IMPACT OF SHORTENED POSTMORTEM AGING TIMES AND USDA QUALITY GRADES ON BEEF TENDERNESS OPTIMIZATION IN THE FOOD SERVICE SECTOR

A Thesis

by

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ABSTRACT

Beef ribeyes, strip loins, and top sirloin butts were selected over two different replicates from Top Choice (Modest and Moderate marbling; $n = 26$), Choice (Small marbling; $n = 26$), and Select (Slight marbling; $n = 26$) carcasses to determine if today's more tender beef requires as many days of postmortem aging to ensure acceptable tenderness as in the past. Steaks were obtained from each subprimal and were allocated to 2, 4, 6, 8, 10, 12, 14, or 21 days of aging under refrigeration temperatures. At each aging period, steaks were cooked on flat-top grills for Warner-Bratzler Shear Force (WBSF) determinations. During the second set of steak tenderness assessments, a severe winter storm prevented the cooking of steaks from days 6 and 8, which were frozen, thawed, and evaluated later. Data were analyzed into include/exclude the day 6 and 8 frozen steaks or to only use the sampling period from the first replication of the study (replicate 1). For ribeye steaks, there were no ($P > 0.05$) grade x postmortem age interactions for any of the subprimals. Grade only impacted ($P < 0.05$) WBSF for ribeye steaks from Replicate 1 (Top Choice < Select;), strip loin steaks from fresh + frozen and without frozen (Choice < Top Choice and Select). Postmortem aging did impact ($P < 0.0001$) WBSF values for all subprimals with most of the differences occurring at day 10. Tenderness thresholds for percentages of steaks that were "Very Tender" or "Tender" support that most of the improvement in tenderness had occurred by day 10. Beef ribeyes, strip loins, and top sirloin butts from Top Choice, Choice, and Select beef carcasses require at least 10 days of postmortem aging to ensure acceptable tenderness, which is fewer days than most foodservice operators use for customer specifications.

DEDICATION

This work is dedicated to my parents. You both have raised me to never give up on my dreams, your support means the world to me. Thank you, mom, for supporting me on this earth, and more recently, in heaven. I love you both so much.

I also dedicate this work to Dr. Michael Seaquist, Class of ’62 and ’64. Without your inspiration, I wouldn’t have entered this industry. Thank you for knowing meat science was my passion before I even did.

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NOMENCLATURE

°C	Degrees Celsius
cm	Centimeter
g	Gram
h	Hours
HCW	Hot Carcass Weight
IMPS	Institutional Meat Purchase Specifications
kg	Kilogram
min	Minute
N	Newton
NBTS	National Beef Tenderness Survey
oz	Ounce
USDA	United States Department of Agriculture
WBSF	Warner-Bratzler Shear Force

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1. INTRODUCTION

Postmortem aging is a technique that has been researched for its effect on improving beef tenderness. Aging of fresh beef has become a standard for the U.S. industry for retail and foodservice to enhance consumer expectation and eating experience. Wet aging is described as vacuum packaging meat under refrigerated conditions that will produce acceptable tender and flavorful products within a shortened aging time (Parrish, Boles, Rust, & Olson, 1991). Space and cost limitations are ongoing challenges faced by the foodservice sector, amplified by seasonal fluctuations, holidays, and limited time offers, possibly leading to inconsistent post-fabrication aging times. It is important to emphasize that longer aging times do not always result in more tender product determined by Warner-Bratzler shear force measurements (Tindel, 2018). The National Beef Tenderness Surveys have documented that beef has become more tender overtime (Brooks et al., 2000; Guelker et al., 2013; Martinez et al., 2017; Morgan et al., 1991; Voges et al., 2007). The question that needs to be addressed is does today's beef need to age as long as current recommendations suggest? Tenderness may also be influenced by variations of marbling within beef. The amount of marbling present and degree of doneness can influence juiciness, tenderness, and flavor (Savell et al., 1987). With improved tenderness in today's cattle, the objective of this study was to assess the effect of shortened aging times and USDA quality grades on beef tenderness using Warner-Bratzler Shear Force determination.

