sensory panel ratings of juiciness and found no correlation between sensory scores and expressible fluid (Baker et al., 1968). Ackerman, Cohen, Swift, and Benedict (1981) also evaluated frankfurters for consumer juiciness ratings and the press moisture loss value, determined by pressing samples at 40 psi for 1 min. A strong correlation (r = 0.95) was found between consumer juiciness scores and press moisture loss (Ackerman et al., 1981). Moreover, Lee and Patel (1984) determined expressible fluids of frankfurters pressed by the Carver press and an Instron testing machine resulted in the Instron being more closely associated (r = 0.92) to sensory juiciness than the Carver press method (r = 0.27). Gundavarapu, Hung, and Reynolds (1998) even pressed shrimp at 2 to 3 kg of force for 17 s length to determine the percent press juice, and found a strong correlation (r = 0.98) for sensory juiciness. Additionally, Zhang, Mittal, and Barbut (1993) tested beef of three different sample sizes (0.3, 0.9, or 1.5 g), force pressures (10, 15, or 30 kN), time duration (1, 2, or 3 min) and salt concentration (0, 1, or 2 %) to determine which variable contributes the most to expressible moisture. The authors found the combination of sample size and salt concentration had the largest effect on WHC (Zhang, Mittal, & Barbut, 1993)

The Pressed Juice Percentage (PJP) method is another that utilizes the press technique. It was developed recently by Woolley (2014), and is described as pressing a 1-cm × 1-cm sample between two pieces of filter paper for 30 s at a force of 8 kg of pressure. The result is the percentage of moisture loss during compression of the sample, calculated by the equation [(sample before press-moisture loss from press)/sample before press] – 100. This method was found to be highly associated (r = 0.45, r = 0.69, and r = 0.67) with consumer juiciness, trained initial and sustained juiciness scores.

Authors have also used methods to measure juiciness that utilized capillary action, Trout (1988) describes three methods: the gypsum block method, analytical filter paper method, and the rapid filter paper method. The gypsum block method involves a combination of compression and capillary suction. The sample is pressed between a non-porous plate and a porous gypsum block, the water that filters through the block results in air displacement from the plate. The water is then measured in a volumetric pipette and the amount of air displaced is measured (Trout, 1988). The advantage of using the gypsum block is that the method is rapid only a 30 - 120 s process, however, the sample undergoes deformation from pressing which disrupts the microstructure of the sample and therefore may result in forcing out bound water rather than just loose and free water. Other authors have used analytical filter paper methods that involve samples being placed in a beaker layered with filter paper and held in the sealed beaker at 6°C for 72 h. The filter paper is then removed and weighed to determine WHC (Labuza & Lewicki, 1978). The advantage of this filter paper method is that the sample’s microstructure isn’t destroyed therefore, it is an accurate method of measuring the actual WHC of the sample, however, the method takes a significant amount of time and has not been found to be repeatable. Moreover, the method described by Kauffman et al. (1986) and Van Oeckel et al. (1999) includes placing filter paper on the cut muscle surface of pork and is visually scored the filter paper from 0 to 5 for wetness on a percentage of wet area (0 = 0%, 1 = 20%, 2 = 40%, 3 = 60%, 4 = 80%, and 5 = 100%) and the filter paper is then reweighed for fluid accumulation. Van Oeckel et al. (1999) determined filter paper weight and visual method was weakly correlated (r = -0.12, r = -0.10) with sensory juiciness scores. The advantage of this method is the length of time to conduct the test, however, many extrinsic factors play a large role in the amount of moisture accumulated on the filter paper.

Drip loss and cook loss are two methods of fluid loss also used to determine WHC (Honikel, 1998). Drip loss methods must assure the structure of the muscle isn't compromised and must avoid the uses of external forces on the samples other than gravity. Honikel (1998) explains the drip loss method with samples placed in netting and suspended in an inflated bag at 1 - 5°C for 24 h. Additionally, Van Oeckel et al. (1999) conducted a drip loss test where 150 g of sample was hung from a nylon cord in a plastic bag at 4°C for 48 h and the percentage of drip loss was determined by the equation [(sample before drip loss – sample after drip loss/sample before drip loss) × 100]. Drip loss was reported highly correlated (r = 0.35) with the filter paper press method from the study; however, drip loss was only slightly correlated (r = -0.09) with trained panel juiciness (Van Oeckel et al., 1999). Also, the drip loss method conducted by Kauffman et al. (1986) was slightly altered from previous works. In this study samples were first blotted with filter paper, packaged in Styrofoam trays with soaker pads and sealed with polyester film. After 48 h the samples were blotted and reweighed to determine sample's drip loss (Kauffman et al., 1986). The percent drip loss was positively associated with the fluid accumulation on the filter paper, however, no sensory work was conducted with the product (Kauffman et al., 1986). Aaslyng, Bejerholm, Ertbjerg, Bertram, and Andersen (2003) and Correa, Méthot, and Faucitano (2007) conducted the EZ-DripLoss method. Both studies followed the protocol outlined by Christensen (2003) in which samples are placed in funnel shaped plastic containers and held for 24 to 48 h then the drip loss is calculated by the amount of fluid that is lost form the sample throughout the storage time. Correa et al. (2007) ran an additional methodology that differed in that the samples were dabbed prior to weighing to remove any surface exudation. This modified EZ-DripLoss method increased the magnitude of correlation with pH, and subjective color score using the Japanese color standards. Additionally, Aaslyng et al. (2003) tested 10 different classes of quality factors and found drip loss was the highest in meat with a low pH, and was highly correlated with percentage of cooking loss measurements.

Moreover, cooking loss has been previously reported as an indicator of water holding capacity in meat products. Cook loss measures protein denaturation and shrink as fluids are squeezed out of the muscle tissue and is calculated as [(cooked weight-raw weight)/raw weight] × 100 (Boylston et al., 2012). The cook loss method described by Honikel (1998) explains that meat is placed in a thin-walled plastic bag and termocoupled to monitor internal temperature and is then submerged in boiling water. After cooking, the sample is removed, blotted, and reweighed. Aaslyng et al. (2003) reported cooking loss increased by an average of 5.0% as oven temperature increased from 90°C to 190°C. Moreover, beef LL steaks were reported to increase 16.4% in cooking loss as internal endpoint temperature increased from 57°C to 74°C (Luchak et al., 1998). Similarly, the LM cook loss was also measured by Lorenzen et al. (2005), who reported as internal endpoint temperature increased, so did the percentage of cooking loss.

Parrish et al. (1973) reported a 9.7% increase in cook loss as the internal temperature of the LD steaks increased from 60°C to 80°C. Therefore, all these studies indicate cook loss was a good indicator of WHC.

Relationships among objective measurements of juiciness

Varying correlations have been reported with instrumental juiciness measures and trained and consumer panel juiciness scores. Lee and Patel (1984) tested two different compression machines to attain the pressed juice percentage; the Carver press and an Instron testing machine. The correlations of objective juiciness measurements and the trained panel juiciness scores were different between the two different methods, with the Instron method having a much higher correlation (r = 0.92) compared to the Carver press (r = 0.27; Lee & Patel, 1984). Additionally, Ackerman et al. (1981) and Gundavarapu et al. (1998) reported correlations (r = 0.61 - 0.95) for objective measurements with panel juiciness scores; however, the correlations in each of these studies were conducted on the treatment mean juiciness scores rather than the juiciness scores for each experimental unit. Therefore, the reported high correlations can be partially attributed to this analysis method.

Woolley (2014) anayzed 34 raw and cooked objective measures of juiciness to determine which was associated closest with sensory juiciness scores. Each method was chosen due to being a sucessful measure of water holding capacity or previously reported to be associated with sensory juiciness scores. Correlations were reported for consumer juiciness scores with the raw measurements of proximate analysis (r = -0.23), free moisture analysis (r = -0.11), bound moisture analysis (r = 0.11), Carver press total circumference (r = 0.20), drip loss at 24 h (r = -0.19) and 48 h (r = -0.14), expressible percentage of moisture (r = -0.14), and water binding ability (r = 0.09). Additionally, correlations were also reported for consumer juiciness with cooked measures of Carver press total circumference (r = 0.38), drip loss at 24 h (r = 0.23) and

48 (r = 0.27), percentage of expressible moisture (r = 0.41), percentage of cook loss (r = -0.51), and the PJP method (r = 0.45). Stronger correlations were reported for the consumer juiciness ratings with the cooked measures of juiciness than the raw measurements. However, the strongest correlations with consumer juiciness were found with PJP and percentage of cooking loss (r = 0.45, r = -0.51, respectively). Moreover, trained panel initial and sustained juiciness was also correlated with PJP (r = 0.69, r = 0.67) and percentage of cooking loss (r = -0.75, r = -0.73).

Threshold determination

Previous tenderness research focused on determining what shear value (WBSF or SSF) is considered tender or not by panelists. Shackelford et al. (1991) conducted a study designed to determine threshold values for WBSF. Trained panelists were served steaks and asked to rate the steaks on overall tenderness using an 8 point scale, steaks from the same loin were cooked consistently and then cooled to room temperature and evaluated for WBSF. The tenderness thresholds developed were determined using regression analysis of the WBSF values and trained sensory panel ratings of overall tenderness (Shackelford et al., 1991). These tenderness threshold values were determined to monitor beef tenderness for foodservice. It was determined that steaks having WBSF values of 4.6 kg or lower have a 50% chance of being rated “slightly tender” or higher, and steaks with a shear force value of 3.9 kg or lower have a 68% chance of being rated “slightly tender” or higher. Moreover, it was determined steaks that have a shear value of 3.2 kg or lower have a 95% success rate for tenderness (Shackelford et al., 1991). Additionally, in an attempt to identify a tenderness threshold, Miller et al. (2001) seperated steaks into three tenderness categories by shear values, tender (1.6 to 2.3 kg), intermediately tender (3.9 to 4.5 kg), and tough (5.4 to 7.4 kg). Steaks from the same strip loins were then served to consumers in stores in five geographically diverse ares. Each comsumer evaluated traits of overall tenderness and acceptability, juiciness, and flavor and were asked how much they would pay for each steak

(Miller et al., 2001). It was determined that shear values of 4.0 kg, 4.3 kg, and 3.4 kg resulted in 94%, 86%, and 99% of consumers rating the sample acceptable for tenderness. The American Society for Testing and Materials (ASTM) performed further research into tenderness thresholds by utilizing studies such as Platter et al. (2003), Wheeler, Shackelford, and Koohmaraie (2004), AMSA (1995), and Voges et al., (2007) to set thresholds for marketing of muscles classified on tenderness. With the determination of tenderness thresholds (ASTM, 2011), the USDA has created marketing claims of "Certified Tender" (WBSF = 4.4 kg, SSF = 20.0 kg) and "Certified Very Tender" (WBSF = 3.9 kg, SSF = 15.4 kg).

Repeatability determination

After creating a new measurement, the method needs to be evaluated for accuracy and repeatability to be able to be utilized within the industry. Repeatability determines the variability of the measurements tested and the precision of the method (Connett, 2007). A study conducted by Shackelford et al. (1999) evaluated the repeatability of the SSF tenderness measurement, using the equation: repeatability = σ^2 pair/ (σ^2 pair + σ^2 residual). To obtain the σ^2 sample and σ^2 error values, PROC VARCOMP in SAS can be used for the random effect of sample to get the estimated variance components of σ^2 sample and σ^2 error (Wheeler et al., 2004). Shackelford et al. (1999) reported the SSF repeatability as 0.89, therefore 89% of the observed variation within the sample set could be attributed to between pair variation, which indicates only 11% of the variation was unexplained. Additionally, Wheeler, Shackelford, and Koohmaraie (1996) determined the repeatability of WBSF was between 0.68 and 0.74. Similarly, Wheeler et al. (1997) evaluated the repeatability of steaks across multiple institutions and reported that when each university followed their normal protocol the repeatability of WBSF ranged 0.39 to 0.73. However, when all universities followed a standardized protocol the repeatability of WBSF increased to a range of 0.67 to 0.87 (Wheeler et al., 1997).

References

Aaslyng, M. D., Bejerholm, C., Ertbjerg, P., Bertram, H. C., & Andersen, H. J. (2003). Cooking loss and juiciness of pork in relation to raw meat quality and cooking procedure. *Food Quality and Preference, 14*(4), 277-288.

Aberle, E. D., Forrest, J. C., Gerrard, D. E., & Mills, E. W. (2001). *Principles of Meat Science* (4th ed.). Dubuque, IA: Kendall/Hunt Publishing Company.

Acheson, R. J., Woerner, D. R., & Tatum, J. D. (2014). Effects of USDA carcass maturity on sensory attributes of beef produced by grain-finished steers and heifers classified as less than 30 months old using dentition. *Journal of Animal Science, 92*(4), 1792-1799.

Ackerman, S. A., Cohen, C. E., Swift, C., & Benedict, R. (1981). Evaluation of the press method for "frankfurter" juiciness estimation. *Fleischwirtsch, 61*(8), 1169-1170.

AMSA. (1995). Research guidlines for cookery, sensory evaluation, and instrumental tenderness measurements of fresh meat. Chicago, IL: National Live Stock and Meat Board.

ASTM. (2011). ASTM F 2925-11 Standard specification for tenderness marketing claims associated with meat cuts derived from beef. In (Vol. 2014).

Bagley, J. L., Nicholson, K. L., Pfeiffer, K. D., & Savell, J. W. (2010). In-home consumer and shear force evaluation of steaks from the M. serratus ventralis thoracis. *Meat Science, 85*(1), 104-109.

Baker, R. C., Darfler, J. M., & Bourne, M. C. (1968). The effect of level of skin on the quality of chicken frankfurters. *Poultry Science, 47*(6), 1989-1996.

Baublits, R. T., Pohlman, F. W., Brown Jr, A. H., Yancey, E. J., & Johnson, Z. B. (2006). Impact of muscle type and sodium chloride concentration on the quality, sensory, and instrumental color characteristics of solution enhanced whole-muscle beef. *Meat Science, 72*(4), 704-712.

Beekman, D. D. (1994). The effects of calcium chloride, sodium chloride, and tripolyphosphate injections on the tenderness, water holding capacity and microscopic structure of beef muscle.

Behrends, J. M., Goodson, K. J., Koohmaraie, M., Shackelford, S. D., Wheeler, T. L., Morgan, W. W., Reagan, J. O., Gwartney, B. L., Wise, J. W., & Savell, J. W. (2005). Beef customer satisfaction: USDA quality grade and marination effects on consumer evaluations of top round steaks. *Journal of Animal Science, 83*(3), 662-670.

Bouton, P. E., Harris, P. V., & Shorthose, W. R. (1971). Effect of ultimate pH upon the water-holding capacity and tenderness of mutton. *Journal of Food Science, 36*(3), 435-439.

Boylston, T., Chen, F., Coggins, P., Hydlig, G., McKee, L., Kerth, C., & Nollet, L. M. (2012). Handbook of meat, poultry and seafood quality: John Wiley & Sons.

Bratzler, L. J. (1932). *Measuring the tenderness of meat by means of a mechanical shear.* Master's Thesis, Kansas State University, Manhattan, KS.

Bratzler, L. J. (1971). Palatability factors and evaluations. In *The Science of Meat and Meat Products*. San Francisco, Calif.: W. H. Freeman and Company.

Breidenstein, B. B., Cooper, C. C., Cassens, R. G., Evans, G., & Bray, R. W. (1968). Influence of marbling and maturity on the palatability of beef muscle. I. chemical and organoleptic considerations. *Journal of Animal Science, 27*(6), 1532-1541.

Brooks, J. C. (2011). Marinating of beef for enhancement. In. Centennial, CO: National Cattlemens Beef Association

Brooks, J. C., Mehaffey, J. M., Collins, J. A., Rogers, H. R., Legako, J., Johnson, B. J., Lawrence, T., Allen, D. M., Streeter, M. N., Nichols, W. T., Hutcheson, J. P., Yates, D. A., & Miller, M. F. (2010). Moisture enhancement and blade tenderization effects on the shear force and palatability of strip loin steaks from beef cattle fed zilpaterol hydrochloride. *Journal of Animal Science, 88*(5), 1809-1816.

Carr, M. A., Crockett, K. L., Ramsey, C. B., & Miller, M. F. (2004). Consumer acceptance of calcium chloride-marinated top loin steaks. *Journal of Animal Science, 82*(5), 1471-1474.

Childs, A. M., & Baldelli, M. (1934). Press fluid from heated beef muscle. *J. Agr. Res, 48*(12), 1127.

Christensen, L. B. (2003). Drip loss sampling in porcine m. longissimus dorsi. *Meat Science, 63*(4), 469-477.

Connett, J. E. (2007). Repeatability and Reproducibility. In Wiley Encyclopedia of Clinical Trials: John Wiley & Sons, Inc.

Corbin, C. H., O'Quinn, T. G., Garmyn, A. J., Legako, J. F., Hunt, M. R., Dinh, T. T. N., Rathmann, R. J., Brooks, J. C., & Miller, M. F. (2015). Sensory evaluation of tender beef strip loin steaks of varying marbling levels and quality treatments. *Meat Science, 100*(0), 24-31.

Correa, J. A., Méthot, S., & Faucitano, L. (2007). A modified meat juice container (EZ-driploss) procedure for a more reliable assessment of drip loss and related quality changes in pork meat. *Journal of Muscle Foods, 18*(1), 67-77.

Cox, R. J., Thompson, J. M., Cunial, C. M., Winter, S., & Gordon, A. J. (1997). The effect of degree of doneness of beef steaks on consumer acceptability of meals in restaurants. *Meat Science, 45*(1), 75-85.

Derington, A. J., Brooks, J. C., Garmyn, A. J., Thompson, L. D., Wester, D. B., & Miller, M. F. (2011). Relationships of slice shear force and Warner-Bratzler shear force of beef strip loin steaks as related to the tenderness gradient of the strip loin. *Meat Science, 88*(1), 203-208.

Dikeman, M. E. (1987). Fat reduction in animals and the effects on palatability and consumer acceptance of meat products. In *Reciprocal Meat Conference* (pp. 93-103).

Dow, D. L., Wiegand, B. R., Ellersieck, M. R., & Lorenzen, C. L. (2011). Prediction of fat percentage within marbling score on beef longissimus muscle using 3 different fat determination methods. *Journal of Animal Science*, *89*(4), 1173-1179.

Emerson, M. R., Woerner, D. R., Belk, K. E., & Tatum, J. D. (2013). Effectiveness of USDA instrument-based marbling measurements for categorizing beef carcasses according to differences in longissimus muscle sensory attributes. *Journal of Animal Science, 91*(2), 1024-1034.

Gilpin, G. L., Batcher, O. M., & Deary, P. A. (1965). Influence of marbling and final internal temperature on quality characteristics of broiled rib and eye of round steaks. *Food Technology*, *19*, 834-837.

Gomes, C. L., Pflanzer, S. B., Cruz, A. G., de Felício, P. E., & Bolini, H. M. A. (2014). Sensory descriptive profiling and consumer preferences of beef strip loin steaks. *Food Research International*, *59*, 76-84.

Guelker, M. R., Haneklaus, A. N., Brooks, J. C., Carr, C. C., Delmore, R. J., Griffin, D. B., Hale, D. S., Harris, K. B., Mafi, G. G., Johnson, D. D., Lorenzen, C. L., Maddock, R. J., Martin, J. N., Miller, R. K., Raines, C. R., VanOverbeke, D. L., Vedral, L. L., Wasser, B. E., & Savell, J. W. (2013). National Beef Tenderness Survey–2010: Warner-Bratzler shear force values and sensory panel ratings for beef steaks from United States retail and food service establishments. *Journal of Animal Science, 91*(2), 1005-1014.

Gundavarapu, S., Hung, Y. C., & Reynolds, A. E. (1998). Consumer acceptance and quality of microwave-cooked shrimp. *Journal of Food Quality*, *21*(1), 71-84.

Honikel, K. O. (1998). Reference methods for the assessment of physical characteristics of meat. *Meat Science, 49*(4), 447-457.

Hoover, L., Cook, K., Miller, M., Huffman, K., Wu, C., Lansdell, J., & Ramsey, C. (1995). Restaurant consumer acceptance of beef loin strip steaks tenderized with calcium chloride. *Journal of Animal Science*, *73*(12), 3633-3638.

Huffman, K. L., Miller, M. F., Hoover, L. C., Wu, C. K., Brittin, H. C., & Ramsey, C. B. (1996). Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. *Journal of Animal Science, 74*(1), 91-97.

Hunt, M. R., Garmyn, A. J., O'Quinn, T. G., Corbin, C. H., Legako, J. F., Rathmann, R. J., Brooks, J. C., & Miller, M. F. (2014). Consumer assessment of beef palatability from four beef muscles from USDA Choice and Select graded carcasses. *Meat Science, 98*(1), 1-8.

Igo, M. W., Arnold, A. N., Miller, R. K., Gehring, K. B., Mehall, L. N., Lorenzen, C. L., Delmore, R. J., Woerner, D. R., Wasser, B. E., & Savell, J. W. (2015). Tenderness assessments of top loin steaks from retail markets in four U.S. cities. *Journal of Animal Science, 93*(10), 4610-4616.

Jauregui, C. A., Regenstein, J. M., & Baker, R. C. (1981). A simple centrifugal method for measuring expressible moisture, a water-binding property of muscle foods. *Journal of Food Science, 46*(4), 1271-1271.

Jennings, T. G., Berry, B. W., & Joseph, A. L. (1978). Influence of fat thickness, marbling and length of aging on beef palatability and shelf-life characteristics. *Journal of Animal Science, 46*(3), 658-665.

Kauffman, R. G., Eikelenboom, G., van der Wal, P. G., Merkus, G., & Zaar, M. (1986). The use of filter paper to estimate drip loss of porcine musculature. *Meat Science, 18*(3), 191-200.

Kerth, C. R., Braden, K. W., Cox, R., Kerth, L. K., & Rankins Jr, D. L. (2007). Carcass, sensory, fat color, and consumer acceptance characteristics of Angus-cross steers finished on ryegrass (Lolium multiflorum) forage or on a high-concentrate diet. *Meat Science, 75*(2), 324-331.

Kerth, C. R., Miller, M. F., & Ramsey, C. B. (1995). Improvement of beef tenderness and quality traits with calcium chloride injection in beef loins 48 hours postmortem. *Journal of Animal Science*, *73*(3), 750-756.

Killinger, K. M., Calkins, C. R., Umberger, W. J., Feuz, D. M., & Eskridge, K. M. (2004). Consumer sensory acceptance and value for beef steaks of similar tenderness, but differing in marbling level. *Journal of Animal Science, 82*(11), 3294-3301.

Labuza, T. P., & Lewicki, P. P. (1978). Measurement of gel water-binding capacity by capillary suction potential. *Journal of Food Science, 43*(4), 1264-1269.

Lansdell, J., Miller, M., Wheeler, T., Koohmaraie, M., & Ramsey, C. (1995). Postmortem injection of calcium chloride effects on beef quality traits. *Journal of Animal Science*, 73(6), 1735-1740.

Lee, C. M., & Patel, K. M. (1984). Analysis of juiciness of commercial frankfurters. *Journal of Texture Studies, 15*(1), 67-73.

Legako, J. F., Brooks, J. C., O'Quinn, T. G., Hagan, T. D. J., Polkinghorne, R., Farmer, L. J., & Miller, M. F. (2015). Consumer palatability scores and volatile beef flavor compounds of five USDA quality grades and four muscles. *Meat Science, 100*(0), 291-300.

Lorenzen, C. L., Miller, R. K., Taylor, J. F., Neely, T. R., Tatum, J. D., Wise, J. W., Buyck, M. J., Reagan, J. O., & Savell, J. W. (2003). Beef customer satisfaction: Trained sensory panel ratings and Warner-Bratzler shear force values. *Journal of Animal Science, 81*(1), 143-149.

Lorenzen, C. L., Neely, T. R., Miller, R. K., Tatum, J. D., Wise, J. W., Taylor, J. F., Buyck, M. J., Reagan, J. O., & Savell, J. W. (1999). Beef customer satisfaction: cooking method and degree of doneness effects on the top loin steak. *Journal of Animal Science, 77*(3), 637-644.

Luchak, G. L., Miller, R. K., Belk, K. E., Hale, D. S., Michaelsen, S. A., Johnson, D. D., West, R. L., Leak, F. W., Cross, H. R., & Savell, J. W. (1998). Determination of sensory, chemical and cooking characteristics of retail beef cuts differing in intramuscular and external fat. *Meat Science, 50*(1), 55-72.

McGee, M. R., Henry, K. L., Brooks, J. C., Ray, F. K., & Morgan, J. B. (2003). Injection of sodium chloride, sodium tripolyphosphate, and sodium lactate improves Warner–Bratzler shear and sensory characteristics of pre-cooked inside round roasts. *Meat Science, 64*(3), 273-277.

McKenna, D. R., Lorenzen, C. L., Pollok, K. D., Morgan, W. W., Mies, W. L., Harris, J. J., Murphy, R., McAdams, M., Hale, D. S., & Savell, J. W. (2004). Interrelationships of breed type, USDA quality grade, cooking method, and degree of doneness on consumer evaluations of beef in Dallas and San Antonio, Texas, USA. *Meat Science, 66*(2), 399-406.

Miller, M. F., Carr, M. A., Ramsey, C. B., Crockett, K. L., & Hoover, L. C. (2001). Consumer thresholds for establishing the value of beef tenderness. *Journal of Animal Science, 79*(12), 3062-3068.

Miller, M. F., Huffman, K. L., Gilbert, S. Y., Hamman, L. L., & Ramsey, C. B. (1995). Retail consumer acceptance of beef tenderized with calcium chloride. *Journal of Animal Science, 73*(8), 2308-2314.

Miller, M. F., Kerth, C. R., Wise, J. W., Lansdell, J. L., Stowell, J. E., & Ramsey, C. B. (1997). Slaughter plant location, USDA quality grade, external fat thickness, and aging time effects on sensory characteristics of beef loin strip steak. *Journal of Animal Science, 75*(3), 662-667.

Miller, R. (2004). Chemical and physical characteristics of meat/palatability. *Encyclopedia of meat sciences*, *1*, 256-266.

O'Quinn, T. G., Brooks, J. C., & Miller, M. F. (2015). Consumer assessment of beef tenderloin steaks from various USDA quality grades at 3 degrees of doneness. *Journal of Food Science, 80*(2), S444-S449.

O'Quinn, T. G., Brooks, J. C., Polkinghorne, R. J., Garmyn, A. J., Johnson, B. J., Starkey, J. D., Rathmann, R. J., & Miller, M. F. (2012). Consumer assessment of beef strip loin steaks of varying fat levels. *Journal of Animal Science, 90*(2), 626-634.

Parrish, F. C., Jr., Olson, D. G., Miner, B. E., & Rust, R. E. (1973). Effect of degree of marbling and internal temperature of doneness on beef rib steaks. *Journal of Animal Science, 37*(2), 430-434.

Pietrasik, Z., & Janz, J. (2009). Influence of freezing and thawing on the hydration characteristics, quality, and consumer acceptance of whole muscle beef injected with solutions of salt and phosphate. *Meat Science, 81*(3), 523-532.

Platter, W. J., Tatum, J. D., Belk, K. E., Chapman, P. L., Scanga, J. A., & Smith, G. C. (2003). Relationships of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. *Journal of Animal Science, 81*(11), 2741-2750.

Prestat, C., Jensen, J., McKeith, F. K., & Brewer, M. S. (2002). Cooking method and endpoint temperature effects on sensory and color characteristics of pumped pork loin chops. *Meat Science, 60*(4), 395-400.

Robbins, K., Jensen, J., Ryan, K., HOMCO-RYAN, C., McKeith, F., & Brewer, M. (2002). Enhancement effects on sensory and retail display characteristics of beef rounds. *Journal of Muscle Foods, 13*(4), 279-288.

Robbins, K., Jensen, J., Ryan, K. J., Homco-Ryan, C., McKeith, F. K., & Brewer, M. S. (2003a). Consumer attitudes towards beef and acceptability of enhanced beef. *Meat Science, 65*(2), 721-729.

Robbins, K., Jensen, J., Ryan, K. J., Homco-Ryan, C., McKeith, F. K., & Brewer, M. S. (2003b). Dietary vitamin E supplementation effects on the color and sensory characteristics of enhanced beef steaks. *Meat Science, 64*(3), 279-285.

Rodas-Gonzalez, A., Narvaez-Bravo, C., Brashears, M. M., Rogers, H. B., Tedford, J. L., Clark, G. O., Brooks, J. C., Johnson, B. J., Rathmann, R. J., & Miller, M. F. (2011). Evaluation of the storage life of vacuum packaged Australian beef. *Meat Science, 88*(1), 128-138.

Sanderson, M., & Vail, G. E. (1963). A method for determining press fluid in cooked beef. *Journal of Food Science, 28*(5), 596-599.

Savell, J. W., Branson, R. E., Cross, H. R., Stiffler, D. M., Wise, J. W., Griffin, D. B., & Smith, G. C. (1987). National consumer retail beef study: palatability evaluations of beef loin steaks that differed in marbling. *Journal of Food Science, 52*(3), 517-519.

Savell, J. W., & Cross, H. R. (1988). The role of fat in the palatability of beef, pork, and lamb. In *Designing Foods: Animal Product Options in the Marketplace*. Washington, D.C.: National Academy Press.

Savell, J. W., Cross, H. R., & Smith, G. C. (1986). Percentage ether extractable fat and moisture content of beef longissimus muscle as related to USDA marbling score. *Journal of Food Science, 51*(3), 838-839.

Savell, J. W., Lorenzen, C. L., Neely, T. R., Miller, R. K., Tatum, J. D., Wise, J. W., Taylor, J. F., Buyck, M. J., & Reagan, J. O. (1999). Beef customer satisfaction: cooking method and degree of doneness effects on the top sirloin steak. *Journal of Animal Science, 77*(3), 645-652.

Sebranek, J. G. (2015). An Overview of Functional Non-Meat Ingredients in Meat Processing: The Current Toolbox. In *Reciprocal Meat Conference* (pp. 42-46). Lincoln, NE: American Meat Science Association.

Shackelford, S., Wheeler, T., & Koohmaraie, M. (1999a). Evaluation of slice shear force as an objective method of assessing beef longissimus tenderness. *Journal of Animal Science*, 77(10), 2693-2699.

Shackelford, S. D., Morgan, J. B., Cross, H. R., & Savell, J. W. (1991). Identification of thresholds for Warner-Bratzler shear force in beef top loin steaks. *Journal of Muscle Foods*, 2(4), 289-296.

Shackelford, S. D., & Wheeler, T. L. (2009). Slice Shear Force In Product Enhancement Research. Centinnial, CO: Beef Checkoff.

Shackelford, S. D., Wheeler, T. L., & Koohmaraie, M. (1999b). Tenderness classification of beef: II. Design and analysis of a system to measure beef longissimus shear force under commercial processing conditions. *Journal of Animal Science,* 77(6), 1474-1481.

Sheard, P. R., & Tali, A. (2004). Injection of salt, tripolyphosphate and bicarbonate marinade solutions to improve the yield and tenderness of cooked pork loin. *Meat Science, 68*(2), 305-311.

Shults, G. W., Russell, D. R., & Wierbicki, E. (1972). Effect of condensed phosphates on pH, swelling and water-holding capacity of beef. *Journal of Food Science, 37*(6), 860-864.

Smith, G. C., Carpenter, Z. L., Cross, H. R., Murphey, C. E., Abraham, H. C., Savell, J. W., Davis, G. W., Berry, B. W., & Parrish Jr, F. C. (1985). Relationship of USDA marbling groups to palatability of cooked beef. *Journal of Food Quality, 7*(4), 289-308.

Smith, L. A., Simmons, S. L., McKeith, F. K., Bechtel, P. J., & Brady, P. L. (1984). Effects of sodium tripolyphosphate on physical and sensory properties of beef and pork roasts. *Journal of Food Science, 49*(6), 1636-1637.

Stetzer, A. J., Cadwallader, K., Singh, T. K., McKeith, F. K., & Brewer, M. S. (2008a). Effect of enhancement and ageing on flavor and volatile compounds in various beef muscles. *Meat Science, 79*(1), 13-19.

Stetzer, A. J., Tucker, E., McKeith, F. K., & Brewer, M. S. (2008b). Quality changes in beef complexus, serratus ventralis, vastus lateralis, vastus medialis, and longissimus dorsi muscles enhanced prior to aging. *Journal of Food Science, 73*(1), S6-S10.

Sutton, D. S., Brewer, M. S., & McKeith, F. K. (1997). Effects of sodium lactate and sodium phosphate on the physical and sensory characteristics of pumped pork loins. *Journal of Muscle Foods, 8*(1), 95-104.

Tatum, J. D., Smith, G. C., Berry, B. W., Murphey, C. E., Williams, F. L., & Carpenter, Z. L. (1980). Carcass characteristics, time on feed and cooked beef palatability attributes. *Journal of Animal Science, 50*(5), 833-840.

Trout, G. R. (1988). Techniques for measuring water-binding capacity in muscle foods—A review of methodology. *Meat Science, 23*(4), 235-252.

USDA-FSIS. (2013). Water in Meat and Poultry. In (Vol. 2016).

Van Oeckel, M. J., Warnants, N., & Boucqué, C. V. (1999). Comparison of different methods for measuring water holding capacity and juiciness of pork versus on-line screening methods. *Meat Science, 51*(4), 313-320.

Voges, K. L., Mason, C. L., Brooks, J. C., Delmore, R. J., Griffin, D. B., Hale, D. S., Henning, W. R., Johnson, D. D., Lorenzen, C. L., Maddock, R. J., Miller, R. K., Morgan, J. B., Baird, B. E., Gwartney, B. L., & Savell, J. W. (2007). National beef tenderness survey - 2006: Assessment of Warner-Bratzler shear and sensory panel ratings for beef from US retail and foodservice establishments. *Meat Science*, 77(3), 357-364.

Vote, D., Platter, W., Tatum, J., Schmidt, G., Belk, K., Smith, G., & Speer, N. (2000). Injection of beef strip loins with solutions containing sodium tripolyphosphate, sodium lactate, and sodium chloride to enhance palatability. *Journal of Animal Science, 78*(4), 952-957.

Wheeler, T. L., Shackelford, S. D., Johnson, L. P., Miller, M. F., Miller, R. K., & Koohmaraie, M. (1997). A comparison of Warner-Bratzler shear force assessment within and among institutions. *Journal of Animal Science*, 75(9), 2423-2432.

Wheeler, T. L., Shackelford, S. D., & Koohmaraie, M. (1999). Tenderness classification of beef: III. Effect of the interaction between end point temperature and tenderness on Warner-Bratzler shear force of beef longissimus. *Journal of Animal Science*, 77(2), 400-407.

Wheeler, T. L., Shackelford, S. D., & Koohmaraie, M. (2004). The accuracy and repeatability of untrained laboratory consumer panelists in detecting differences in beef longissimus tenderness. *Journal of Animal Science*, 82(2), 557-562.

Wheeler, T. L., Shackelford, S. D., & Koohmaraie, M. (1996). Sampling, cooking, and coring effects on Warner-Bratzler shear force values in beef. *Journal of Animal Science, 74*(7), 1553-1562.

Wicklund, S. E., Homco-Ryan, C., Ryan, K. J., Mckeith, F. K., Mcfarlane, B. J., & Brewer, M. S. (2005). Aging and enhancement effects on quality characteristics of beef strip steaks. *Journal of Food Science, 70*(3), S242-S248.

Wierbicki, E., & Deatherage, F. E. (1958). Water content of meats, determination of water-holding capacity of fresh meats. *Journal of Agricultural and Food Chemistry, 6*(5), 387-392.

Woolley, L. D. (2014). *Evaluation of objective beef juiciness measurement techniques and their relationships to subjective taste panel juiciness ratings.* Master's Thesis, Texas Tech University, Lubbock, TX.

Wulf, D., Morgan, J., Tatum, J., & Smith, G. (1996). Effects of animal age, marbling score, calpastatin activity, subprimal cut, calcium injection, and degree of doneness on the palatability of steaks from limousin steers. *Journal of Animal Science*, 74(3), 569-576.

Xiong, Y. L. (2005). Role of myofibrillar proteins in water-binding in brine-enhanced meats. *Food Research International*, 38(3), 281-287.

Zhang, M., Mittal, G. S., & Barbut, S. (1993). Optimum conditions for determining water holding capacity of beef by the press method. *Journal of Muscle Foods*, *4*(4), 255-268.

Chapter 2 - Consumer and Trained Panel Evaluation of Enhanced Beef Strip Loin Steaks Cooked to Three Degrees of Doneness

Abstract

Consumer and trained sensory panelists evaluated strip steak palatability traits of three USDA quality grades: Prime, Low Choice, and Low Select. Additional strip loins from each grade were enhanced to 108% with water, salt, and alkaline phosphates. All steaks were cooked to three degrees of doneness (DOD; Rare: 60°C, Medium: 71°C, or Very Well-Done: 82°C). Consumer panelists rated all enhanced treatments similar ($P > 0.05$) for each palatability trait. Enhanced steaks had greater ($P < 0.05$) juiciness, tenderness, flavor liking, and overall liking ratings than non-enhanced treatments, regardless of grade. Consumer juiciness, tenderness, and overall liking scores increased ($P < 0.05$) as DOD decreased. Trained panelists rated all enhanced treatments and non-enhanced Prime similar ($P > 0.05$) for initial juiciness and greater ($P < 0.05$) than non-enhanced Low Choice and Select. Therefore, enhancement largely increases palatability, but there is a limit to the overall improvement potential and these results do not indicate an additive palatability effect with marbling level.

Keywords: beef, consumer, degree of doneness, enhancement, palatability, quality grade

Introduction

Numerous studies demonstrate increases in USDA quality grade have been positively associated with palatability characteristics (Behrends et al., 2005; Hunt et al., 2014; O'Quinn et al., 2012; Smith et al., 1985). Premiums are applied to higher quality graded cuts with a $1.84 premium for USDA Prime over USDA Select for strip loins (USDA, 2015a, 2015b). Woolley (2014) and Hunt et al. (2014) reported as quality grade increased consumer acceptability of all palatability traits increased. Additionally, as quality grade increases the percentage of samples rated “Premium quality” increased from USDA Select (2.15 - 8.26 %) to USDA Prime (17.43 - 35.83 %; Corbin et al., 2015; Hunt et al., 2014; O'Quinn et al., 2012; Woolley, 2014).

Degree of doneness (DOD) elicits a large impact on consumer overall eating experience (Cox, Thompson, Cunial, Winter, & Gordon, 1997). Increased DOD results in elevated cook loss and protein hardening (Cross, Stanfield, & Koch, 1976; Lorenzen, Davuluri, Adhikari, & Grün, 2005; Wheeler, Shackelford, & Koohmaraie, 1999). Additionally, increased DOD has a negative impact on palatability traits of steaks evaluated by consumer and trained panelists (Lorenzen et al., 2005; O'Quinn, Brooks, & Miller, 2015; Parrish, Olson, Miner, & Rust, 1973). Studies have reported consumers prefer a higher DOD. Cox et al. (1997) reported 27% of consumers preferred Well Done DOD, and Reicks et al. (2011) reported 40% of consumers preferred is Medium Well or Well Done DOD.

Previous research evaluating beef enhancement has focused on either lower quality (tougher) muscles or lower quality grades (USDA Select or lower). Moreover, steaks enhanced with a solution of salt and alkaline phosphates have been associated with increased consumer and trained panel palatability traits, and decreases in shear-force values and percentages of purge, and cooking loss (Baublits, Pohlman, Brown Jr, Yancey, & Johnson, 2006; Brooks et al., 2010; Pietrasik & Janz, 2009; Robbins et al., 2002). However, few studies have used higher quality grades of USDA Choice or Prime for enhancement. Additionally, research on cooking enhanced steaks to different degrees of doneness is limited. Therefore, the objective of this study was to determine the effect of enhancement on consumer and trained beef palatability scores of three quality grades when cooked to three degrees of doneness.

Materials and Methods

Experimental Treatments and Sample Preparation

Beef strip loins (n = 72; IMPS #180; NAMP 2010) were selected to equally represent three USDA quality grades: Prime, Low Choice, and Low Select. Strip loins were collected from a commercial beef processing plant in the Midwest. While at the facility, the Kansas State University (KSU) research team recorded skeletal, lean, overall maturity, marbling score, preliminary fat thickness, adjusted fat thickness, ribeye area, hot carcass weight, kidney pelvic and heart fat percentage, and USDA yield grade. Product was vacuum packaged and transported under refrigeration (2 °C) to the KSU Meat Laboratory for further processing.

Following 14 d of aging, half (n = 12) of the strip loins within each quality grade were selected for enhancement. Strip loins designated for enhancement were enhanced with a solution formulated to result in 0.35% salt and 0.40% sodium phosphate (Brifisol 512, ICL Food Specialties, Saint Louis, MO) at a target 8% pump in the final injected product. Solution (pH = 8.09) was injected into product using a multi-needle (Wolf-tec, IMAX 420 eco, Kingston, NY) injector. Weights of strip loins were recorded before and 15 min after injection for calculation of actual percentage pump (6.91 ± 1.42%). Enhanced loins were then vacuum packaged and held at 2 – 4°C for an additional 7 d. Strip loins not designated for enhancement were aged for 21 d under vacuum at 2 - 4°C.

At the end of the 21 d aging period, strip loins were fabricated into 2.5-cm thick steaks. The most anterior (wedge) steak was removed and used to obtain measurements of instrumental color (L*, a*, b*), pH, and proximate analysis. Immediately following slicing, the freshly cut surface of the wedge steak was allowed to bloom for 15 min prior to color measurement using a

Hunter Lab Miniscan spectrophotometer (Illuminant A, 2.54-cm aperture, 10° observer; Hunter Associates Laboratory, Reston, VA). Scans were taken at three locations on each steak and the readings were averaged for L*, a*, and b* values. The pH was measured using a pH meter (model HI 99163; Hannah Instruments, Smithfield, RI). After readings were collected, wedge steaks were packaged and frozen at -20°C for proximate analysis.

Each strip loin was designated into thirds (from anterior to posterior), with each third randomly assigned to one of the three degree of doneness (Rare: 60°C; Medium: 71°C; or Very Well-Done: 82°C). Within each section, four 2.5-cm thick steaks were cut, with one steak randomly assigned to consumer panel, trained panel, objective measurements, or flavor analysis. Steak assignment was balanced across all strip loins in each treatment. All steaks were identified with a unique four digit number and were vacuum packaged individually and frozen at -20°C.