2. LITERATURE REVIEW

2.1. Foodservice utilizing beef protein

Beef is a popular protein utilized in the foodservice industry. Consumers enjoy eating animal protein with their meals, making beef a one of the most popular foodservice items (Beef. It's What's For Dinner, 2019). Beef volume results in 51% of all protein growth and had the highest gain in volume compared to other protein sources like chicken and pork in 2017 (Technomic, 2017). In 2018, beef purchasing remained constant, however, the value of beef increased (Technomic, 2018). As an economic incentive, predicting beef tenderness is paramount. It was demonstrated that consumers will pay more for steaks that are known to be tender (Boleman et al., 1997; Koohmaraie, Wheeler, & Shackelford, 1995). Most common high-end meat cuts that restaurants use are ribeye, filet, strip steak, and flat iron. Pre-cut steaks only account for 13% of annual beef product volume ordered, but consists of 30% the value in price (Beef. It's What's For Dinner, 2019). Storing beef can be costly for the foodservice sector, inconsistencies with aging beef products can occur due to storage times. Achieving optimal tenderness that produces consistent tender beef steaks is crucial to limit the cost of storage while shortening the postmortem aging time.

The trend of eating away from home impacted the American diet since the 1970s (United States Department of Agriculture, 2019). Foodservice sectors have benefited from this change in lifestyle in the last fifty years as eating at home shifted to eating out more. In 1994, 40% of the consumer dollar was spent on food (Neel, Williams, Johnson,

& Reagan, 1994). Furthermore, nearly 40% of the consumer food dollar is spent in restaurants and eating establishments (Barkema, Drabenstott, & Novack, 2001). Trends in 2017 demonstrate American consumers spent $1.2 trillion on food, and the largest percentage of the food dollar went to foodservice establishments at 36.7 percent (Canning, 2019). Eating out at restaurants became popular due to food preparation convenience and consistency in dining quality. Food that is easily accessible and consistent will sustain the dining quality consumers look forward to when eating out. Cuts from the middle meat region, rib and loin, of the beef carcass, capture higher percentages of beef sales than other primal cuts (Neel et al., 1994). Middle meats can generate more than 50% of beef sales, although this can fluctuate based on region within North America (Neel et al., 1994). Utilizing middle meat cuts combined with higher quality grades, such as USDA Choice and USDA Prime, can increase palatability and enhance eating satisfaction for consumers. Establishments purchase lower beef volume of lesser quality grades to minimize palatability issues (Neel et al., 1994). Quality grades may influence palatability and tenderness while aging beef products may further enhance consumer satisfaction.

2.2. Factors influencing meat tenderness

USDA Beef Quality Grades are derived at the interface of the 12th and 13th rib and are generated based on the amount of intramuscular fat present, carcass maturity, texture, and color of lean at the 12th and 13th rib (Hale, Goodson, & Savell, 2013). There are nine degrees of marbling from practically devoid to abundant. Variations of marbling exist within each quality grade that provide differences in eating experience. The greater amount of marbling within a steak will enhance flavor and tenderness compared to a leaner product. Foodservice establishments advertise using USDA Prime, USDA Choice, and USDA Select grades for steak consumption. In Phase 1 of the National Consumer Retail Beef Study, there was a significant effect between marbling levels and degree of doneness (Savell et al., 1987). It is possible that steaks with higher degrees of marbling would be more acceptable to consumers when cooked at a higher degree of doneness, such as "medium-well" and "well," compared to steaks with lower marbling levels cooked to the same degree of doneness may be considered tough and dry (Savell et al., 1987). Trace amounts of marbling can decrease the flavor rating, juiciness of the steak, and decrease tenderness ratings for trained sensory evaluations with correlation to an increase in Warner-Bratzler Shear Force values (Savell et al., 1987).