Consumer Panel Evaluation

Panelists (n = 252) were recruited from Manhattan, KS and the surrounding communities and monetarily compensated for participation. Consumer panels were conducted at the KSU Meat Science Sensory Laboratory. Each panelist was placed in individual sensory booths and samples were served under low intensity (< 107.64 lumens) red incandescent lighting used to mask DOD variations among samples. A total of 36 panels were conducted with seven consumers per session and lasted approximately 1 h.

Panelists were provided with a ballot, toothpick, napkin, fork, knife, water cup, expectorant cup, unsalted crackers, and apple juice which were used as palate cleansers between samples. Each ballot contained an informational sheet, a demographic questionnaire, a purchasing motivator sheet, and survey ballots for each sample to be evaluated. Prior to the start of each panel, instructions were given to consumers about how to fill out the ballot sheets and the testing procedures.

Steaks were thawed (2 – 4°C) 24 h prior to evaluation. A thaw weight was recorded and remaining external fat and accessory muscles (*Multifidus dorsi* and *Gluteus medius*) were removed prior to cooking and weighing for cook loss evaluation. Steaks were cooked to the preassigned DOD [Rare (60°C), Medium (71°C), or Very Well-Done (82°C)] on a clamshell grill (Cuisinart Griddler Deluxe, East Windsor, NJ). Thermocouples (30-gauge copper and constantan; Omega Engineering, Stamford, CT) monitored temperatures with a Doric Mini-trend Data Logger (Model 205 B-1-c OFT, Doric Scientific, San Diego, CA) and peak temperatures were verified with a probe thermometer (Model 450-ATT, Omega Engineering, Stamford, CT). Following a 2 min rest period, steaks were cut into 1.3-cm by 1.3-cm by 2.54-cm cubes. Two cubes were immediately served to seven consumers, with six samples served per panel representing multiple DOD and quality treatments. The study was designed as a partially balanced, incomplete block design so that every quality treatment × DOD combination was compared as close to an equal number of times as possible across all 36 panel sessions. This was done to allow for consumers to evaluate multiple degrees of doneness within the same panel session. Prior to evaluation, panelists were asked to rate a list of 15 beef purchasing motivators in terms of importance with anchors located at 0 mm and 100 mm. The 0 mm anchor was labeled as extremely unimportant and 100 mm was labeled as extremely important. Additionally, panelists rated each sample for the traits of juiciness, tenderness, flavor liking, and overall liking on 100-mm line scales. Anchors were located at 0 mm and 100 mm, with 0 mm labeled as extremely dry, extremely tough, and extremely dislike and 100 mm labeled as extremely juicy, extremely tender, and like extremely. Each scale also had a midpoint at 50 mm labeled as neither dry nor juicy, neither tough nor tender, and neither dislike nor like. Finally, consumers rated each trait evaluated as either acceptable or unacceptable and also classified samples into one of four quality levels: unsatisfactory, everyday quality, better than everyday quality, or premium quality.

Trained Panel Evaluation

Training of panelists and taste matching tests were performed using the protocols described by AMSA (2015). Ten sensory training sessions were held three weeks prior to starting the trained sensory panels. Additionally, flavor trait references and anchors were consistent with those identified by Adhikari et al. (2011).

Steaks were prepared as described previously for consumer panel evaluation. A total of 36 panel sessions were conducted by an eight-member trained panel. Steaks were cut into 1.3-cm by 1.3-cm cubes and placed into double broilers, and held on the stove top (Model AKC-35D, Amana Corporation, Newton, IA) at 43°C for no more than 15 min prior to sample evaluation.

Panelists were given an electronic tablet (Model 5709 HP Steam 7; Hewlett-Packard, Palo Alto, CA), toothpick, napkin, fork, knife, water cup, expectorant cup, and unsalted crackers and sliced apples which were used as palate cleansers between samples. Panelists were served in individual sensory booths at the KSU Sensory Laboratory. Samples were served under low intensity (< 107.64 lumens) red incandescent lighting used to mask DOD variations among samples. Samples were rated on digital ballots designed through the Qualtrics survey software (Version 2417833). Each sample was evaluated for initial juiciness, sustained juiciness, myofibrillar tenderness, amount of connective tissue, overall tenderness, beef flavor identity, beef flavor intensity, salt flavor intensity, off flavor intensity, and panelists were asked to describe any off-flavor detected. The traits were rated on a continuous line scales. The 0 anchors were labelled as extremely dry, extremely tough, none, extremely unbeef-like, and extremely bland and the 100 anchors were labelled as extremely juicy, extremely tender, abundant, extremely beef-like, and extremely intense. Midpoint (50%) anchors for initial juiciness, sustained juiciness, myofibrillar tenderness, overall tenderness, and beef flavor identity were labelled as neither dry nor juicy, neither tough nor tender, and neither unbeef-like nor beef-like. Also, there were boxes labelled “not applicable” to check for salt intensity and off flavor intensity for samples where none were detected.

Slice Shear Force

The protocol followed for Slice Shear Force (SSF) are described by Shackelford, Wheeler, and Koohmaraie (1999). In short, after a 3 min rest period, a 1 to 2-cm portion of the lateral end of the steak was removed to expose muscle fiber orientation. A 5-cm length portion was removed from the lateral end of the steak with the use of a sizing box. A double bladed knife was used to remove a 1-cm thick sample parallel to the muscle fiber orientation from the 5-cm piece from the lateral end at a 45° angle. The sample was then sheared using a shearing machine (Model GR-150, G-R Manufacturing Co., Manhattan, KS) and a basic force gauge (BFG500N, Mecmesin Ltd., West Sussex, UK) which was attached to a slice shear force blade to measure peak force (kg) required to shear through the warm slice.

Pressed Juice Percentage

The PJP protocol used was developed and described by Woolley (2014). In short, after SSF sample removal, a 1-cm thick by steak-width slice was removed using a double-bladed knife immediately medial to SSF sample removal (Figure 2.1). Three 1-cm width pieces were removed parallel to the muscle fiber orientation from the slice. Each sample was weighed on 2 pieces of filter paper (VWR Filter Paper 415, 12.5 cm, VWR International, Radnor, PA) and compressed for 30 s at 8 kg of pressure using an INSTRON Model 5569 testing machine (Instron, Canton, MA). After sample compression, samples were discarded and filter paper was re-weighed. The PJP was calculated as the percentage of moisture lost during compression of the sample: PJP = (moisture loss / initial sample weight) × 100. A single PJP was calculated for each steak by averaging the three values.

Warner-Bratzler Shear Force

After PJP and SSF sample removal, steaks were cooled for 12 hours at 2 – 4°C prior to Warner-Bratzler shear force (WBSF) analysis. Six cores (1.27-cm diameter) were removed parallel to muscle fiber orientation. Cores were sheared once, perpendicular to muscle fibers using an INSTRON Model 5569 testing machine (Instron, Canton, MA) with a WBSF blade attached. Values were reported as peak kg of force required to shear through the core. Values were averaged across all cores from a single steak.

Proximate Analysis

All exterior fat and accessory muscles (*Multifidus dorsi* and *Gluteus medius*) were removed from the *Longissimus dorsi* of each sample for proximate analysis. Samples were submerged in liquid nitrogen and homogenized using a commercial 4 blade blender (Model 33BL 79, Waring Products, New Hartford, CT). Powdered samples were then placed in Whirl-Pac (Nasco, Ft. Atkinson, WI) bags and stored (-20°C) until further analysis. The procedures followed for lipid extraction are described by Martin et al. (2013). Moisture content was determined using the AOAC approved oven drying method (AOAC, 2005). Nitrogen content was determined using combustion method (TruMac N Nitrogen/Protein determination Instruction manual, 2014, Leco Corp., St. Joseph, MI) and multiplied by 6.25 to determine protein content. A muffle furnace was used to determine percent ash following the AOAC ash oven method (AOAC, 2005).

Statistical Analysis

SAS (Version 9.4; SAS Inst. Inc., Cary, NC) was used for statistical analyses. Comparisons among treatment means were evaluated for significance using PROC GLIMMIX with $\alpha = 0.05$. All sensory panel and objective data were analyzed as a split-plot arrangement of factors. The model included the whole-plot factor of quality treatment and the sub-plot factors of DOD and the quality treatment × DOD interaction. For sensory data, panel session number was included as a random effect. Consumer acceptability data was analyzed with a model that included a binomial error distribution. All carcass, color, pH, and proximate data were analyzed with a model that included the fixed effect of quality treatment. For all analyses, the Kenward – Roger approximation was utilized for estimation of denominator degrees of freedom and the PDIFF option was used to separate treatment means when the F-test on the overall effect was significant ($P < 0.05$). The quality treatment × DOD interaction was non-significant ($P > 0.05$) for all dependent variables, unless otherwise denoted.

Results

Carcass Data

Carcass traits for product selected for this study are presented in Table 2.1. All strip loins were from "A" maturity cattle, with no differences ($P > 0.05$) found among all treatments for lean, skeletal, or overall maturity scores. As was expected, marbling level differed ($P < 0.05$) among quality grades (Prime > Low Choice > Low Select). Additionally, no difference ($P > 0.05$) in marbling score was found between strip loins of the same quality grades in enhanced and non-enhanced treatment groups. Prime carcasses were fatter ($P < 0.05$) than all lower grading samples, with only Low Choice carcasses from the enhanced treatment having a similar ($P > 0.05$) amount of preliminary and adjusted fat. Moreover, Prime carcasses were heavier ($P < 0.05$) than Low Choice and Low Select carcasses, with no difference ($P > 0.05$) between the latter two. As a consequence of the increased fat cover and carcass weight, Prime carcasses had a higher ($P < 0.05$) numeric yield grade than Low Choice and Low Select carcasses, with only Low Choice carcasses in the enhanced treatment having a similar ($P > 0.05$) yield grade as Prime carcasses.

Consumer Demographics and Purchasing Motivators

The demographic profile of the 252 consumers who participated in the consumer sensory analysis are presented in Table 2.2. Participants were primarily Caucasian/White (87.76%) from a household size of at least three people (61.69%), and at least 30 years of age (45.13%). The number of males (60%) was greater than females (40%), with close to half (47.58%) of participants married. Most consumers (47.11%) had completed some college/technical school or were college graduates (22.31%). Within the group of participants, 51.21% consumed beef at least 4 times a week and 65.87% reported their preferred degree of doneness to be medium-rare or medium. Also, beef was chosen as the product preferred for flavor by a large majority (70.56%) of consumers, more than eight times higher than chicken (8.06%), or pork (7.26%). When asked what palatability trait was most important when eating beef, flavor was chosen by nearly half (49.90%) of the consumers, followed by tenderness (36.55%), and juiciness (14.06%).

Consumer panelists rated a list of 15 different beef purchasing motivators in terms of importance when purchasing beef at retail (Table 2.3). Traits identified as “steak color”, “price”, “size, weight, and thickness”, and “USDA grade” were found to be the most important ($P < 0.05$)

to consumers. Additionally, “marbling level” and “familiarity with cut” were rated more important ($P < 0.05$) than “nutrient content”, “country of origin”, and all animal production claims. “Natural or Organic claims” was rated less important ($P < 0.05$) than all other traits evaluated, except “brand of the product” and “packaging type”.

Consumer Sensory Evaluation

Table 2.4 contains least squares means of consumer ratings of palatability traits. In non-enhanced samples, Prime and Low Choice were similar ($P > 0.05$) for all palatability traits and higher ($P < 0.05$) for juiciness and tenderness than Low Select samples. Moreover, non-enhanced Low Choice samples were similar ($P > 0.05$) to non-enhanced Low Select samples for flavor and overall liking. All enhanced treatments, regardless of quality grade, were similar ($P > 0.05$) for all palatability traits evaluated. Additionally, enhanced treatments had greater ($P < 0.05$) ratings of juiciness, tenderness, flavor liking, and overall liking than all non-enhanced treatments.

A higher ($P < 0.05$) percentage of samples from each enhanced treatment were rated acceptable for juiciness, tenderness, flavor liking, and overall liking than all non-enhanced samples, except for non-enhanced Prime samples for juiciness, tenderness, and overall liking (Table 2.5). Additionally, no difference ($P > 0.05$) was found among all enhanced treatments for the percentage of samples rated acceptable for all palatability traits, with each trait having more than 85% of samples rated acceptable. No difference ($P > 0.05$) was found between non-enhanced Prime and Low Choice samples for the percentage rated acceptable for all palatability traits. Additionally, non-enhanced Low Select samples were rated unacceptable overall more ($P < 0.05$) than all other treatments for each palatability trait, with more than 40% of samples rated unacceptable overall. A smaller ($P < 0.05$) percentage of Prime and Low Choice enhanced samples were classified as unsatisfactory quality and a greater ($P < 0.05$) percentage of enhanced samples were identified as better than everyday quality and premium quality than all non-enhanced treatments (Table 2.6). There was no difference (*P* > 0.05) between non-enhanced Prime and Low Choice samples for the percentage of samples rated unsatisfactory and better than everyday quality. Also, all non-enhanced samples were similar (*P* > 0.05) in the percentage classified as premium quality.

When cooked to Rare and Medium, a smaller (*P* < 0.05) percentage of enhanced samples of each treatment were classified as everyday quality than non-enhanced samples (Table 2.7). Whereas when cooked to Very Well-Done, no difference (*P* > 0.05) among treatments was found for the percentage of samples identified as everyday quality. When evaluating consumer ratings for steaks differing by DOD, juiciness, tenderness, and overall liking scores increased (*P* < 0.05) as DOD decreased (Rare > Medium > Very Well-Done; Table 2.4). Moreover, Rare samples were rated higher (*P* < 0.05) for flavor liking than Medium or Very Well-Done samples. Similar results were found in the percentage of samples rated acceptable for each palatability trait, with a greater (*P* < 0.05) number of samples rated acceptable for juiciness, tenderness, and overall liking as DOD decreased from Very Well-Done to Medium to Rare (Table 2.5). Additionally, more (*P* < 0.05) Rare samples were rated acceptable for flavor liking than Very Well-Done samples. A greater (*P* < 0.05) percentage of Very Well-Done samples were identified as unsatisfactory quality than Medium or Rare samples (Table 2.6). Moreover, a higher (*P* < 0.05) percentage of Rare samples were classified as better than everyday quality than Medium and Very Well-Done samples and a lower (*P* < 0.05) percentage of Very Well-Done samples were rated as premium quality than Rare or Medium samples.

Trained Sensory Panel Evaluation

A quality treatment × DOD interaction was found for initial juiciness ($P < 0.05$; Table 2.7). Regardless of quality treatment, initial juiciness scores increased ($P < 0.05$) as DOD decreased (Rare > Medium > Very Well-Done). Across all three DOD, all enhanced samples were similar ($P > 0.05$) for initial juiciness. Moreover, non-enhanced Prime was similar ($P > 0.05$) to all enhanced treatments when cooked to Rare, but was drier ($P < 0.05$) than enhanced Prime samples at Medium and Very Well-Done degrees of doneness. Within non-enhanced treatments, initial juiciness increased ($P < 0.05$) with increased marbling scores (Prime > Low Choice > Low Select) when cooked to Medium, however Prime was similar ($P > 0.05$) to Low Choice in Rare samples and Low Choice was similar ($P > 0.05$) to Low Select when samples were cooked to Very Well-Done.

Trained panel ratings for all other sensory traits are presented in Table 2.8. Similar to initial juiciness, no difference ($P > 0.05$) was found among all enhanced treatments, regardless of quality grade for sustained juiciness. Non-enhanced Prime samples were similar to enhanced Low Choice and Low Select samples for sustained juiciness, but juicier ($P < 0.05$) than non-enhanced Low Choice and Low Select samples, with non-enhanced Low Choice samples rated juicier ($P < 0.05$) than non-enhanced Low Select samples. When evaluating measures of tenderness, no differences ($P > 0.05$) were found among enhanced treatments for overall and myofibrillar tenderness. Also, non-enhanced Low Select samples were tougher ($P < 0.05$) overall and for myofribrillar tenderness than all other treatments. Little variation in connective tissue amount was found among treatments, with only non-enhanced Low Select samples having a greater ($P < 0.05$) amount of connective tissue than all other treatments.

Beef flavor intensity increased ($P < 0.05$) with increased marbling level in non-enhanced samples. Additionally, both enhanced and non-enhanced Prime samples had a more ($P < 0.05$)

intense beef flavor than all other treatments. Moreover, beef identity scores also increased (*P* < 0.05) with marbling level in non-enhanced samples. As was expected, all enhanced treatments had a greater (*P* < 0.05) salt intensity than all non-enhanced treatments, with close to no salt flavor (< 0.14 units) observed in the non-enhanced samples. Despite all enhanced products having a similar salt content, the salt flavor intensity rating decreased (*P* < 0.05) as the quality grade increased. Differences were observed among treatments for off-flavor presence, however only a low amount (< 6 units) of off-flavor was observed within any treatment group.

When comparing different degrees of doneness, initial juiciness, sustained juiciness, myofibrillar tenderness, and overall tenderness all decreased (*P* < 0.05) as DOD increased (Rare > Medium > Very Well-Done). No difference (*P* > 0.05) was found among DOD for connective tissue amount, beef intensity, or off-flavor intensity scores. However, Very Well-Done samples were rated higher (*P* < 0.05) for beef flavor identity than Rare and Medium samples.

Proximate Composition and Objective Measures

Instrumental color readings, pH values, and percentages of chemical moisture, protein, fat, and ash are presented in Table 2.9. Enhanced treatments were all similar (*P* > 0.05) for pH and had a higher (*P* < 0.05) pH than all non-enhanced treatments. Moreover, fat percentage increased (*P* < 0.05) with increased USDA quality grade in both enhanced and non-enhanced treatments. Moisture content was inversely related (*P* < 0.01) to fat percentage (r = -0.75). Consequently, Prime samples had the lowest (*P* < 0.05) moisture content in both enhanced and non-enhanced treatment groups. It is noteworthy that enhancement resulted in only numerical increases in moisture content for samples from each quality grade, however no statistical differences (*P* > 0.05) were found between enhanced and non-enhanced samples of the same quality grade. Instrumental color readings indicated L* values increased (*P* < 0.05) as quality grade increased in the enhanced and non-enhanced samples (Table 2.9). The L* values of the non-enhanced Low Choice and Low Select samples were higher ($P < 0.05$) than their enhanced counterparts, and no differences ($P > 0.05$) were found for a* and b* values among non-enhanced treatments. Enhanced and non-enhanced Prime samples were similar ($P > 0.05$) for both a* and b* values and Low Choice samples only had lower ($P < 0.05$) b* values as a result of enhancement.

Table 2.10 contains results from objective juiciness and tenderness measurements. Objective measures of tenderness (WBSF and SSF) showed similar results, with non-enhanced Low Select samples determined to be the toughest ($P < 0.05$) of all treatment groups and non-enhanced Prime and Low Choice to be similar ($P > 0.05$) for tenderness. However, WBSF indicated non-enhanced Low Choice samples were tougher ($P < 0.05$) than all enhanced treatments. Conversely, SSF indicated a similar ($P > 0.05$) tenderness among all enhanced treatments and non-enhanced Prime and Low Choice samples. These findings may be attributed to the high level of tenderness (all < 121.90 N) found among these treatments, likely due in part to the 21 d age period used in the current study. No difference ($P > 0.05$) in SSF value was found among DOD treatments. Additionally, WBSF was similar ($P > 0.05$) between Medium and Very Well-Done samples, with Rare samples being more tender ($P < 0.05$) than either.

The percentages of cooking loss, thaw loss, and total (initial weight – cooked weight) loss for steaks used for consumer and trained panels are reported in Table 2.10. The percentage of cooking loss was lower ($P < 0.05$) for all enhanced treatments when compared to non-enhanced treatments. Percentages of thaw loss decreased ($P < 0.05$) for non-enhanced consumer steaks as quality grade increased. Overall, percentages of thaw loss tended to be lower for enhanced treatments when compared to non-enhanced treatments. When comparing steaks cooked to different DOD, it is not surprising that the amount of cooking loss increased (*P* < 0.05) as DOD increased from Rare to Very Well-Done. Rare samples had close to half the amount of weight lost as a result of cooking compared to Very Well-Done steaks in the current study. The total loss and cooking loss for enhanced treatments were found similar (*P* > 0.05) and lower (*P* < 0.05) than the non-enhanced treatments for trained and consumer panel steaks.

Relationships Among Sensory Traits

Relationships among sensory traits were determined by Pearson correlation coefficients (Table 2.11). Consumer overall liking was highly correlated (*P* < 0.01) to consumer tenderness rating (r = 0.76), juiciness rating (r = 0.72) and flavor liking (r = 0.90). Also, consumer juiciness scores were highly correlated (*P* < 0.01) with the percentage of weight lost during thawing (r = -0.29), cooking (r = -0.76), and overall (r = -0.79). The percentage of cook loss for consumer steaks was highly associated (*P* < 0.01) with total loss (r = 0.97). Additionally, consumer juiciness scores were associated (*P* < 0.01) with trained panel traits of initial juiciness (r = 0.75) and sustained juiciness (r = 0.75). Trained panel initial and sustained juiciness scores were related (*P* < 0.05) to the percentage of cooking loss (r = -0.88) and total weight loss (r = -0.87). Moreover, consumer tenderness scores were associated (*P* < 0.01) with trained panel myofibrillar tenderness (r = 0.67) and overall tenderness (r = 0.67) scores. Mechanical tenderness WBSF values were also closely associated (*P* < 0.01) with consumer tenderness scores (r = -0.55) and trained myofibrillar tenderness (r = -0.74) and overall tenderness (r = -0.75). Scores of SSF were also correlated (*P* < 0.01) with consumer tenderness scores (r = -0.40) and scores of trained panel myofibrillar tenderness (r = -0.57) and overall tenderness (r = -0.61).

In our study, PJP was correlated (*P* < 0.01) with consumer juiciness scores (r = 0.55), trained panel initial juiciness scores (r = 0.59), and trained panel sustained juiciness scores (r =

0.57). Values of WBSF and SSF were correlated to consumer tenderness rating (r = -0.55; -0.40;*P* < 0.01). Additionally, SSF was correlated (*P* < 0.01) with myofibrillar tenderness (r = -0.57) and overall tenderness (r = -0.61). Likewise, WBSF was associated (*P* < 0.01) with both myofibrillar tenderness (r = -0.74) and overall tenderness (r = -0.75).

Discussion

Objective Measures

Fat percentages in our study are slightly lower than those reported in previous studies evaluating beef of the same quality grades (Emerson, Woerner, Belk, & Tatum, 2013; Legako et al., 2015; O'Quinn et al., 2012; Savell, Cross, & Smith, 1986). In these studies, the authors used either NIR, ether extraction, or Foltch methodology to quantify fat percentage. In the current study, a modified chloroform/methanol extraction protocol described by Martin et al. (2013) was used for fat quantification. This methodological difference may explain the differences between fat percentages observed in the current study and the values reported by previous authors. However, the results of the current study are consistent with authors who have used CEM to quantify the fat percentage of beef of different quality grades (Dow, Wiegand, Ellersieck, & Lorenzen, 2011) and show a similar increase in fat percentage and the same relative differences among quality grades for fat percentage as in previous reports.

Studies by Pietrasik and Janz (2009) enhanced steaks to either 112 or 125% and Baublits, Pohlman, Brown Jr, Yancey, and Johnson (2006) enhanced steaks to 112%, and reported enhanced steaks had between 2.97 to 3.30% increase in moisture percentage from control. However, in the current study steaks were enhanced to 108% and no such increase in moisture percentage was observed. Similar to our results, Stetzer, Tucker, McKeith, and Brewer (2008) and Smith, Simmons, McKeith, Bechtel, and Brady (1984) reported no difference in enhanced and non-enhanced steaks moisture content when steaks were enhanced to 108% and 110%, respectively. Additionally, Woolley (2014) reported Select steaks enhanced to 107% did not differ in moisture content from non-enhanced Select steaks; however, Select steaks enhanced to 112% had a 2.77% increased moisture percentage compared to non-enhanced Select steaks in that study. Collectively these studies indicate for differences to be detected among percent chemical moisture of raw samples, enhanced treatments require greater than a 10% pump level.

Increased muscle pH as a result of alkaline phosphate enhancement have been previously observed by authors, with increases in pH of 2.90%, 2.10%, and 7.50% previously reported by Robbins et al. (2003b), Baublits et al. (2006), and Wicklund et al. (2005), respectively. Our study reported pH increases of 2.90% to 3.41% for enhanced treatments. Additionally, Robbins et al. (2003b) found when enhancing beef strip loins with a solution similar to the current study (water, salt, and alkaline phosphates) L* readings of enhanced strip loins were darker (3.91 – 7.93% lower) than non-enhanced control samples. Robbins et al. (2003b) also reported enhanced treatments had 9.09 – 14.38% and 5.69 – 11.19% lower a* and b* values, respectively, than non-enhanced counterparts. Similarly, Wicklund et al. (2005) reported enhanced steaks had lower values of L* by 9.89%, a* by 9.67%, and b* by 17.41% than the control treatment. The current study reported comparable results to previous research, as the enhanced treatments had a 5.43 – 8.18% decrease for L* value. Also, decreases of 6.99% in a* values for enhanced Low Select, and 9.56 – 10.69% decrease in b* values for enhanced Low Choice and Low Select were observed when compared to the non-enhanced treatments. Collectively, these studies indicate enhancement with salt and alkaline phosphate solutions result in darker lean color with lower a* and b* values. This is important as color has been reported as the most influential factor affecting consumer decision within the marketplace and consumers prefer a steak that is a bright cherry-red colored than dark or dull red colored steak (Mancini & Hunt, 2005). Robbins et al. (2002), Stetzer et al. (2008), and Wicklund et al. (2005) used trained panelists to evaluate visual color and found results similar to the instrumental color scores reported in the current and previous studies. Though, to date, no studies have evaluated consumer acceptance of the color of enhanced beef.

Degree of Doneness

Cox et al. (1997) determined when consumers were served a different DOD than what was ordered at a restaurant, consumer palatability scores decreased, which demonstrated the large role DOD plays in the consumer eating experience. Additionally, Gomes, Pflanzer, Cruz, de Felício, and Bolini (2014) reported consumers found the appearance of steaks cooked to higher DOD to result in decreased ratings of apparent juiciness and internal red color. Multiple studies have prescreened consumers and fed only a single, preferred DOD (O'Quinn et al., 2015; Woolley, O'Quinn, Legako, Brooks, & Miller, 2015); however, this often limits the ability to make meaningful comparisons and conclusions across different DOD within the same study. Moreover, other authors have had consumers evaluate steaks of differing DOD under white lighting (Gomes et al., 2014; Lorenzen et al., 2005) though this is not recommended (AMSA, 2015) due to the inherent consumer bias due to DOD preference described by Cox et al. (1997). In our study, similar to Cross et al. (1976) and Parrish et al. (1973), panelists evaluated samples from multiple DOD under red lighting to mask the DOD appearance differences among samples. This was done in order to allow for consumers to evaluate samples of varying DOD without an inherent bias due to product appearance. Our study reports Rare was rated the most juicy, tender, flavorful, and the highest liked by consumers, whereas Rare was only the preferred DOD by

4.42% of consumers. Therefore, minimal consumer bias was observed for the DOD. The greatest preferred DOD reported by consumers was Medium-Rare at 39.63%. Gomes, Pflanzer, Cruz, de Felício, and Bolini (2014) reported the appearance of the samples biased consumers as they were asked to rate the internal red and brown color prior to sensory evaluation. Savell et al. (1999) reported a decrease in panel ratings of tenderness, juiciness, and overall liking as DOD increased; however, results were less drastic than results reported in the current study. Many studies have reported as DOD increases, palatability ratings of juiciness and tenderness decrease (Cross et al., 1976; Gomes et al., 2014; Lorenzen et al., 2005; O'Quinn et al., 2015; Parrish et al., 1973). Lorenzen et al. (2005) cooked steaks to a range of DOD (55, 60, 63, 71, 77 and 82°C) and reported a 58.46% and 70.59% increase in tenderness and juiciness respectively as DOD decreased. Similarly, a wide range of DOD (60, 70, 80 and 90°C) were evaluated and as internal temperature increased from 60°C to 90°C, ratings of tenderness and juiciness decreased 27.27% and 69.66%, respectively (Cross et al., 1976). Parrish et al. (1973) reported as temperature increased from 60°C to 80°C the ratings of tenderness and juiciness decreased by 20.10% and 33.65%. O'Quinn et al. (2015) cooked steaks to three internal temperatures (55, 63 and 77°C) and determined a 2.45% and 3.68% increase in tenderness and juiciness as DOD decreased. Woolley (2014) also determined juiciness ratings decreased 16.38% when internal temperature increased from 60°C to 77°C. The current study shows an increase similar to previous research as internal temperature increased from 60°C to 82°C tenderness and juiciness decreased 22.51% and 36.55% respectively.

Moreover, the importance of end-point cooking temperature and resulting dehydration of samples due to cooking loss at elevated DOD on beef tenderness is evident. Many authors have reported as DOD increases, WBSF values also increase (Gomes et al., 2014; Lorenzen et al., 2005; Luchak et al., 1998). It is also well documented that as internal temperature increases, so does the percentage of cooking loss (Lorenzen et al., 2005; Luchak et al., 1998; Parrish et al., 1973). Our results mimic those of previous studies as it was reported as the percentage of cook loss and total loss are found to increase as DOD increased. However, tenderness differences were seen as the Rare samples had the lowest WBSF values but Medium and Very-Well Done were found similar, and no differences among DOD were seen for SSF. Therefore, the higher end point temperature, the higher the percentage of cooking loss and the concurrent negative effects on beef tenderness and juiciness.

Quality Treatment

Previous studies evaluating enhancement have focused on either lower quality muscles or enhancing lower quality grades such as USDA Select. Prior research has found that enhancement increased consumer sensory scores for tenderness, juiciness, flavor liking, and overall liking of USDA Select beef (Brooks et al., 2010; Igo et al., 2015; Miller et al., 1995; Woolley, 2014). The current study agrees with theses previous findings for the Low Select enhanced treatment. Previous studies reported enhancement of steaks resulted in a 11.54% – 35.50% increase of tenderness (Brooks et al., 2010; Igo et al., 2015; Woolley, 2014), and the current study found a 30.21% increase from non-enhanced Low Select to the enhanced counterpart. Additionally, prior research reported enhanced steaks had an increase of 10.53% – 28.26% in consumer juiciness scores, and the current study reported a 30.60% increase (Brooks et al., 2010; Igo et al., 2015; Woolley, 2014). An increase in flavor liking was also reported for enhanced steaks by 5.00% - 28.36% in previous research (Brooks et al., 2010; Igo et al., 2015; Woolley, 2014), with the current study reporting a 27.98% increase for the Low Select enhanced treatment over the non-enhanced Low Select. The current study also reported a 27.33% increase in overall liking for the enhanced Low Select over the non-enhanced counterpart, with similar increases (10.39% - 33.12%) in overall liking observed in previous studies (Brooks et al., 2010; Igo et al., 2015; Woolley, 2014). However, research has not previously evaluated the enhancement of higher quality cuts. Our study enhanced a range of quality grades, and found that all enhanced treatments preformed similar, regardless of the marbling level. As quality grade increased the percent increase in all palatability traits decreased. Our study reported consumer ratings of tenderness increased for enhanced treatments by 30.21% for Low Select, 16.88% for Low Choice, and 10.61% for Prime. Ratings for juiciness were 30.60%, 19.44%, and 11.92% higher for the enhanced Low Select, Low Choice, and Prime respectively. Flavor liking was rated greater for the enhanced samples by 27.98% for Low Select, 22.06% for Low Choice, and 17.13% for Prime. Also, overall liking was reported to increase with enhancement, with Low Select increasing 27.33%, Low Choice increasing 23.50%, and Prime increasing 17.28%. Therefore, enhancement has a large positive impact on beef palatability; however, improvement potential is not independent of or additive with quality grade. This demonstrates a more limited benefit to enhancing higher quality beef and indicates the most appropriate use of enhancement technology remains in lower quality beef cuts.

Additionally, enhanced beef has been reported as having a greater salt flavor and greater beef flavor than similar non-enhanced beef products (Pietrasik & Janz, 2009; Robbins et al., 2003a). In the current study, trained panelists indicated a significant increase in salt intensity in enhanced samples. However, there was an increase in salt intensity among enhanced samples as the quality grade decreased. This dilution effect is quality grade specific and mirrors that of the chemical fat content observed in the proximate results. As the fat content is shown to increase as quality grade increases regardless of enhancement.

Previous research indicates as quality grade increases, the palatability traits of juiciness, flavor, and tenderness increase for consumer and trained panelists (Acheson, Woerner, & Tatum, 2014; Corbin et al., 2015; Neely et al., 1998). Furthermore, prior research indicates that as quality grade increases the percentage of samples rated acceptable by consumers for all palatability traits also increases (Behrends et al., 2005; Corbin et al., 2015; O'Quinn et al., 2012; Tatum, 2015). In the current study, though differences were found, quality grade did not have as large of an effect as reported in previous studies. The non-enhanced treatments of Prime and Low Choice were rated similarly in all aspects of consumer panel ratings. In the current study, the range of palatability traits in samples consumers evaluated was large. Both enhanced and non-enhanced samples of the three quality grades cooked to multiple DOD were served during the same panel sessions. It is possible that DOD and enhancement effects had a greater influence on consumer eating quality than quality grade in the current study, allowing for fewer differences among quality grades to be found than in previous reports that evaluated samples within the same degree of doneness and did not include enhanced samples.

Within the current study it is important to note that with consumer data, no difference was found in palatability rating, acceptability, or perceived quality level among the enhanced treatments, regardless of quality grade. Additionally, the enhanced treatments were all similar in acceptability to the non-enhanced Prime treatment. Therefore, eating a Low Select enhanced steak would yield the same eating experience as a Prime steak. However, there is currently a $1.84 per pound premium for Prime strip loins over Select (USDA, 2015a, 2015b). Therefore, a similar eating experience is attained without the premium money required for the higher quality grade. Additionally, it is notable that in the current study, enhancing the high quality graded cuts did not result in increased eating quality. This indicates enhancement does not provide an additive effect with quality level for beef palatability. It appears that enhancement improves the palatability of strip loins to a constant level, regardless of product initial quality grade or palatability level. These results give clear evidence that enhancement of higher grading beef (Choice and Prime) is not advantageous to producers, as no added benefit is gained when compared to enhancement of lower grading beef. However, these results also indicate the large opportunity for beef eating quality improvement of Select beef through the use of enhancement technology.

References

Acheson, R. J., Woerner, D. R., & Tatum, J. D. (2014). Effects of USDA carcass maturity on sensory attributes of beef produced by grain-finished steers and heifers classified as less than 30 months old using dentition. *Journal of Animal Science, 92*(4), 1792-1799.

Adhikari, K., Chambers Iv, E., Miller, R., Vazquez-Araujo, L., Bhumiratana, N., & Philip, C. (2011). Development of a lexicon for beef flavor in intact muscle. *Journal of Sensory Studies, 26*(6), 413-420.

AMSA. (2015). *Research guidelines for cookery, sensory evaluation, and intrumental tenderness measurements of meat* (2 ed.). Champaign, IL: American Meat Science Association.

AOAC. (2005). *Official Methods of Analysis* (18th ed.). Arlington, VA: Assoc. Off. Anal. Chem.

Baublits, R. T., Pohlman, F. W., Brown Jr, A. H., Yancey, E. J., & Johnson, Z. B. (2006). Impact of muscle type and sodium chloride concentration on the quality, sensory, and instrumental color characteristics of solution enhanced whole-muscle beef. *Meat Science, 72*(4), 704-712.

Behrends, J. M., Goodson, K. J., Koohmaraie, M., Shackelford, S. D., Wheeler, T. L., Morgan, W. W., Reagan, J. O., Gwartney, B. L., Wise, J. W., & Savell, J. W. (2005). Beef customer satisfaction: USDA quality grade and marination effects on consumer evaluations of top round steaks. *Journal of Animal Science, 83*(3), 662-670.

Brooks, J. C., Mehaffey, J. M., Collins, J. A., Rogers, H. R., Legako, J., Johnson, B. J., Lawrence, T., Allen, D. M., Streeter, M. N., Nichols, W. T., Hutcheson, J. P., Yates, D. A., & Miller, M. F. (2010). Moisture enhancement and blade tenderization effects on the shear force and palatability of strip loin steaks from beef cattle fed zilpaterol hydrochloride. *Journal of Animal Science, 88*(5), 1809-1816.

Carr, M. A., Crockett, K. L., Ramsey, C. B., & Miller, M. F. (2004). Consumer acceptance of calcium chloride-marinated top loin steaks. *Journal of Animal Science, 82*(5), 1471-1474.

Corbin, C. H., O'Quinn, T. G., Garmyn, A. J., Legako, J. F., Hunt, M. R., Dinh, T. T. N., Rathmann, R. J., Brooks, J. C., & Miller, M. F. (2015). Sensory evaluation of tender beef strip loin steaks of varying marbling levels and quality treatments. *Meat Science, 100*(0), 24-31.

Cox, R. J., Thompson, J. M., Cunial, C. M., Winter, S., & Gordon, A. J. (1997). The effect of degree of doneness of beef steaks on consumer acceptability of meals in restaurants. *Meat Science, 45*(1), 75-85.

Cross, H. R., Stanfield, M. S., & Koch, E. J. (1976). Beef palatability as affected by cooking rate and final Internal temperature. *Journal of Animal Science, 43*(1), 114-121.

Dow, D. L., Wiegand, B. R., Ellersieck, M. R., & Lorenzen, C. L. (2011). Prediction of fat percentage within marbling score on beef longissimus muscle using 3 different fat determination methods. *Journal of Animal Science, 89*(4), 1173-1179.

Emerson, M. R., Woerner, D. R., Belk, K. E., & Tatum, J. D. (2013). Effectiveness of USDA instrument-based marbling measurements for categorizing beef carcasses according to differences in longissimus muscle sensory attributes. *Journal of Animal Science, 91*(2), 1024-1034.

Gomes, C. L., Pflanzer, S. B., Cruz, A. G., de Felício, P. E., & Bolini, H. M. A. (2014). Sensory descriptive profiling and consumer preferences of beef strip loin steaks. *Food Research International, 59*, 76-84.

Hunt, M. R., Garmyn, A. J., O'Quinn, T. G., Corbin, C. H., Legako, J. F., Rathmann, R. J., Brooks, J. C., & Miller, M. F. (2014). Consumer assessment of beef palatability from four beef muscles from USDA Choice and Select graded carcasses. *Meat Science, 98*(1), 1-8.

Igo, M. W., Arnold, A. N., Miller, R. K., Gehring, K. B., Mehall, L. N., Lorenzen, C. L., Delmore, R. J., Woerner, D. R., Wasser, B. E., & Savell, J. W. (2015). Tenderness assessments of top loin steaks from retail markets in four U.S. cities. *Journal of Animal Science, 93*(10), 4610-4616.

Kerth, C. R., Miller, M. F., & Ramsey, C. B. (1995). Improvement of beef tenderness and quality traits with calcium chloride injection in beef loins 48 hours postmortem. *Journal of Animal Science, 73*(3), 750-756.

Killinger, K. M., Calkins, C. R., Umberger, W. J., Feuz, D. M., & Eskridge, K. M. (2004). Consumer sensory acceptance and value for beef steaks of similar tenderness, but differing in marbling level. *Journal of Animal Science, 82*(11), 3294-3301.

Kim, Y. H., Hunt, M. C., Mancini, R. A., Seyfert, M., Loughin, T. M., Kropf, D. H., & Smith, J. S. (2006). Mechanism for Lactate-Color Stabilization in Injection-Enhanced Beef. *Journal of Agricultural and Food Chemistry, 54*(20), 7856-7862.

Legako, J. F., Brooks, J. C., O'Quinn, T. G., Hagan, T. D. J., Polkinghorne, R., Farmer, L. J., & Miller, M. F. (2015). Consumer palatability scores and volatile beef flavor compounds of five USDA quality grades and four muscles. *Meat Science, 100*(0), 291-300.

Lorenzen, C. L., Davuluri, V. K., Adhikari, K., & Grün, I. U. (2005). Effect of End-point Temperature and Degree of Doneness on Sensory and Instrumental Flavor Profile of Beefsteaks. *Journal of Food Science, 70*(2), S113-S118.

Luchak, G. L., Miller, R. K., Belk, K. E., Hale, D. S., Michaelsen, S. A., Johnson, D. D., West, R. L., Leak, F. W., Cross, H. R., & Savell, J. W. (1998). Determination of sensory, chemical and cooking characteristics of retail beef cuts differing in intramuscular and external fat. *Meat Science, 50*(1), 55-72.

Mancini, R. A., & Hunt, M. C. (2005). Current research in meat color. *Meat Science*, 71(1), 100-121.

Martin, J. N., Brooks, J. C., Thompson, L. D., Savell, J. W., Harris, K. B., May, L. L., Haneklaus, A. N., Schutz, J. L., Belk, K. E., Engle, T., Woerner, D. R., Legako, J. F., Luna, A. M., Douglass, L. W., Douglass, S. E., Howe, J., Duvall, M., Patterson, K. Y., & Leheska, J. L. (2013). Nutrient database improvement project: The influence of U.S.D.A. Quality and Yield Grade on the separable components and proximate composition of raw and cooked retail cuts from the beef rib and plate. *Meat Science, 95*(3), 486-494.

McKenna, D. R., Lorenzen, C. L., Pollok, K. D., Morgan, W. W., Mies, W. L., Harris, J. J., Murphy, R., McAdams, M., Hale, D. S., & Savell, J. W. (2004). Interrelationships of breed type, USDA quality grade, cooking method, and degree of doneness on consumer evaluations of beef in Dallas and San Antonio, Texas, USA. *Meat Science, 66*(2), 399-406.

Miller, M. F., Huffman, K. L., Gilbert, S. Y., Hamman, L. L., & Ramsey, C. B. (1995). Retail consumer acceptance of beef tenderized with calcium chloride. *Journal of Animal Science, 73*(8), 2308-2314.

Neely, T. R., Lorenzen, C. L., Miller, R. K., Tatum, J. D., Wise, J. W., Taylor, J. F., Buyck, M. J., Reagan, J. O., & Savell, J. W. (1998). Beef customer satisfaction: role of cut, USDA quality grade, and city on in-home consumer ratings. *Journal of Animal Science, 76*(4), 1027-1033.