Cuts of beef varying from carcass location may affect eating experience. Strip loin steaks are popular within the foodservice industry and commonly used for consumer tenderness evaluation research. Strip loins steaks can be used to determine tenderness by consumer perception (Boleman et al., 1997). Top sirloin steaks are also favored for restaurant menus due to portion size (Beef. It's What's For Dinner, 2018). Top sirloin steaks are known to be less tender with high variability in tenderness compared to strip loin steaks (Harris, Miller, Savell, Cross, & Ringer, 1992). Aging top sirloin steak is necessary to improve consumer perception of tenderness due high variability during cooking and sarcomere lengths in the *M. gluteus medius*. Shorter sarcomere lengths typically cause the steak to be less tender (Harris et al., 1992; Tindel, 2018). *M. gluteus medius* had an average sarcomere length of 1.66 μm (Rhee, Wheeler, Shackelford, &

Koohmaraie, 2004), which was shorter than the *M. longissimus thoracis et lumborum* sarcomere lengths that averaged 1.78 μm (Ertbjerg & Puolanne, 2017).

It is known that the age of an animal is associated with tenderness (Shorthose & Harris, 1990). Tenderness is affected by muscle location, usage, and influenced by the animals age (Shorthose & Harris, 1990). The younger the animal is, the more tender the muscle will be when converted to meat. The myofibrillar strength varies with age and can be affected by chilling rates, pH, and cooking conditions (Harris, 1976; Shorthose & Harris, 1990). Physiological age of an animal can influence the amount of connective tissue that will form heat-stable cross-linkages in collagen. As the animal's age increases, structural changes in collagen will occur and increase the number of covalent crosslinks collagen acquires (Shimokomaki, Elsden, & Bailey, 1972). Toughness within muscles can be due to the connective tissue strength, related to the age of the animal (Shorthose & Harris, 1990).

Postmortem aging is a common technique used to improve meat quality and tenderness. Tenderization occurs due to proteolysis during breakdown of proteins. Postmortem aging provides muscle structure weakening that affects structural protein integrity at the sarcomere level. Aging meat is influenced by endogenous muscle enzymes (Wilson, 1957), myofibrillar muscle cell tensile strength loss, and muscle fibers shortening during the phases of rigor mortis (Davey, Kuttel, & Gilbert, 1967; Smith, Culp, & Carpenter, 1978). There are two calpain proteases that are required for activity for postmortem tenderization; μ-calpain and m-calpain. μ-calpain is considered the primary protease to activate postmortem aging but is regulated by the inhibitor, calpastatin (Koohmaraie & Geesink, 2006; Pomponio & Ertbjerg, 2012). When μ-calpain is activated, it can autolyze, leading to a loss of activity (Koohmaraie & Geesink, 2006). Calpains cause z-disc degradation, which alters myofibrils in the Z-line region, affecting the integrity of the muscle structure. With the dissolution of Z-line material, it can lead to the weakening inter-myofibrillar linkages and loss of tensile strength in myofibrils (Davey & Gilbert, 1969). The most noticeable indicator of aging is the fading of Z lines as it disintegrates the myofibrils during aging. Aging occurs immediately after the slaughter process and continues typically under refrigerated conditions. The initial 24 hr period of cooling carcasses can impact meat quality (Savell, Mueller, & Baird, 2005). The muscle experiences rigor mortis, a biochemical change in the muscle that occurs shortly after death. After 24 hours, enzymatic degradation within muscle tissue occurs (Savell et al., 2005). Chilling carcasses too quickly can cause a high degree of overlap between sarcomeres and muscle fibers (Savell et al., 2005). Cold shortening is a consequence of rapid chilling that can affect the contractile state of muscle. With the decrease in temperature, shortening increases, decreasing tenderness of the product (Olsson, Hertzman, & Tornberg, 1994). The contractile state with more degrees of overlap in the sarcomeres can indicate tougher meat.