O'Quinn, T. G. (2012). *Identifying preferences for specific beef flavor characteristics.* Ph.D. Dissertation, Colorado State University, Fort Collins, CO.

O'Quinn, T. G., Brooks, J. C., & Miller, M. F. (2015). Consumer assessment of beef tenderloin steaks from various USDA quality grades at 3 degrees of doneness. *Journal of Food Science, 80*(2), S444-S449.

O'Quinn, T. G., Brooks, J. C., Polkinghorne, R. J., Garmyn, A. J., Johnson, B. J., Starkey, J. D., Rathmann, R. J., & Miller, M. F. (2012). Consumer assessment of beef strip loin steaks of varying fat levels. *Journal of Animal Science, 90*(2), 626-634.

Parrish, F. C., Jr., Olson, D. G., Miner, B. E., & Rust, R. E. (1973). Effect of degree of marbling and internal temperature of doneness on beef rib steaks. *Journal of Animal Science, 37*(2), 430-434.

Pietrasik, Z., & Janz, J. (2009). Influence of freezing and thawing on the hydration characteristics, quality, and consumer acceptance of whole muscle beef injected with solutions of salt and phosphate. *Meat Science, 81*(3), 523-532.

Robbins, K., Jensen, J., Ryan, K., HOMCO-RYAN, C., McKeith, F., & Brewer, M. (2002). Enhancement effects on sensory and retail display characteristics of beef rounds. *Journal of Muscle Foods, 13*(4), 279-288.

Robbins, K., Jensen, J., Ryan, K. J., Homco-Ryan, C., McKeith, F. K., & Brewer, M. S. (2003a). Consumer attitudes towards beef and acceptability of enhanced beef. *Meat Science, 65*(2), 721-729.

Robbins, K., Jensen, J., Ryan, K. J., Homco-Ryan, C., McKeith, F. K., & Brewer, M. S. (2003b). Dietary vitamin E supplementation effects on the color and sensory characteristics of enhanced beef steaks. *Meat Science, 64*(3), 279-285.

Savell, J. W., Cross, H. R., & Smith, G. C. (1986). Percentage ether extractable fat and moisture content of beef longissimus muscle as related to USDA marbling score. *Journal of Food Science, 51*(3), 838-839.

Savell, J. W., Lorenzen, C. L., Neely, T. R., Miller, R. K., Tatum, J. D., Wise, J. W., Taylor, J. F., Buyck, M. J., & Reagan, J. O. (1999). Beef customer satisfaction: cooking method and degree of doneness effects on the top sirloin steak. *Journal of Animal Science, 77*(3), 645-652.

Shackelford, S. D., Wheeler, T. L., & Koohmaraie, M. (1999). Tenderness classification of beef: II. Design and analysis of a system to measure beef longissimus shear force under commercial processing conditions. *Journal of Animal Science, 77*(6), 1474-1481.

Tatum, J. D. (2015). Recent trends: beef quality, value and price.

USDA. (2015a). National daily boxed beef cutout and boxed beef cuts. Des Moines, IA USDA Market News.

USDA. (2015b). National weekly boxed beef cuts for prime product. Des Moines, IA.

Wheeler, T. L., Shackelford, S. D., & Koohmaraie, M. (1999). Tenderness classification of beef: III. Effect of the interaction between end point temperature and tenderness on Warner-Bratzler shear force of beef longissimus. *Journal of Animal Science, 77*(2), 400-407.

Wicklund, S. E., Homco-Ryan, C., Ryan, K. J., Mckeith, F. K., Mcfarlane, B. J., & Brewer, M. S. (2005). Aging and enhancement effects on quality characteristics of beef strip steaks. *Journal of Food Science, 70*(3), S242-S248.

Woolley, L. D. (2014). *Evaluation of objective beef juiciness measurement techniques and their elationships to subjective taste panel juiciness ratings.* Master's Thesis, Texas Tech University, Lubbock, TX.

Table 2.1 Least squares means for beef grading measures of carcasses of varying fat level and quality treatments.

Treatment	Lean Maturity[1]	Skeletal Maturity[1]	Overall Maturity[1]	USDA Marbling Score[2]	Preliminary Fat Thickness, cm.	Adjusted Fat Thickness, cm.	Ribeye Area, cm^2	Hot Carcass Weight, kg	Kidney, Pelvic, Heart Fat, %	Yield Grade
Non-Enhanced										
Prime	160.83	165.00	161.67	779.17[a]	1.52[ab]	1.70[a]	87.42[a]	407.74[a]	2.46	3.75[a]
Low Choice	164.17	164.17	165.00	446.67[b]	1.02[c]	1.17[b]	79.48[b]	330.44[b]	2.67	3.03[bc]
Low Select	170.83	170.83	170.83	319.17[c]	0.81[c]	0.99[b]	82.39[ab]	343.82[b]	2.38	2.78[c]
Enhanced[3]										
Prime	168.33	158.33	163.33	763.33[a]	1.85[a]	2.03[a]	85.94[a]	391.87[a]	3.04	4.14[a]
Low Choice	165.00	165.83	166.67	447.50[b]	1.40[b]	1.63[a]	78.26[b]	334.60[b]	2.79	3.57[ab]
Low Select	166.67	170.83	168.33	323.33[c]	0.84[c]	1.02[b]	86.64[a]	352.18[b]	2.42	2.66[c]
SEM[4]	3.02	5.32	3.70	11.30	0.05	0.06	0.28	24.97	0.17	0.20
P – value	0.2645	0.5714	0.5406	< 0.0001	< 0.0001	< 0.0001	0.0011	< 0.0001	0.0560	< 0.0001

[1]100: A; 200: B; 300: C; 400: D; 500: E.

[2]200: Traces; 300: Slight; 400: Small; 500: Modest; 600: Moderate; 700: Slightly Abundant.

[3]Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

[4]SE (largest) of the least squares means.

[abc]Least squares means in the same column without a common superscript differ ($P < 0.05$).

Table 2.2 Demographic characteristics of consumers (n = 252) who participated in consumer sensory panels.

Characteristic	Response	Percentage of Consumers
Gender	Male	60.00
	Female	40.00
Household size	1 person	12.90
	2 people	25.40
	3 people	14.92
	4 people	25.40
	5 people	10.48
	6 people	5.24
	>6 people	5.65
Marital status	Single	52.42
	Married	47.58
Age	Under 20	10.57
	20-29	44.31
	30-39	15.04
	40-49	14.23
	50-59	9.76
	Over 60	6.10
Ethnic origin	African-American	3.27
	Asian	3.67
	Caucasian/White	87.76
	Hispanic	2.86
	Native American	0.41
	Other	2.04
Annual household income	Under $25,000	5.28
	$25,000 - $34,999	6.50
	$35,000 - $49,999	12.20
	$50,000 - $74,999	28.86
	$75,000 - $100,000	26.42
	>$100,000	20.73
Education level	Non-high school graduate	1.65
	High school graduate	9.50
	Some college/Technical school	47.11
	College graduate	22.31
	Post graduate	19.42
Weekly beef consumption	1 to 3 times	48.79
	4 to 6 times	46.37
	7 or more times	4.84
Most important palatability trait when eating beef	Flavor	49.40
	Juiciness	14.06
	Tenderness	36.55
Degree of doneness preferred	Very Rare	1.61
	Rare	4.42
	Medium-Rare	39.36
	Medium	26.51
	Medium-Well	21.69
	Well-Done	5.22
	Very Well-Done	1.20
Meat product preferred for flavor	Beef	70.56
	Chicken	8.06
	Fish	2.82
	Lamb	4.84
	Mutton	0.81
	Pork	7.26
	Shellfish	2.02
	Turkey	0.40
	Veal	1.61
	Venison	1.61

Table 2.3 Fresh beef strip loin steak purchasing motivators[1] of consumers (n = 252) who participated in consumer sensory panels.

Trait	Importance
Steak Color	70.57[a]
Price	70.06[a]
Size, weight, and thickness	69.29[a]
USDA Grade	67.69[a]
Marbling level	63.03[b]
Familiarity with cut	59.90[b]
Nutrient content	54.19[c]
Eating satisfaction claims (Guaranteed Tender)	53.49[c]
Country of origin	49.84[c]
Animal Welfare	44.96[d]
Growth promotant use	43.02[de]
Antibiotic use in the animal	42.33[de]
Packaging type	40.65[def]
Brand of product	39.20[ef]
Natural or Organic claims	37.81[f]
SEM[2]	1.58
P - value	< 0.0001

[1]Purchasing motivators: 0 = extremely unimportant, 100 = extremely important
[2]SE (largest) of the least squares means.

Table 2.4 Least squares means for consumers (n = 252) ratings[1] of the palatability traits for grilled beef strip loin steaks of varying quality treatments and degrees of doneness.

Treatment	Juiciness	Tenderness	Flavor Liking	Overall Liking
Quality Treatment				
Non-Enhanced				
Prime	61.53[b]	63.83[b]	56.02[b]	57.43[b]
Low Choice	57.77[b]	61.06[b]	51.83[bc]	52.74[bc]
Low Select	50.29[c]	49.75[c]	48.65[c]	49.17[c]
Enhanced[2]				
Prime	69.86[a]	71.41[a]	67.60[a]	69.43[a]
Low Choice	71.71[a]	73.46[a]	66.50[a]	68.94[a]
Low Select	72.46[a]	71.29[a]	67.55[a]	67.66[a]
SEM[3]	1.90	2.48	2.00	1.98
P – value[4]	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Degree of Doneness				
Rare (60°C)	77.15[a]	73.11[a]	62.79[a]	65.84[a]
Medium (71°C)	65.72[b]	65.63[b]	58.89[b]	61.36[b]
Very Well Done (82°C)	48.95[c]	56.65[c]	57.39[b]	55.49[c]
SEM[3]	1.45	1.67	1.50	1.44
P – value[5]	< 0.0001	< 0.0001	0.0119	< 0.0001

[1]Sensory scores: 0 mm = extremely dry/tough/dislike extremely; 100 mm = extremely juicy/tender/like extremely; 50 = neither dry nor juicy, neither tough nor tender, neither like nor dislike.

[2] Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

[3] SE (largest) of the least squares means.

[4] *P* – value for main effect Quality Treatment.

[5] *P* – value for main effect Degree of Doneness.

[abc]Least squares means in the same section of the same column without a common superscript differ ($P < 0.05$).

Table 2.5 **Percentage of beef strip loin steaks of varying quality treatments cooked to different degrees of doneness rated as acceptable for palatability traits by consumers (n = 252).**

Treatment	Juiciness	Tenderness	Flavor Liking	Overall Liking
Quality Treatment				
Non-Enhanced				
Prime	85.52[ab]	93.15[ab]	73.81[b]	78.37[bc]
Low Choice	79.63[b]	86.59[b]	71.29[b]	74.06[c]
Low Select	63.97[c]	67.49[c]	60.71[c]	58.48[d]
Enhanced[1]				
Prime	93.72[a]	96.24[a]	88.59[a]	89.38[a]
Low Choice	93.92[a]	96.09[a]	85.29[a]	86.61[ab]
Low Select	91.99[a]	93.60[a]	85.69[a]	85.89[ab]
SEM[2]	4.79	4.91	3.77	4.23
P – value[3]	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Degree of Doneness				
Rare (60°C)	96.41[a]	96.49[a]	82.91[a]	86.79[a]
Medium (71°C)	88.04[b]	91.23[b]	78.24[ab]	81.45[b]
Very Well Done (82°C)	62.47[c]	81.92[c]	75.59[b]	70.66[c]
SEM[2]	2.76	2.17	2.19	2.39
P – value[4]	< 0.0001	< 0.0001	0.0303	< 0.0001

[1] Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

[2] SE (largest) of the least squares means.

[3] *P* – value for main effect Quality Treatment.

[4] *P* – value for main effect Degree of Doneness.

[abcd]Least squares means in the same section of the same column without a common superscript differ ($P < 0.05$).

Table 2.6 Percentage of beef strip loin steaks of varying treatments and degrees of doneness identified as different perceived quality levels by consumer panelists (n = 252).

Treatment	Unsatisfactory Quality	Better than Everyday Quality	Premium Quality
Quality Treatment			
Non-Enhanced			
Prime	12.77[b]	25.18[b]	3.22[b]
Low Choice	16.55[ab]	20.50[bc]	4.33[b]
Low Select	26.55[a]	14.64[c]	1.90[b]
Enhanced[1]			
Prime	5.98[c]	39.90[a]	11.76[a]
Low Choice	5.09[c]	34.66[a]	17.79[a]
Low Select	9.17[bc]	35.40[a]	11.75[a]
SEM[2]	4.11	3.18	3.09
P – value[3]	< 0.0001	< 0.0001	< 0.0001
Degree of Doneness			
Rare (60°C)	7.03[c]	35.34[a]	10.65[a]
Medium (71°C)	11.23[b]	25.54[b]	7.41[a]
Very Well Done (82°C)	16.58[a]	22.23[b]	3.39[b]
SEM[2]	2.07	2.22	1.69
P – value[4]	0.0003	< 0.0001	0.0016

[1] Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

[2] SE (largest) of the least squares means.

[3] *P* – value for main effect Quality Treatment.

[4] *P* – value for main effect Degree of Doneness.

[abc]Least squares means in the same section of the same column without a common superscript differ ($P < 0.05$).

Table 2.7 Interaction between degree of doneness and quality treatment for percentage of beef strip loin steaks perceived Everyday Quality (P = 0.0011) by consumers and for the Initial juiciness trait (P = 0.0256) rated[1] by trained sensory panelists.

Treatment	Everyday Quality	Initial Juiciness
Rare (60°C)		
Non-Enhanced		
Prime	53.04^{b}	76.92^{ab}
Low Choice	56.08^{a}	71.09^{b}
Low Select	53.05^{b}	66.43^{c}
Enhanced[2]		
Prime	28.54^{c}	81.92^{a}
Low Choice	23.48^{d}	83.55^{a}
Low Select	28.61^{c}	81.36^{a}
SEM[3]	5.89	2.08
P – value	< 0.0001	< 0.0001
Medium (71°C)		
Non-Enhanced		
Prime	65.30^{a}	60.97^{b}
Low Choice	54.28^{b}	48.66^{c}
Low Select	60.38^{ab}	42.86^{d}
Enhanced[2]		
Prime	43.18^{c}	70.83^{a}
Low Choice	36.79^{d}	66.66^{ab}
Low Select	37.89^{d}	66.43^{ab}
SEM[3]	5.89	2.08
P – value	0.0016	< 0.0001
Very Well Done (82°C)		
Non-Enhanced		
Prime	46.98	43.44^{b}
Low Choice	52.60	24.25^{c}
Low Select	47.58	18.56^{c}
Enhanced[2]		
Prime	46.36	51.21^{a}
Low Choice	56.13	45.70^{ab}
Low Select	53.63	47.05^{ab}
SEM[3]	5.89	2.08
P - value	0.7853	< 0.0001

[1]Sensory Scores: 0 = Extremely dry, 100 = Extremely juicy; 50 = Neither dry nor juicy.

[2]Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

[3]SE (largest) of the least squares means.

[abcd]Least squares means in the same section of the same column without a common superscript differ (P < 0.05).

Table 2.8 Least squares means for trained sensory panel ratings[1] of grilled strip loin steaks of varying quality treatments and degrees of doneness.

Treatment	Sustained Juiciness	Myofibrillar Tenderness	Connective Tissue Amount	Overall Tenderness	Beef Identity	Beef Intensity	Salt Intensity	Off Flavor Intensity
Quality Treatment								
Non-Enhanced								
Prime	51.78[b]	71.57[bc]	13.85[b]	67.29[bc]	63.89[a]	47.48[a]	0.14[d]	5.50[a]
Low Choice	38.45[c]	67.80[c]	12.89[b]	63.63[c]	60.17[b]	39.03[b]	0.00[d]	2.96[bc]
Low Select	32.92[d]	55.04[d]	22.66[a]	47.63[d]	53.74[c]	32.83[c]	0.12[d]	5.84[a]
Enhanced[2]								
Prime	60.30[a]	78.41[a]	9.98[b]	75.60[a]	63.86[a]	50.95[a]	13.36[c]	1.65[c]
Low Choice	56.98[ab]	79.14[a]	9.15[b]	76.88[a]	54.81[c]	41.59[b]	20.62[b]	4.92[ab]
Low Select	55.73[ab]	75.27[ab]	11.20[b]	72.12[ab]	53.83[c]	39.85[b]	26.04[a]	2.46[bc]
SEM[3]	2.04	2.07	1.76	2.51	1.12	1.42	0.94	0.91
P – value[4]	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0032
Degree of Doneness								
Rare (60°C)	68.52[a]	76.88[a]	13.09	72.64[a]	56.77[b]	40.93	11.58[a]	3.54
Medium (71°C)	50.78[b]	70.24[b]	13.72	66.35[b]	58.29[b]	42.00	9.97[ab]	4.32
Very Well Done (82°C)	28.79[c]	66.49[c]	13.06	62.58[c]	60.09[a]	42.93	8.54[b]	3.80
SEM[3]	1.38	1.08	0.88	1.32	0.77	0.94	0.69	0.57
P – value[5]	< 0.0001	< 0.0001	0.4863	< 0.0001	0.0009	0.1839	0.0028	0.4849

[1]Sensory Scores: 0 mm = Extremely dry/tough/none/unbeef-like/bland; 100 mm = Extremely juicy/tender/abundant/beef-like/intense; 50 mm = neither dry nor juicy, neither tough nor tender, neither unbeef-like nor beef-like.

[2]Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

[3]SE (largest) of the least squares means.

[4] *P* – value for main effect Quality Treatment

[5] *P* – value for main effect Degree of Doneness

[abcd]Least squares means in the same section of the same column without a common superscript differ ($P < 0.05$).

Table 2.9 Least squares means for proximate, pH, and instrumental color analysis of raw beef strip loin steaks of varying quality and enhancement treatments.

	%							
Treatment	Fat	Moisture	Protein	Ash	pH	L*[2]	a*[3]	b*[4]
Non-Enhanced								
Prime	8.03[a]	68.51[c]	22.43[ab]	1.19[d]	5.70[b]	47.55[a]	25.98[a]	18.98[a]
Low Choice	3.51[cd]	71.25[b]	23.12[a]	1.35[cd]	5.66[b]	44.47[b]	26.30[a]	18.52[a]
Low Select	2.34[e]	71.99[ab]	23.24[a]	1.25[d]	5.68[b]	42.64[bc]	26.34[a]	17.78[ab]
Enhanced[1]								
Prime	6.78[b]	69.05[c]	21.29[b]	1.52[bc]	5.87[a]	44.97[ab]	25.95[a]	18.40[a]
Low Choice	3.91[c]	72.37[ab]	21.65[b]	1.76[a]	5.86[a]	40.62[cd]	25.38[ab]	16.75[bc]
Low Select	2.46[de]	73.40[a]	22.03[ab]	1.68[ab]	5.88[a]	39.15[d]	24.50[b]	15.88[c]
SEM[5]	0.40	0.52	0.43	0.07	0.03	1.05	0.43	0.49
P – value	< 0.0001	< 0.0001	0.0094	< 0.0001	< 0.0001	< 0.0001	0.0187	< 0.0001

[1]Enhanced 108% of raw weight with a water, salt, and alkaline phosphate solution.
[2]L* = lightness (0 = black and 100 = white).
[3]a* = redness (-60 = green and 60 = red).
[4]b* = blueness (-60 = blue and 60 = yellow).
[5]SE (largest) of the least squares means.
[abc]Least squares means in the same column without a common superscript differ ($P < 0.05$).

Table 2.10 Least squares means for objective analyses of grilled beef strip loin steaks cooked to three degrees of doneness.

Treatment	PJP[1], %	Slice Shear Force, N	Warner-Bratzler shear force value, N	Consumer panel thaw loss[2],%	Consumer panel cook loss[3], %	Consumer panel total loss[4], %	Trained panel thaw loss[5], %	Trained panel cook loss[6], %	Trained panel total loss[7], %
Quality Treatment									
Non-Enhanced									
Prime	20.10	130.23[b]	22.65[bc]	1.92[c]	18.99[a]	21.44[b]	1.82[bc]	17.69[b]	19.87[b]
Low Choice	20.25	121.90[b]	26.38[b]	2.56[b]	18.40[a]	22.17[ab]	2.78[a]	18.95[ab]	22.05[a]
Low Select	19.88	169.66[a]	33.34[a]	3.11[a]	19.61[a]	23.28[a]	2.47[ab]	20.17[a]	23.19[a]
Enhanced[8]									
Prime	20.02	112.09[b]	17.06[d]	1.30[d]	16.75[b]	18.54[c]	1.05[c]	15.63[c]	17.28[c]
Low Choice	20.30	108.66[b]	17.65[d]	1.51[cd]	15.52[b]	17.28[c]	1.33[c]	14.50[c]	16.32[c]
Low Select	19.96	115.52[b]	21.08[cd]	1.29[d]	15.97[b]	17.66[c]	1.11[c]	14.78[c]	16.06[c]
SEM[9]	0.53	1.04	0.16	0.18	0.53	0.52	0.28	0.52	0.53
P – value[10]	0.9925	0.0007	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0005	< 0.0001	< 0.0001
Degree of Doneness									
Rare (60°C)	23.68[a]	127.19	20.99[b]	2.00	11.91[c]	14.71[c]	1.73	11.63[c]	13.98[c]
Medium (71°C)	20.38[b]	129.06	23.44[a]	1.94	16.98[b]	19.29[b]	1.77	16.41[b]	18.51[b]
Very Well Done (82°C)	16.20[c]	122.78	24.61[a]	1.92	23.72[a]	26.19[a]	1.78	22.81[a]	24.90[a]
SEM[9]	0.36	0.49	0.08	0.12	0.38	0.36	0.14	0.36	0.38
P – value[11]	< 0.0001	0.3243	< 0.0001	0.8744	< 0.0001	< 0.0001	0.9312	< 0.0001	< 0.0001

[1]Pressed Juice Percentage (PJP): Percentage moisture lost during compression of sample between filter paper at 8 kg pressure for 30 seconds.

[2]Consumer thaw loss = [(initial weight - thaw weight) / initial weight] × 100.

[3]Consumer cook loss = [(raw weight - cooked weight) / raw weight] × 100.

[4]Consumer total loss = [(initial weight - cooked weight) / initial weight] × 100.

[5]Trained thaw loss = [(initial weight - thaw weight) / initial weight] × 100.

[6]Trained cook loss = [(raw weight - cooked weight) / raw weight] × 100.

[7]Trained total loss = [(initial weight - cooked weight) / initial weight] × 100.

[8]Enhanced to 108% of raw weight with a water, salt, alkaline phosphate solution.

[9]SE (largest) of the least squares means.

[10] *P* – value for main effect Quality Treatment

[11] *P* – value for main effect Degree of Doneness

[abcd]Least squares means in the same section without a common superscript differ ($P < 0.05$).

Table 2.11 Pearson correlation coefficients for sensory scores and objective measurements of beef strip loin steaks varying in quality treatment and degree of doneness.

	Consumer Panel rating							Trained Panel Rating								Objective Measurements	
Measurement	Tenderness	Juiciness	Flavor Liking	Overall Liking	Thaw Loss, %	Cook Loss, %	Total Loss, %	Initial Juiciness	Sustained Juiciness	Myofibrillar Tenderness	Overall Tenderness	Beef Flavor Identity	Thaw Loss, %	Cook Loss, %	Total Loss, %	PJP, %	WBSF, N
Consumer panel																	
Juiciness	0.81**																
Flavor Liking	0.55**	0.53**															
Overall Liking	0.76**	0.72**	0.90**														
Thaw Loss, %	-0.27**	-0.29**	-0.38**	-0.36**													
Cook Loss, %	-0.57**	-0.76**	-0.35**	-0.48**	0.09												
Total Loss, %	-0.60**	-0.79**	-0.41	-0.53**	0.32**	0.97**											
Trained Panel																	
Initial Juiciness	0.59**	0.75**	0.38**	0.51**	-0.28**	-0.78**	-0.81**										
Sustained Juiciness	0.58**	0.75**	0.38**	0.51**	-0.28**	-0.77**	-0.80**	0.99**									
Myofibrillar Tenderness	0.67**	0.59**	0.47**	0.55**	-0.36**	-0.50**	-0.54**	0.69**	0.70**								
Overall Tenderness	0.67**	0.56**	0.46**	0.54**	-0.36**	-0.46**	-0.50**	0.65**	0.65**	0.98**							
Beef Flavor Identity	0.02	-0.07	0.08	0.06	-0.13	0.14*	0.12	0.04	0.04	0.07	0.07						
Thaw Loss, %	-0.24**	-0.25**	-0.25**	-0.27**	0.39**	0.08	0.25**	-0.24**	-0.25**	-0.27**	-0.26**	0.01					
Cook Loss, %	-0.56**	-0.73**	-0.35**	-0.48**	0.27**	0.80**	0.84**	-0.88**	-0.88**	-0.60**	-0.56**	0.11	0.16*				
Total Loss, %	-0.58**	-0.74**	-0.37**	-0.50**	0.31**	0.77**	0.83**	-0.87**	-0.87**	-0.61**	-0.57**	0.12	0.38**	0.97**			
Objective Measurements																	
PJP, %	0.39**	0.55**	0.14*	0.26**	-0.03	-0.65**	-0.62**	0.59**	0.57**	0.34**	0.30**	-0.15*	-0.03	-0.58**	-0.55**		
WBSF, N	-0.55**	-0.43**	-0.41**	-0.49**	0.34**	0.32**	0.37**	-0.45**	-0.46**	-0.74**	-0.75**	-0.09	0.28**	0.34**	0.38**	-0.25**	
Slice Shear force value, N	-0.40**	-0.22**	-0.28**	-0.34**	0.21**	0.09	0.12	-0.17*	-0.17*	-0.57**	-0.61**	-0.07	0.18**	0.11	0.15*	-0.02	0.67**

**Correlation coefficient differs from 0 (*P* < 0.01).

*Correlation coefficient differs from 0 (*P* < 0.05).

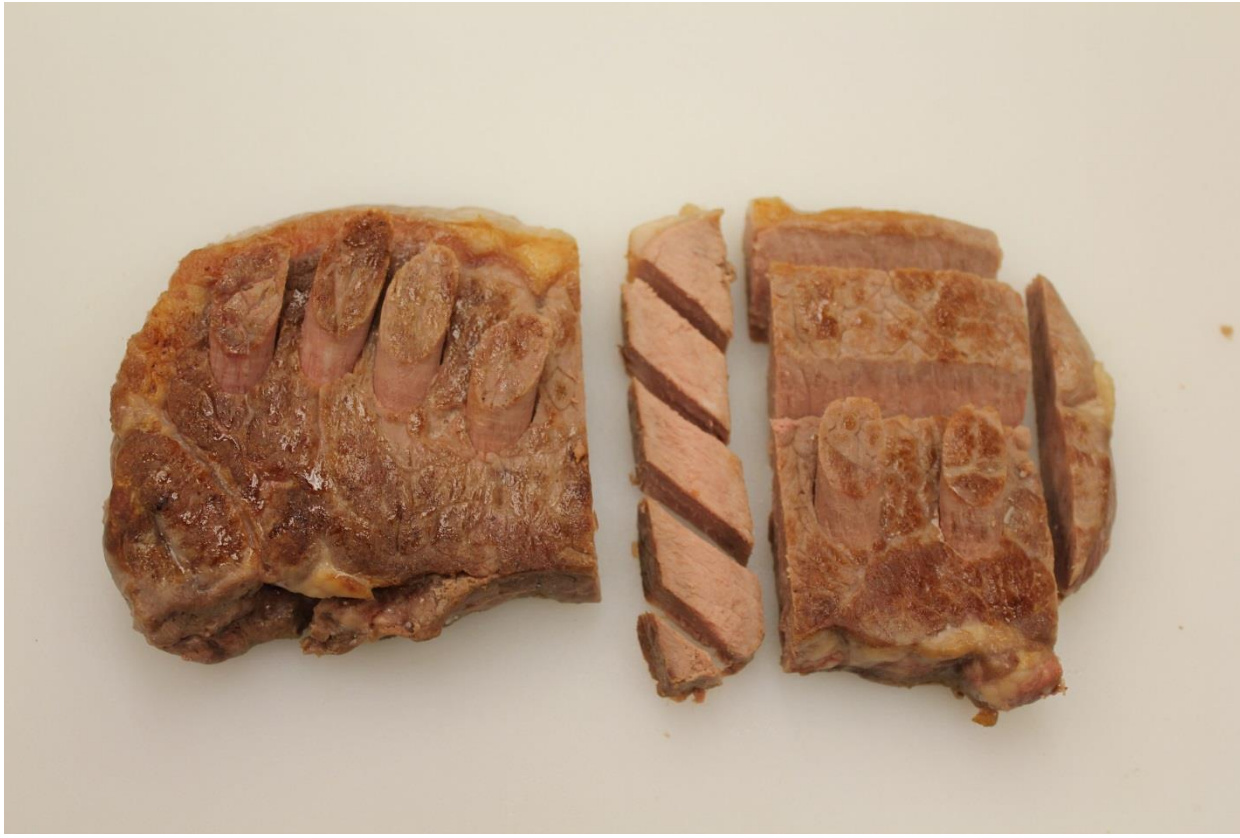

Figure 2.1 Location of sample removal for Pressed Juice Percentage, Slice Shear Force, and Warner-Bratzler Shear Force.

Chapter 3 - Determining the Repeatability and Accuracy of the Pressed Juice Percentage (PJP) method at sorting strip loin steaks into categories of known juiciness

Abstract

The repeatability and ability of the Pressed Juice Percentage (PJP) method to segregate steaks were evaluated using USDA Prime, Low Choice, and Low Select strip steaks. Select steaks were either enhanced to 108% with water, salt, and alkaline phosphates or non-enhanced. All steaks were cooked to one of three degrees of doneness (DOD; Rare: 60 °C, Medium: 71 °C, or Very Well-Done: 82 °C). Results indicated PJP had a high repeatability coefficient of 0.70, indicating only a small portion (30%) of the variation observed was due to sample measurement differences between paired samples. The evaluated PJP threshold values accurately segregated strip loin steaks by the probability that a sample would be rated "juicy" by consumers. The actual percentage of "juicy" samples was determined to be 41.67%, 72.31%, 89.33%, and 98.08% for the predicted <50%, 50 – 75%, 75 – 90%, and > 90% categories, respectively. Results of this study indicate the PJP method is both repeatable and accurate at sorting steaks based on the likelihood of a steak being "juicy".

Keywords: beef, enhancement, juiciness, pressed juice percentage, repeatability, threshold

Introduction

The three traits contributing the most to beef palatability are tenderness, juiciness, and flavor (Bratzler, 1971; Corbin et al., 2015; Platter et al., 2003). These traits must not just excel individually, but must interact to deliver an optimal eating experience (Emerson, Woerner, Belk, & Tatum, 2013; Savell & Cross, 1988). Among these traits, tenderness has been the most researched over the past 20 years and this has resulted in large improvements in the tenderness of the U.S. beef supply. According to the most recent National Beef Tenderness Audit, beef at retail from the top loin would be considered “very tender” 84.78% of the time (Guelker et al., 2013). With such a large portion of the U.S. beef supply considered “tender”, the importance of beef products delivering on consumer juiciness and flavor expectations is greater than ever before.

Juiciness has been found to be highly correlated (r = 0.73 - 0.93) with consumer overall liking (Corbin et al., 2015; Killinger, Calkins, Umberger, Feuz, & Eskridge, 2004; O'Quinn et al., 2012). Many studies have attempted to use a variety of methods to objectively measure and quantify juiciness, with limited success (Lee & Patel, 1984; Pearce, Rosenvold, Andersen, & Hopkins, 2011; Sanderson & Vail, 1963). Authors of a recent study developed an instrumental juiciness measurement technique that compliments and can be conducted simultaneously with Slice Shear Force (SSF) tenderness evaluation (Woolley, 2014). In that study, the Pressed Juice Percentage (PJP) accounted for 48%, 45%, and 20% of the variation in trained sensory panel initial juiciness, trained sensory panel sustained juiciness, and consumer juiciness scores, respectively (Woolley, 2014).

The PJP values of 14.64%, 18.94%, and 23.25% correspond to the probability of a steak being rated as “juicy” 50%, 75%, and 90% of the time, respectively (Woolley, 2014). The objectives of the current study were to validate these proposed threshold values, evaluate the accuracy of PJP at identifying “juicy” steaks, and determine the repeatability of the PJP method.

Materials and Methods

Experimental Treatments and Sample Preparation

Detailed description of meat collection and carcass data collection are described in chapter 2. In brief, beef strip loins (IMPS #180; NAMP 2010) used in this study representing four quality treatments: USDA Prime, Low Choice, Low Select, and Enhanced Low Select (n = 5 / treatment). Upon selection, carcasses were evaluated for skeletal, lean, and overall maturity, marbling score, preliminary fat thickness, adjusted fat thickness, ribeye area, hot carcass weight, kidney pelvic and heart fat, and USDA yield grade. After fabrication, strip loins were selected from a Midwestern beef processing plant, were vacuum packaged and transported under refrigeration (2 °C) to the Kansas State University (KSU) Meat Laboratory for further processing. Strip loins not allocated for enhancement were stored under vacuum at 2 - 4°C, in the absence of light for a 21 d aging period. Low Select Enhanced (SE) strip loins (n = 5) were aged 14 days and then injected with a solution formulated to result in 0.35% salt and 0.40% sodium phosphate (Brifisol 512, ICL Food Specialties, Saint Louis, MO) in the final product at 8% pump. A multi-needle injector (Wolf-tec, IMAX 420 eco, Kingston, NY) was utilized for the injection of the solution (pH = 8.09). Actual enhancement level (8.63 ± 1.53%) was verified by recording weights of the strip loins before and after injection. All final weights were recorded after a 15 min rest period. Enhanced product was vacuum packaged and stored at 2 – 4 °C, in the absence of light for the remainder of the 21 d aging period.

After aging, strip loins were fabricated into 2.5-cm thick steaks. Prior to cutting, the most anterior (wedge) steak was cut and utilized for pH, objective color analysis (L*, a*, b*), and proximate analysis. Wedge steaks were placed on trays with the fresh cut surface exposed to the environment and permitted to bloom for a 15 min period prior to color evaluation. Each steak was evaluated for pH using a pH meter (model HI 99163; Hannah Instruments, Smithfield, RI). L*, a*, and b* values were measured using a Hunter Lab Miniscan spectrophotometer

(Illuminant A, 2.54-cm aperture, 10° observer; Hunter Associates Laboratory, Reston, VA). Scans were taken at three areas of each steak and the observations were averaged. After color and pH analysis, steaks were individually packaged, frozen (-20 °C), and stored for proximate analysis.

Strip loins were then fabricated from anterior to posterior end. Consecutively cut steaks were paired for use in PJP repeatability testing. Each pair was assigned to one of three degrees of doneness (DOD; Rare, Medium, Very Well-Done). Two pairs from each strip loin were assigned to each DOD. Steaks were weighed fresh, packaged individually, and frozen (-20 °C).

Cooked Sample Preparation

Steaks were thawed (2 – 4 °C) for 24 h prior to evaluation. A raw thaw weight was recorded and remaining external fat and accessory muscles (*Multifidus dorsi* and *Gluteus medius*) were removed prior to cooking and weighing for cook loss evaluation. Steaks were cooked to the assigned DOD [Rare (60 °C), Medium (71 °C), or Very Well-Done (82 °C)] on a clamshell grill (Cuisinart Griddler Deluxe, East Windsor, NJ). Thermocouples (30-gauge copper and constantan; Omega Engineering, Stamford, CT) were utilized to monitor temperatures with a Doric Mini-trend Data Logger (Model 205 B-1-c OFT, Doric Scientific, San Diego, CA) and peak temperatures were verified with a probe thermometer (Model 450-ATT, Omega Engineering, Stamford, CT). Steaks were rested for two min (23 °C) prior to testing.

Slice Shear Force

Slice Shear Force (SSF) testing was conducted utilizing the procedures described by Shackelford, Wheeler, and Koohmaraie (1999). In brief, a 1 to 2-cm portion of the lateral end of the steak was removed to expose muscle fiber orientation. With the use of a sizing box, a 5-cm length portion was removed from the lateral end of each steak. A 1-cm thick sample was removed parallel to the muscle fiber orientation from the 5-cm piece from the lateral end at a 45° angle of each steak using a double-bladed knife. The sample was then center sheared using a shearing machine (Model GR-150, G-R Manufacturing Co., Manhattan, KS) and a basic force gauge (BFG500N, Mecmesin Ltd., West Sussex, UK) attached to slice shear force blade to measure peak force (kg) required to shear through the warm slice.

Pressed Juice Percentage

The PJP protocol used was developed and described by Woolley (2014). In brief, following SSF sample removal, the double-bladed knife was used to cut a 1-cm thick by steak-width slice immediately medial to SSF sample removal. Three 1-cm width pieces were removed parallel to the muscle fiber orientation from the slice. Each sample was weighed on 2 pieces of filter paper (VWR Filter Paper 415, 12.5cm, VWR International, Radnor, PA) and compressed at 8 kg of pressure for 30 s on an INSTRON Model 5569 testing machine (Instron, Canton, MA). After sample compression, samples were discarded and filter paper was re-weighed. The PJP was calculated as the moisture lost during compression of sample: PJP = Moisture Loss / initial sample weight. The three values from each steak were averaged for a single PJP value for each steak. To determine if using six rather than three samples from each steak improved the precision of the PJP method, an additional 1-cm slice was removed immediately medial to the first slice and an additional set of three samples were compressed and PJP quantified as previously described.

Warner-Bratzler Shear Force

Following PJP and SSF sample removal, the remaining portion of steaks were cooled for 12 hours at 2 – 4 °C prior to Warner-Bratzler shear force (WBSF) analysis according to the methods described by AMSA (2015). Six 1.27-cm diameter cores were removed parallel to muscle fiber orientation. The cores were sheared once, perpendicular to muscle fibers on an INSTRON Model 5569 testing machine (Instron, Canton, MA) with the use of a Warner-Bratzler shear blade. Values were reported as the peak kg of force required to shear through the core. Values were averaged across all cores from a single steak.

Proximate Analysis

For sample preparation for proximate analysis, all exterior fat and accessory muscles (*Multifidus dorsi* and *Gluteus medius*) were removed from the *Longissimus dorsi* of each sample. Samples were submerged in liquid nitrogen and homogenized using a commercial 4 blade blender (Model 33BL 79, Waring Products, New Hartford, CT). Powdered samples were then placed in Whirl-Pac (Nasco, Ft. Atkinson, WI) bags and stored (-20 °C) until further analysis. Lipid extraction was performed following procedures described by Martin et al. (2013). Moisture content was determined using the AOAC approved oven drying method (AOAC, 2005). Nitrogen content was determined using a combustion method (TruMac N Nitrogen/Protein determination Instruction manual, 2014, Leco Corp., St. Joseph, MI) and multiplied by 6.25 to determine protein content. Percent ash was determined using a muffle furnace, following the AOAC ash oven method (AOAC, 2005).

Statistical Analysis

SAS (Version 9.4; SAS Inst. Inc., Cary, NC) was used for statistical analyses. Comparisons among treatment means were evaluated for significance using PROC GLIMMIX with $\alpha = 0.05$. All sensory panel and objective data were analyzed with a model with a split-plot arrangement of factors. The model included the whole-plot factor of quality treatment and the sub-plot factors of DOD and the quality treatment × DOD interaction. All carcass, color, pH, and proximate data was analyzed with a model that included the fixed effect of quality treatment. For all analyses, the Kenward – Roger approximation was utilized for estimation of denominator degrees of freedom and the PDIFF option was used to separate treatment means when the *F*-test on the overall effect was significant ($P < 0.05$). The quality treatment × DOD interaction was non-significant ($P > 0.05$) for all dependent variables, unless otherwise denoted. Variance components for repeatability measures were calculated using the GLIMMIX procedure and PROC CORR was used for the calculation and analysis of all Pearson correlation coefficients.

Results and Discussion

Carcass Characteristics, Instrumental Color, and Proximate Composition

Carcass characteristics of the beef used in this study are presented are Table 3.1. As was expected, marbling score increased ($P < 0.05$) as quality grade increased from Low Select to Prime, with only carcasses from the Low Select and SE treatments having a similar ($P > 0.05$) amount of marbling. All carcasses were "A" maturity, with no differences ($P > 0.05$) among treatments for all maturity, fat, carcass weight, yield grade, and ribeye size measures.

Instrumental color readings, pH values, and proximate composition of strip loins used in this study are presented in Table 3.2. Instrumental color readings of L* value indicated SE samples were darker ($P < 0.05$) in color than all other treatments, as well as had lower ($P < 0.05$) a* and b* values. Additionally, Prime samples had a greater ($P < 0.05$) L* value than all other treatments. This lighter color reading is likely due to the higher marbling level of these samples and the resulting influence of the white marbling color during measurement. Moreover, no differences ($P > 0.05$) were found in a* and b* values among the non-enhanced treatments. Similar results for instrumental color readings of enhanced steaks have been previously reported. Previous studies reported L* readings of beef strip loins that had been enhanced with a similar salt and phosphate solution to be darker than non-enhanced control samples (Robbins et al., 2003). Similarly, Kim et al. (2006) reported lower L*, a*, and b* values for enhanced strip loin steaks. Therefore, these studies indicate salt and alkaline phosphate enhancement solutions result in lower a* and b* values and darker lean color. However, it is unclear if these color changes as a result of enhancement would be detrimental to color preference and desirability by consumers.

Due to the inclusion of alkaline phosphates in the enhancement solution, SE samples had a greater ($P < 0.05$) pH than all non-enhanced samples. Similar results of increased pH from alkaline phosphate enhancement have been reported by previous authors. Increases in pH of 2.9, 2.1, and 7.5% have been previously reported by Robbins et al. (2003), Baublits, Pohlman, Brown Jr, Yancey, and Johnson (2006), and Wicklund et al. (2005), respectively. Alkaline phosphates have been known to increase pH, which is due to the phosphate pH that are usually a pH of 7 or higher (Sebranek, 2015). Additionally, enhancement resulted in an increase ($P < 0.05$) in moisture content of more than 2.5% in SE samples over all non-enhanced samples.

Due to quality grade, fat percentage increased ($P < 0.05$) as USDA quality grade increased from Low Select (2.84%) to Prime (8.74%). Additionally, no difference ($P > 0.05$) in fat percentage was found between Low Select, and SE samples. The results of the current study are consistent with authors who have used CEM to determine the fat percentages of beef (Dow, Wiegand, Ellersieck, & Lorenzen, 2011) and show a similar increase in fat percentage and differences among quality grades. Fat percentages in our study were found lower than those reported in previous studies evaluating the same quality grades (Emerson et al., 2013; Legako et al., 2015; O'Quinn et al., 2012; Savell, Cross, & Smith, 1986). However, methodology in those studies consisted of NIR, ether extraction, or Foltch methodology to determine fat percentage. The modified chloroform/methanol extraction protocol described by Martin et al. (2013) was used for fat qualification in this study. This difference in methodology may explain the difference in fat percentages in the current study and the higher values reported by previous authors.

Objective Measures of Juiciness and Tenderness

Objective measurements for PJP and percentages for thaw loss, cooking loss, and total loss of all treatments are presented in Table 3.3. When evaluating PJP, no quality treatment × DOD interaction ($P > 0.05$) was found, indicating the effect of quality treatment on PJP was similar across all DOD evaluated. No differences ($P > 0.05$) were found among quality treatments for PJP; however, DOD had a large effect on PJP. The PJP was inversely related to DOD and decreased ($P < 0.05$) as DOD increased (Rare > Medium > Very Well-Done). Rare samples had, on average, approximately 9% more moisture lost during PJP measurement than Very Well-Done samples and greater than 3% more than Medium samples. These results give a clear indication of the importance of DOD to beef juiciness. This large effect of DOD may be in part responsible for the lack of observed differences in PJP among quality treatments, as the reported quality treatment means were pooled across all three DOD.

PJP results reported by Woolley (2014) were similar to the current study among quality treatments evaluated. In that study, differences were only found among the Select High Enhanced (12% pump) and the Standard quality treatments. Otherwise, Woolley (2014) found no differences among all other quality grades evaluated. These results are consistent with the current study, with Select Low Enhanced (7% pump) found to be similar to steaks from Prime – Select quality grades (Woolley, 2014). Similar to our study, among DOD (Rare – Well-Done), Woolley (2014) found large differences in PJP.

The percentage of weight lost as a result of freezing and thawing samples (thaw loss) is presented in Table 3.3. As quality grade increased from Low Select to Prime, the amount of thaw loss decreased ($P < 0.05$), with only SE samples having a similar ($P > 0.05$) percentage of thaw loss as Prime. However, observed thaw loss differences were minimum across all quality treatments, with the two most extreme treatments differing by only slightly more than 1% (1.09%). No differences ($P > 0.05$) were found among non-enhanced samples for the percentage of cooking loss observed; however, SE samples had more than 3% less ($P < 0.05$) cook loss than all other treatments. This is due to the added water-holding capacity associated with alkaline phosphates. Previous studies by Wicklund et al. (2005) and Baublits et al. (2006) have reported improvements in percentage of cooking loss of 3.2% and 2.5% due to alkaline phosphate enhancement when compared to non-enhanced samples. The same trend was observed in the current study for the percentage of total (initial weight – cooked weight) loss, with no difference ($P > 0.05$) found among non-enhanced samples and SE samples having a lower ($P < 0.05$) percentage of total loss than all other treatments.

The percentage of cooking loss increased ($P < 0.05$) concurrently with degree of doneness (Rare < Medium < Very Well-Done; Table 3.3). Rare samples had less than half (12.15% vs 24.76%) the percentage of cooking loss as samples cooked to Very Well-Done. This large difference in cooking loss is partially responsible for the large observed differences among DOD for PJP, with elevated DOD having less available moisture for juiciness quantification during compression. Moreover, percentage of total loss increased ($P < 0.05$) as DOD increased from Rare to Very Well-Done. This is due in large part to the relative high percentage (> 86%) of the total weight loss accounted for by cooking loss as opposed to thaw loss, with only minimal variation observed among DOD groups for the percentage of thaw loss.

No differences ($P > 0.05$) were found among quality treatments or among DOD for SSF (Table 3.3). Among quality treatments, mean SSF values differed by almost 3.5 kg, however were not significantly different, likely due to the low number of samples used in this study and the amount of variation (SEM = 1.14 kg) within treatment groups. Previous authors reported SSF values decreased as quality grade increased (Emerson et al., 2013). In the current study, as with WBSF, SSF values indicated a high degree of tenderness among samples, with mean values all below the 15.3 kg threshold established by the USDA for “Certified Very Tender” (ASTM, 2011). This high level of tenderness may be partially responsible for the lack of observed SSF differences among treatments.

When evaluating objective tenderness measures, a quality treatment × DOD interaction were found for WBSF ($P < 0.05$; Table 3.4). As DOD increased, WBSF values also increased (Very Well-Done > Medium > Rare; $P < 0.05$). When cooked to Rare, no difference ($P > 0.05$) was found for WBSF across all quality treatments. However, when cooked to Medium, SE samples had the lowest ($P < 0.05$) WBSF value and Prime samples were more tender ($P < 0.05$) than Low Select samples, but similar ($P > 0.05$) to Low Choice samples. Though when cooked to Very Well-Done, Prime samples were more tender ($P < 0.05$) than both Low Choice and Low Select samples (SE < Prime < Low Choice = Low Select). These results indicate an increased importance of marbling level for beef tenderness when steaks are cooked to elevated degrees of doneness and are consistent with the “insurance theory” associated with beef palatability (Smith & Carpenter, 1974).

It is noteworthy that all of the beef used in this study was very tender and the mean values indicate that a large number of the samples at each DOD and quality treatment would have met WBSF thresholds for “USDA Certified Very Tender” (ASTM, 2011). Steaks in our study were aged a total of 21-d postmortem and this aging period likely contributed to the high level of tenderness observed among samples. Data from the most recent beef tenderness survey indicates that 83.78% to 84.78% of retail and foodservice beef from the top loin would be considered “tender” based on WBSF value (Guelker et al., 2013). Additionally, the average age time of beef found in U.S. retail markets is 20.5 d (Guelker et al., 2013). This indicates that the beef used in the current study is consistent with beef commonly purchased and consumed by U.S. beef consumers at both retail and foodservice.

PJP Repeatability

The repeatability of the PJP, WBSF, and SSF were calculated as described by Shackelford et al. (1999). Repeatability represented the proportion of the total variance that could be attributed to the steak pair: repeatability = σ^2pair / (σ^2pair + σ^2residual). The PJP method had a high repeatability coefficient calculated at 0.70 (Figure 3.4). This indicates that 70% of the observed variation within the sample set of maximum juiciness variation (four quality treatments cooked to three DOD) could be attributed to between-pair variation, indicating only 30% of the variation was unexplained or due to within-pair variation between the paired samples. As a point of comparison, SSF in the current study had a similar repeatability as PJP, with a repeatability coefficient of 0.68. However, WBSF was more repeatable (repeatability = 0.85) than either PJP or SSF in the current study. Our calculated repeatability falls within the range reported previously (0.67 to 0.87) for WBSF (Wheeler et al., 1997; Wheeler, Shackelford, & Koohmaraie, 1996). However, Shackelford et al. (1999) reported the repeatability of SSF at 0.89, which is much higher than the 0.68 calculated in the current study. This difference may be due in part to the differenecs in cooking protocals used in the two studies. Shackelford et al. (1999) used a belt-grill to cook steaks to a single DOD as opposed to the clamshell grills used in the current study to cook to three DOD. The belt-grill allowed Shackelford et al. (1999) to more conistently cook steaks and likely resulted in less between-steak variation than the current study and may explain some of the differences in reported repeatability.

The original PJP method developed by Woolley (2014) averaged across three samples per steak for PJP determination. Other objective measures of beef palatability (WBSF) often average across at least six samples from each steak for a final sample average. Our study compared the use of three vs six samples to determine if the added samples improved the precision and repeatability of the PJP method. The use of six cores produced a repeatability coefficient of 0.72 and had an average CV of 13.83%. When three samples were used for PJP determination, the repeatability was estimated at 0.70 and samples had an average CV of 12.64%. Therefore, it was determined that the use of an additional three samples did not improve the precision or repeatability of the method enough to justify the added time and costs associated with the supplementary sampling.

Accuracy of PJP for Sorting Steaks Based on Juiciness

Woolley (2014) proposed multiple PJP threshold levels to predict the likelihood of a sample being rated "juicy" by consumers: PJP of <14.64% = < 50% chance of being rated as "juicy"; PJP of 14.64-18.94% = 50 – 75% chance of being rated as "juicy"; PJP of 18.94 – 23.25% = 75 – 90% chance of being rated as "juicy"; and PJP of >23.25% = >90% chance of being rated as "juicy". It was therefore one of the objectives of the current study to test the accuracy of these threshold values and evaluate the efficacy of PJP at sorting steaks into juiciness categories.

Steaks representing a variety of USDA quality grades and enhancement levels were cooked to three degrees of doneness and evaluated for PJP as previously discussed in Chapter 2. Consumer and trained panel data reported in Chapter 2 was used to sort the steaks into the various categories identified by Woolley (2014). Paired samples were then evaluated by both consumer panelists and trained panelists for juiciness. Within each threshold range, the percentage of samples rated "juicy" (average sensory panel juiciness score of >50) by sensory panelists was determined and compared to the predicted percentage to determine the accuracy of the threshold values.

Threshold results for PJP corresponding to consumer ratings of juiciness are presented in Figure 3.1. Within all threshold categories, the actual percentage of samples rated "juicy" by consumers was within the predicted probability ranges. In the first category with a predicted percentage of samples rated as "juicy" of less than 50%, the actual percentage rated "juicy" was 41.67%. In the second category, with a predicted probability of 50% to 75%, the actual percentage of samples rated "juicy" was 72.31%, and within the third category (75% to 90% predicted "juicy"), the actual percentage of samples rated "juicy" was 89.33%. Lastly, within the final category with an expected probability over 90% rated "juicy", the actual percentage rated "juicy" was 98.08%. These results indicate the established threshold values by Woolley (2014) were accurate and successful in identifying the probability of a steak being rated as "juicy" by consumers. Validating these thresholds on an independent data set, as was done with the current study, indicates the PJP as an effective objective juiciness evaluation method and allows for the possibility of identification and marketing of "guaranteed juicy" steaks that will meet consumer expectations for juiciness.

Figure 3.2 presents results from PJP threshold identification and trained panel ratings of initial juiciness. The established thresholds were accurate in the predicted percentage of samples rated “juicy” in the first, second, and fourth categories. However, the actual percentage of samples rated “juicy” in the third (75 – 90%) category did not fall within the predicted range, but was very close (73.33%) to the predicted 75%. Overall, the PJP thresholds accurately sorted steaks for trained panel initial juiciness scores. In all categories, a lower percentage of samples were rated as “juicy” for initial juiciness than was observed with consumer data. This indicates trained panelists had a higher expectation level for what is “juicy” than the untrained consumers.

The established PJP thresholds were not able to accurately sort steaks for trained panel sustained juiciness (Figure 3.3). For all categories except the lowest (< 50%), a lower percentage of samples were rated “juicy” than was predicted. There was a notable decrease from initial to sustained juiciness as over the time the sample is chewed and instead of the first initial impression of juiciness, sustained juiciness is a slow release of juice from the fat and enacts the salivary flow (Bratzler, 1971). The decrease of sustained juiciness was consistent across all treatment groups, as indicated by both initial and sustained juiciness having a similar relationship with consumer panel juiciness scores (r = 0.75). This decrease in juiciness observed between initial and sustained measures was responsible for the decreased number of samples rated as “juicy” at each PJP and the corresponding inaccuracy of the PJP thresholds due to the downward shift in sustained juiciness scores.

The PJP thresholds established by Woolley (2014) and tested in the current study were based upon consumer data and were intended to segregate and identify the probability of consumers considering steaks as “juicy”. Similar threshold values could be established for trained panelists and would likely improve the accuracy of PJP at sorting steaks for initial and sustained juiciness. In our study, the consumer-based thresholds were accurate in sorting steaks for trained panel initial juiciness scores, though to a lesser degree than consumer data. By the very nature of trained panels, panelists are "trained" and orientated with the scaling used for evaluation. Because of this, potential variation among trained panels at various institutions may result in variation in the accuracy of the established trained panel thresholds. Moreover, trained sensory panels in the future could be trained to match and evaluate samples based upon the consumer-based threshold values. Data from untrained consumer panelists inherently possesses a greater amount of variation than trained panel data. This is clearly indicated by the amount of variation in sensory panel data accounted for by objective measures of both tenderness (WBSF and SSF) and juiciness (PJP) reported in Chapter 2. However, thresholds used for juiciness segregation and potential marketing will ultimately be required to meet the standards of consumers who purchase and consume the product in home or in restaurant. For this reason, juiciness thresholds should be developed from untrained consumer sensory evaluation as opposed to from trained panel data.

References

AOAC. (2005). *Official Methods of Analysis* (18th ed.). Arlington, VA: Assoc. Off. Anal. Chem.

ASTM. (2011). ASTM F 2925-11 Standard specification for tenderness marketing claims associated with meat cuts derived from beef. (Vol. 2014).

Baublits, R. T., Pohlman, F. W., Brown Jr, A. H., Yancey, E. J., & Johnson, Z. B. (2006). Impact of muscle type and sodium chloride concentration on the quality, sensory, and instrumental color characteristics of solution enhanced whole-muscle beef. *Meat Science, 72*(4), 704-712.

Bratzler, L. J. (1971). Palatability factors and evaluations. In *The Science of Meat and Meat Products*. San Francisco, Calif.: W. H. Freeman and Company.

Corbin, C. H., O'Quinn, T. G., Garmyn, A. J., Legako, J. F., Hunt, M. R., Dinh, T. T. N., Rathmann, R. J., Brooks, J. C., & Miller, M. F. (2015). Sensory evaluation of tender beef strip loin steaks of varying marbling levels and quality treatments. *Meat Science, 100*(0), 24-31.

Dow, D. L., Wiegand, B. R., Ellersieck, M. R., & Lorenzen, C. L. (2011). Prediction of fat percentage within marbling score on beef longissimus muscle using 3 different fat determination methods. *Journal of Animal Science, 89*(4), 1173-1179.

Emerson, M. R., Woerner, D. R., Belk, K. E., & Tatum, J. D. (2013). Effectiveness of USDA instrument-based marbling measurements for categorizing beef carcasses according to differences in longissimus muscle sensory attributes. *Journal of Animal Science, 91*(2), 1024-1034.

Guelker, M. R., Haneklaus, A. N., Brooks, J. C., Carr, C. C., Delmore, R. J., Griffin, D. B., Hale, D. S., Harris, K. B., Mafi, G. G., Johnson, D. D., Lorenzen, C. L., Maddock, R. J., Martin, J. N., Miller, R. K., Raines, C. R., VanOverbeke, D. L., Vedral, L. L., Wasser, B. E., & Savell, J. W. (2013). National Beef Tenderness Survey–2010: Warner-Bratzler shear force values and sensory panel ratings for beef steaks from United States retail and food service establishments. *Journal of Animal Science, 91*(2), 1005-1014.

Killinger, K. M., Calkins, C. R., Umberger, W. J., Feuz, D. M., & Eskridge, K. M. (2004). Consumer sensory acceptance and value for beef steaks of similar tenderness, but differing in marbling level. *Journal of Animal Science, 82*(11), 3294-3301.

Kim, Y. H., Hunt, M. C., Mancini, R. A., Seyfert, M., Loughin, T. M., Kropf, D. H., & Smith, J. S. (2006). Mechanism for Lactate-Color Stabilization in Injection-Enhanced Beef. *Journal of Agricultural and Food Chemistry, 54*(20), 7856-7862.

Lee, C. M., & Patel, K. M. (1984). Analysis of juiciness of commercial frankfurters. *Journal of Texture Studies, 15*(1), 67-73.

Legako, J. F., Brooks, J. C., O'Quinn, T. G., Hagan, T. D. J., Polkinghorne, R., Farmer, L. J., & Miller, M. F. (2015). Consumer palatability scores and volatile beef flavor compounds of five USDA quality grades and four muscles. *Meat Science, 100*(0), 291-300.

Martin, J. N., Brooks, J. C., Thompson, L. D., Savell, J. W., Harris, K. B., May, L. L., Haneklaus, A. N., Schutz, J. L., Belk, K. E., Engle, T., Woerner, D. R., Legako, J. F., Luna, A. M., Douglass, L. W., Douglass, S. E., Howe, J., Duvall, M., Patterson, K. Y., & Leheska, J. L. (2013). Nutrient database improvement project: The influence of U.S.D.A. Quality and Yield Grade on the separable components and proximate composition of raw and cooked retail cuts from the beef rib and plate. *Meat Science, 95*(3), 486-494.

Miller, M. F., Carr, M. A., Ramsey, C. B., Crockett, K. L., & Hoover, L. C. (2001). Consumer thresholds for establishing the value of beef tenderness. *Journal of Animal Science, 79*(12), 3062-3068.

O'Quinn, T. G., Brooks, J. C., Polkinghorne, R. J., Garmyn, A. J., Johnson, B. J., Starkey, J. D., Rathmann, R. J., & Miller, M. F. (2012). Consumer assessment of beef strip loin steaks of varying fat levels. *Journal of Animal Science, 90*(2), 626-634.

Pearce, K. L., Rosenvold, K., Andersen, H. J., & Hopkins, D. L. (2011). Water distribution and mobility in meat during the conversion of muscle to meat and ageing and the impacts on fresh meat quality attributes — A review. *Meat Science, 89*(2), 111-124.

Platter, W. J., Tatum, J. D., Belk, K. E., Chapman, P. L., Scanga, J. A., & Smith, G. C. (2003). Relationships of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. *Journal of Animal Science, 81*(11), 2741-2750.

Robbins, K., Jensen, J., Ryan, K. J., Homco-Ryan, C., McKeith, F. K., & Brewer, M. S. (2003). Dietary vitamin E supplementation effects on the color and sensory characteristics of enhanced beef steaks. *Meat Science, 64*(3), 279-285.

Sanderson, M., & Vail, G. E. (1963). A method for determining press fluid in cooked beef. *Journal of Food Science, 28*(5), 596-599.

Savell, J. W., & Cross, H. R. (1988). The role of fat in the palatability of beef, pork, and lamb. In *Designing Foods: Animal Product Options in the Marketplace*. Washington, D.C.: National Academy Press.

Savell, J. W., Cross, H. R., & Smith, G. C. (1986). Percentage ether extractable fat and moisture content of beef longissimus muscle as related to USDA marbling score. *Journal of Food Science, 51*(3), 838-839.

Sebranek, J. G. (2015). An Overview of Functional Non-Meat Ingredients in Meat Processing: The Current Toolbox. In Reciprocal Meat Conference (pp. 42-46). Lincoln, NE: American Meat Science Association.

Shackelford, S. D., Morgan, J. B., Cross, H. R., & Savell, J. W. (1991). Identification of thresholds for Warner-Bratzler shear force in beef top loin steaks. *Journal of Muscle Foods*, *2*(4), 289-296.

Shackelford, S. D., Wheeler, T. L., & Koohmaraie, M. (1999). Tenderness classification of beef: II. Design and analysis of a system to measure beef longissimus shear force under commercial processing conditions. *Journal of Animal Science, 77*(6), 1474-1481.

Smith, G., & Carpenter, Z. (1974). Eating quality of animal products and their fat content. In *Proc. Symposium on changing the fat content and composition of animal products. National Research Council, Washington DC, USA: Natl Academy of Sciences*.

Wheeler, T. L., Shackelford, S. D., Johnson, L. P., Miller, M. F., Miller, R. K., & Koohmaraie, M. (1997). A comparison of Warner-Bratzler shear force assessment within and among institutions. *Journal of Animal Science*, *75*(9), 2423-2432.

Wheeler, T. L., Shackelford, S. D., & Koohmaraie, M. (1996). Sampling, cooking, and coring effects on Warner-Bratzler shear force values in beef. *Journal of Animal Science, 74*(7), 1553-1562.

Wicklund, S. E., Homco-Ryan, C., Ryan, K. J., Mckeith, F. K., Mcfarlane, B. J., & Brewer, M. S. (2005). Aging and enhancement effects on quality characteristics of beef strip steaks. *Journal of Food Science, 70*(3), S242-S248.

Woolley, L. D. (2014). *Evaluation of objective beef juiciness measurement techniques and their relationships to subjective taste panel juiciness ratings.* Master's Thesis, Texas Tech University, Lubbock, TX.

Table 3.1 Least squares means for beef grading measures of carcasses of varying fat level and quality treatments.

Treatment	Lean Maturity[1]	Skeletal Maturity[1]	Overall Maturity[1]	USDA Marbling Score[2]	Preliminary Fat Thickness, cm.	Adjusted Fat Thickness, cm.	Ribeye Area, cm^2	Hot Carcass Weight, kg	Kidney, Pelvic, Heart Fat, %	Yield Grade
Prime	160.00	168.00	164.00	730.00[a]	1.40	1.50	88.52	374.49	2.80	3.30
Low Choice	168.00	158.00	160.00	436.00[b]	0.94	1.07	87.61	337.02	2.90	2.63
Low Select	164.00	162.00	162.00	330.00[c]	0.71	0.79	88.39	325.59	2.70	2.21
Low Select Enhanced[3]	168.00	166.00	166.00	328.00[c]	0.76	0.97	87.35	337.93	2.50	2.47
SEM[4]	4.30	7.21	4.36	7.91	0.08	0.09	0.64	34.31	0.26	0.30
P – value	0.5156	0.7700	0.7891	<0.0001	0.1159	0.1733	0.9963	0.1765	0.7274	0.0967

[1]100: A; 200: B; 300: C; 400: D; 500: E.

[2]200: Traces; 300: Slight; 400: Small; 500: Modest; 600: Moderate; 700: Slightly Abundant.

[3]Enhanced to 108% of raw weight with a water, salt, and alkaline phosphate solution.

[4]SE (largest) of the least squares means.

[abc]Least squares means in the same column of the same section without a common superscript differ ($P < 0.05$).

Table 3.2 Least squares means for proximate, pH, and color analysis of raw beef strip loin steaks of varying quality and enhancement treatment.

	%							
Treatment	Moisture	Protein	Fat	Ash	pH	L*[2]	a*[3]	b*[4]
Prime	67.81[c]	23.43	8.74[a]	1.35[b]	5.60[b]	47.76[a]	26.57[a]	19.53[a]
Low Choice	72.02[b]	21.77	3.67[b]	1.39[b]	5.62[b]	43.27[b]	26.58[a]	18.46[a]
Low Select	70.94[b]	22.40	2.84[bc]	1.22[b]	5.64[b]	43.87[b]	26.58[a]	18.59[a]
Low Select Enhanced[1]	74.77[a]	21.39	1.91[c]	1.64[a]	5.89[a]	39.40[c]	24.46[b]	15.42[b]
SEM[5]	0.89	1.13	0.36	0.07	0.03	1.02	0.39	0.36
P – value	0.0005	0.6117	< 0.0001	0.0056	< 0.0001	0.0003	0.0023	< 0.0001

[1]Enhanced to 108% of raw weight with a water, salt, alkaline phosphate solution.
[2]L* = lightness (0 = black and 100 = white).
[3]a* = redness (-60 = green and 60 = red).
[4]b* = blueness (-60 = blue and 60 = yellow).
[5]SE (largest) of the least squares means.
[abc]Least squares means in the same column of the same section without a common superscript differ ($P < 0.05$).

Table 3.3 Least squares means for beef strip loin steaks objective measures Slice Shear Force (SSF), PJP[1], Thaw Loss[2], Cook Loss[3], and Total Loss[4].

Treatment	SSF, N	PJP[1], %	Thaw Loss, %	Cook Loss, %	Total Loss, %
Quality Treatment					
Prime	120.72	20.04	1.64[c]	18.94[a]	21.04[a]
Low Choice	138.86	19.44	2.09[b]	18.87[a]	21.44[a]
Low Select	140.73	20.97	2.62[a]	19.23[a]	22.16[a]
Low Select Enhanced[5]	106.79	20.70	1.53[c]	15.86[b]	17.52[b]
SEM[6]	1.14	0.63	0.15	0.64	0.73
P - value	0.1461	0.3469	0.0003	0.0057	0.0016
DOD					
Rare (60°C)	127.19	24.34[a]	2.17[a]	12.15[c]	14.96[c]
Medium (71°C)	124.94	21.15[b]	1.76[b]	17.76[b]	19.78[b]
Very Well Done (82°C)	128.17	15.37[c]	1.98[ab]	24.76[a]	26.88[a]
SEM[6]	0.62	0.40	0.10	0.45	0.48
P - value	0.709	< 0.0001	0.0028	< 0.0001	< 0.0001

[1]Pressed Juice Percentage (PJP): Percentage moisture lost during compression of sample between filter paper at 8 kg pressure for 30 seconds.

[2]Thaw loss = [(initial weight-thaw weight) / initial weight].

[3]Cook loss = [(raw weight-cooked weight) / raw weight].

[4]Total loss = [(initial weight-cooked weight) / initial weight].

[5]Enhanced to 108% of raw weight with a water, salt, alkaline phosphate solution.

[6]SE (largest) of the least squares means.

[abc]Least squares means in the same column of the same section without a common superscript differ ($P < 0.05$).

Table 3.4 Interaction between degree of doneness and treatment (*P* = 0.0003) for Warner-Bratzler shear force values of grilled beef strip loin steaks.

Treatment	Warner-Bratzler shear force value, N
Rare (60°C)	
Prime	21.18
Low Choice	24.81
Low Select	25.20
Low Select Enhanced[1]	18.44
SEM[2]	0.26
P - value	0.2371
Medium (71°C)	
Prime	25.20[b]
Low Choice	28.34[ab]
Low Select	31.77[a]
Low Select Enhanced[1]	18.63[c]
SEM[2]	0.26
P - value	0.0130
Very Well Done (82°C)	
Prime	26.18[b]
Low Choice	34.81[a]
Low Select	34.91[a]
Low Select Enhanced[1]	21.28[c]
SEM[2]	0.26
P – value	0.0028

[1]Enhanced to 108% of raw weight with a water, salt, alkaline phosphate solution.

[2]SE (largest) of the least squares means.

[abcde]Least squares means in the same column of the same section without a common superscript differ ($P < 0.05$).

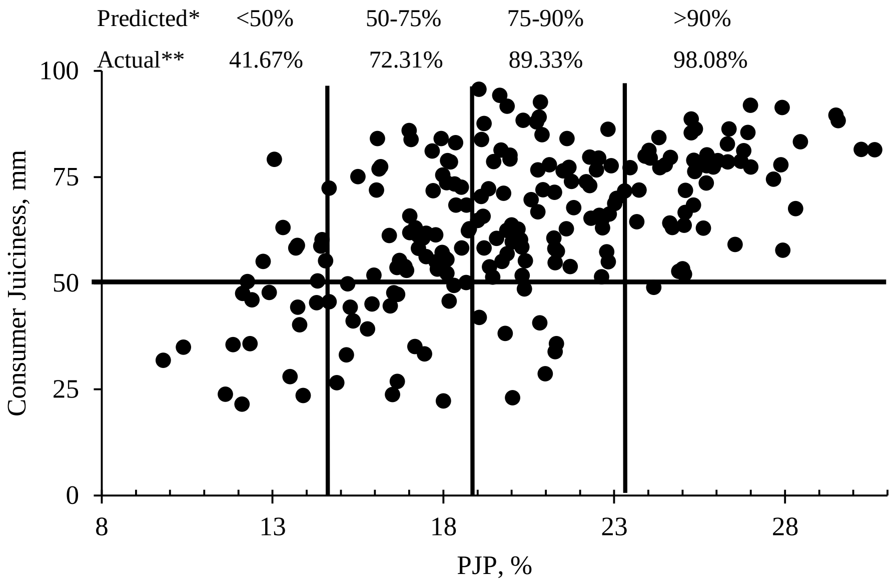

Figure 3.1 Use of instrumental juiciness classification PJP to predict consumer juiciness ratings.

*Predicted probability percentages were determined by a previous study conducted by Woolley (2014).

**Actual percentage of "juicy" samples in current study.

Plotted points in figure are data points from current study.

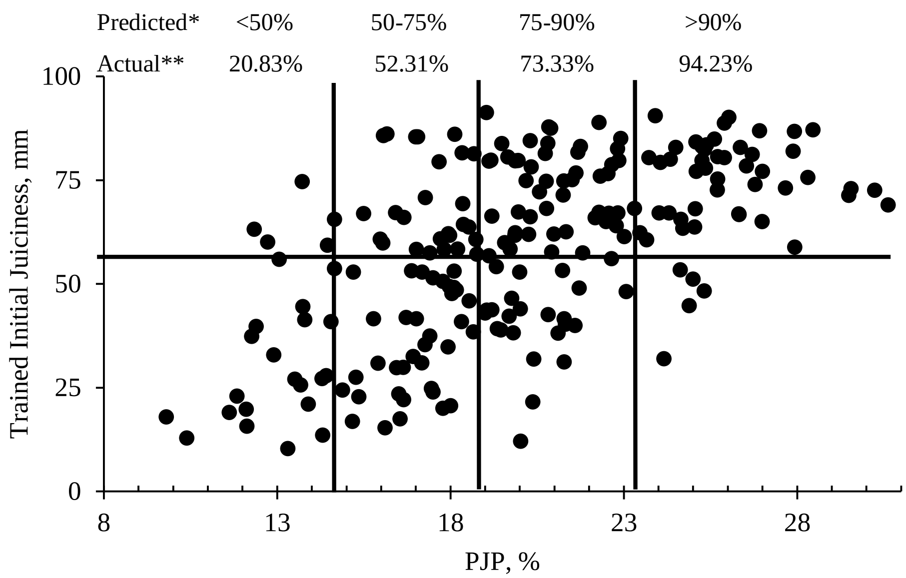

Figure 3.2 Use of instrumental juiciness classification PJP to predict trained initial juiciness ratings.

*Predicted probability percentages were determined by a previous study conducted by Woolley (2014).

**Actual percentage of "juicy" samples in current study.

Plotted points in figure are data points from current study.

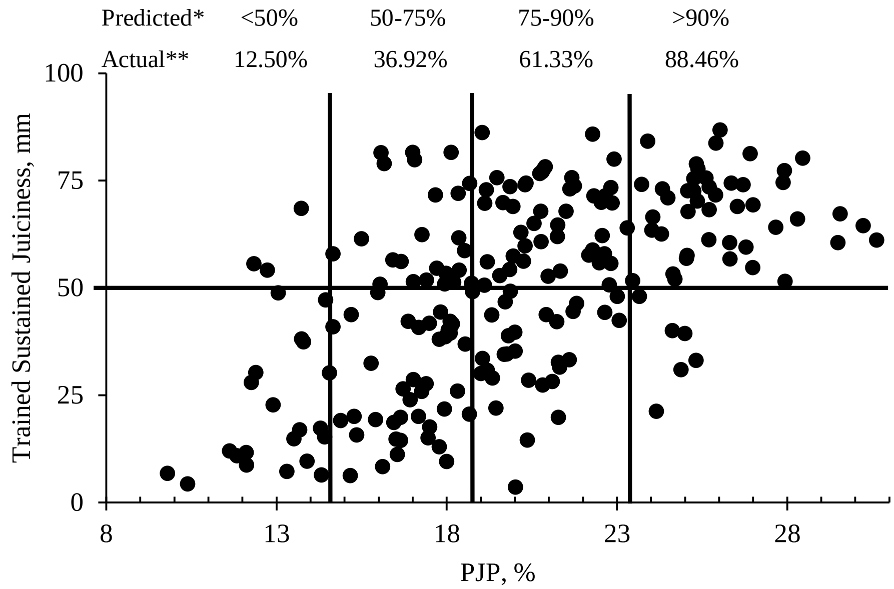

Figure 3.3 Use of instrumental juiciness classification PJP to predict trained sustained juiciness ratings.

*Predicted probability percentages were determined by a previous study conducted by Woolley (2014).

**Actual percentage of "juicy" samples in current study.

Plotted points in figure are data points from current study.

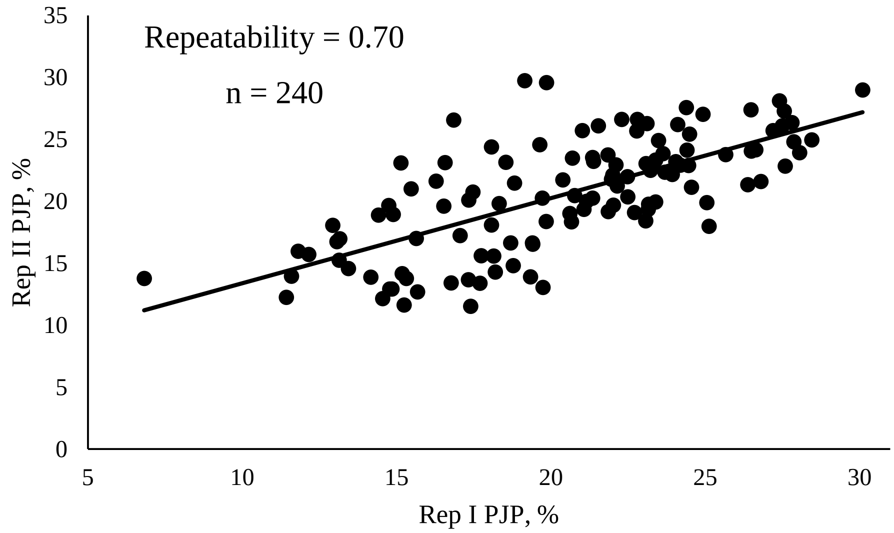

Figure 3.4 Repeatability of PJP.

Appendix A - Consumer and Trained Evaluation Forms

INFORMED CONSENT STATEMENT

1. I volunteer to participate in research involving Sensory Evaluation of Meat. This research will be conducted by personnel in the Department of Animal Sciences and Industry at Kansas State University.

2. I fully understand the purpose of the research is for the evaluation of beef steaks, pork chops, lamb chops, goat meat, poultry meat, ground meat, and processed meat products from the previously mentioned species for the sensory traits of tenderness, juiciness, flavor intensity, connective tissue amount, off flavor presence, odor, and color and sensory evaluation will last approximately one hour.

3. I understand that there are minimal risks associated with participating and that those risks are related to possible food allergies. All meat products will be USDA inspected and all ingredients are GRAS (generally accepted as safe) by FDA.

4. I understand that my performance as an individual will be treated as research data and will in no way be associated with me for other than identification purposes, thereby assuring confidentiality of my performance and responses.

5. My participation in this study is purely voluntary; I understand that my refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled and that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

6. If I have any questions concerning my rights as a research subject, injuries or emergencies resulting from my participation, I understand that I can contact the Committee on Research Involving Human Subjects, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, at (785) 532-3224.

7. If I have questions about the rationale or method of the study, I understand that I may contact, Dr. Travis O'Quinn, 247 Weber Hall, Kansas State University, Manhattan, KS 66506, at (785) 532-3469 or Sally Stroda, 107 Weber Hall, at 785-532-1273.

I have read the Subject Orientation and Test Procedure statement and signed this informed consent statement, this ________________________ day of _____________________, __________.

_______________________________   ____________________________

Printed name   Signature

Gender	**Household Size**	**Marital Status**	**Age**	**Ethnic Origin**
Male	1 person	Single	Under 20	African-American
Female	2 people	Married	20-29	Asian
	3 people		30-39	Caucasian/White
	4 people		40-49	Hispanic
	5 people		50-59	Native American
	6 people		Over 60	Other
	Over 6 people			

Annual Household Income	**Education Level**
Under $25,000	Non-high School graduate
$25,000 - $34,999	High school graduate
$35,000 - $49,999	Some College/Technical School
$50,000 - $74,999	College graduate
$75,000 to $100,000	Post graduate
more than $100,000	

How many times a week do you consume beef?

None 1 to 3 4 to 6 7 or more

When eating beef, which palatability trait is the most important to you (circle one)?

Flavor Juiciness Tenderness

When eating beef steaks, what degree of doneness do you prefer? (circle one)?

Very Rare Rare Medium-Rare Medium

Medium-Well Well-Done Very Well-Done

Which meat product do you prefer the flavor of the most (circle one)?

Beef Chicken Fish Lamb Mutton

Pork Shellfish Turkey Veal Venison

Juiciness:

Extremely Dry — Neither Dry nor Juicy — Extremely Juicy

Was the steak acceptable for juiciness? Yes ______ No ______

Tenderness:

Extremely Tough — Neither Tough nor Tender — Extremely Tender

Was the steak acceptable for tenderness? Yes ______ No ______

Flavor:

Dislike Extremely — Neither Dislike nor Like — Like Extremely

Was the steak acceptable for flavor? Yes ______ No ______

Overall Liking:

Dislike Extremely — Neither Dislike nor Like — Like Extremely

Was the steak acceptable for overall liking? Yes ______ No ______

Please check one of the following to **rate the quality** of the beef sample you have just eaten. Choose only **one** (you must make a choice).

Unsatisfactory ☐

Everyday quality ☐

Better than everyday quality ☐

Premium quality ☐

RECIPIENT INFORMATION

By signing this form, I certify that I received $20 cash for participation in a beef taste testing research study conducted by Kansas State University.

By signing this form, you are certifying that the information provided below is true and correct to the best of your knowledge.

Name ____

Address ____

City ____

State ____

Zip ____

Amount Received: $ **_20____**

______________________________________ ________________

Signature Date

Trained Sensory Evaluation Form

Panelist ID: ____________ Date: ______________ Time: ______________

Sample ID: ___________________

Initial Juiciness:
Extremely Dry | Neither Dry nor Juicy | Extremely Juicy

Sustained Juiciness:
Extremely Dry | Neither Dry nor Juicy | Extremely Juicy

Myofibrillar Tenderness:
Extremely Tough | Neither Tough nor Tender | Extremely Tender

Amount of connective
None | Abundant

Overall Tenderness:
Extremely Tough | Neither Tough nor Tender | Extremely Tender

Beef Flavor Identity:
Extremely Unbeef-like | Neither Unbeef-like nor beef-like | Extremely Beef-like

Beef Flavor Intensity:
Extremely Bland | Extremely Intense

Salt Flavor Intensity:
Extremely Bland | Extremely Intense

Off-Flavor Intensity:
Extremely Bland | Extremely Intense

Off-Flavor Description: (Please list if present) _______________________________
None Present

Appendix B - Data Sheets

Color Data Sheet

Steak #	Scan	L*	A*	B*

<u>PJP Data Sheet</u>

KSU ID #	rep	Weight of Filter paper	Filter paper + sample	Filter paper after press
	1			
	2			
	3			
	4			
	5			
	6			
	1			
	2			
	3			
	4			
	5			
	6			
	1			
	2			
	3			
	4			
	5			
	6			
	1			
	2			
	3			
	4			
	5			
	6			
	1			
	2			
	3			
	4			
	5			
	6			
	1			
	2			
	3			
	4			
	5			
	6			

Weight and Peak Temperature Data Sheet

Steak #	Raw Weight	Fat Weight	Peak Temp	Cooked Weight	DOD

Appendix C - Tables

Table C.1 Pressed Juice Percentage (PJP) thresholds and the corresponding predicted and actual percentage of beef strip loin steaks rated juicy by consumer panelists.

PJP Threshold Range (%)	Predicted probability of sample rated juicy (%)	Actual number of samples rated juicy	Total number of samples in PJP range	Actual percentage of samples rated juicy
< 14.64	< 50	10	24	41.67%
14.64 - 18.94	50 - 75	47	65	72.31%
18.94 - 23.25	75 - 90	67	75	89.33%
> 23.25	> 90	51	52	98.08%

Table C.2 Pressed Juice Percentage (PJP) thresholds and the corresponding predicted and actual percentage of beef strip loin steaks rated juicy for initial juiciness by trained panelists.

PJP Threshold Range (%)	Predicted probability of sample rated juicy (%)	Actual number of samples rated juicy	Total number of samples in PJP range	Actual percentage of samples rated juicy
< 14.64	< 50	5	24	20.83%
14.64 - 18.94	50 - 75	34	65	52.31%
18.94 - 23.25	75 - 90	55	75	73.33%
> 23.25	> 90	49	52	94.23%

Table C.3 Pressed Juice Percentage (PJP) thresholds and the corresponding predicted and actual percentage of beef strip loin steaks rated juicy for sustained juiciness by trained panelists.

PJP Threshold Range (%)	Predicted probability of sample rated juicy (%)	Actual number of samples rated juicy	Total number of samples in PJP range	Actual percentage of samples rated juicy
< 14.64	< 50	3	24	12.50%
14.64 - 18.94	50 - 75	24	65	36.92%
18.94 - 23.25	75 - 90	46	75	61.33%
> 23.25	> 90	46	52	88.46%

Table C.4 Pearson correlation coefficients for objective measurements of beef strip loin steaks varying in quality treatments and degree of doneness.

Measurement	USDA Marbling Score	Fat %	Protein %	Moisture %	Ash %	Slice Shear Force (N)
Fat %	0.89**					
Protein %	-0.22**	-0.21**				
Moisture %	-0.70**	-0.75**	0.12			
Ash %	-0.20**	-0.13	-0.13	0.26**		
Slice Shear Force (N)	-0.14*	-0.13	0.10	0.10	-0.31**	
Warner Bratzler (N)	-0.32**	-0.28**	0.31**	0.10	-0.40**	0.67**

**Correlation coefficient differs from 0 ($P < 0.01$).

*Correlation coefficient differs from 0 ($P < 0.05$).

Table C.5 Least squares means for objective measurements[1] of grilled strip loin steaks of varying treatments and degree of doneness.

Treatment	3 Sample PJP	6 Sample PJP
Non-Enhanced		
Prime	20.10	19.99
Low Choice	20.25	19.87
Low Select	19.88	19.79
Enhanced[2]		
Prime	20.02	19.93
Low Choice	20.30	20.08
Low Select	19.96	19.57
SEM[3]	0.53	0.56
P - value	0.9925	0.9919
Degree of Doneness		
Rare (60°C)	23.68[a]	23.40[a]
Medium (71°C)	20.38[b]	20.29[b]
Very Well Done (82°C)	16.20[c]	15.93[c]
SEM[3]	0.36	0.35
P - value	< 0.0001	< 0.0001

[1]Objective measurement consisted of pressed juice percentage that was pressed at 8 Kilograms of force for 30 seconds.

[2]Enhanced 108% of raw weight with a water, salt, alkaline phosphate solution.

[3]SEM (largest) of the least squares means.