Collagen's ability to breakdown is related to the meat tenderness and affects WBSF values. The structural weakening of myofibrils can rapidly increase tenderness, however, the intramuscular connective tissue structural weakening is a slower process (Nishimura, Liu, Hattori, & Takahashi, 1998). As postmortem aging continues, intramuscular connective tissue will weaken to improve overall beef tenderness. To evaluate mechanical properties to determine the weakening mechanism of aged meat, raw beef was used in Nishimura et al. (1998) study. Nishimura et al. (1998) determined that shear force values rapidly decreased up to 10 d, then gradually decreased up to 35 d. Although cooking drastically affects shear properties of meat (Bouton, Harris, & Ratcliff, 1981), raw beef shear force measurements can be a predictor of cooked shear force values (Nishimura et al., 1998). Under refrigerated conditions, for raw and cooked beef, tenderization rapidly occurs within the first 10 d postmortem and proceeds gradually with no significant differences between 14 and 21 d and 21, 28, and 35 d (Nishimura et al., 1998). Storing meat above freezing conditions improves tenderness and palatability throughout the aging process (Laster et al., 2008; Parrish et al., 1991). It is crucial to age the meat above freezing temperatures to assure meat will become more tender, however, it also increases beef storage inventories (Smith et al., 1978). Aging 11 d postmortem deemed to produce optimal tenderness without any further advancements in 14, 21, or 28 d steaks taken from the *longissimus* muscle from the chuck and rib for USDA Choice steaks (Smith et al., 1978). Warner-Bratzler Shear Force values for strip loin steaks were significantly lower for 12 d and 16 d days compared to 4 d (Davis, Huffman, & Cordray, 1975). Extended aging times allow protein degradation and weakening of muscle ultrastructure to ensure more tender meat.

2.3. Beef importance in foodservice

The National Cattlemen's Beef Association released an assessment of beef usage in the foodservice sector in 2017, resulting in key findings of: (1) of all proteins, beef had the highest gain in volume; (2) beef is up 2.8% for two consecutive years; (3) there has been a rebound in premium, pre-cut steaks; (4) forty-five percent of operators say that having a steak on the menu increases traffic (Technomic, 2017). Comparing the data from the 2017 and 2018 beef usage in the foodservice sector, the importance of having steak on the menu increased traffic from 56% in 2017 to 72% in 2018 (Technomic, 2017, 2018). Restaurants also noticed a large increase in check averages due to steaks on the menu that contributed to bringing in bigger parties (Technomic, 2018). With the increase of beef in food service expected to continue to trend upward, it is paramount to provide consistent, high-quality beef products to ensure positive customer experiences. The purpose of this study is to re-evaluate the postmortem beef aging curve across three subprimal types and three USDA quality grades commonly used by foodservice operators. Data from this study may impact the beef industry by supporting lower minimum aging targets, thus optimizing beef tenderness, and creating an opportunity to improve the consistency of beef sold throughout foodservice outlets.

3. MATERIALS AND METHODS

3.1. Product Collection

Beef carcasses, from a Texas commercial beef harvest and processing facility that used instrument-assisted grading technology, were selected for this study across three USDA quality grades: upper two-thirds USDA Choice (n = 26), lower one-third USDA Choice (n = 26), and USDA Select (n = 26). USDA-certified, branded beef programs with carcass specifications focusing on marbling scores of Modest to Moderate were termed "Top Choice" or "Upper 2/3rd Choice." Carcasses with marbling scores of Small^{00} were termed "Choice" or "Lower 1/3rd Choice." Carcass with marbling scores of Slight^{00} were termed "Select." Other selection criteria included: under 30 months of age, carcass weight range within 317 kg to 453 kg, and no dairy or *Bos indicus* influence, indicated visually by carcass conformation or hump height. Two product collections occurred within a year from each other and 13 carcasses per quality grade (n = 39) were collected in the first replication and 13 carcasses per quality grade (n = 39) were collected in the second replication. Five subprimals were not collected due to misplacement during fabrication; one Select strip loin from the first replication, three Select ribeyes and one Choice ribeye from the second replication.

Institutional Meat Purchase Specifications (IMPS) are described by (USDA, 2014) were used for nomenclature purposes. From each carcass, one each of the following subprimals were procured: ribeye roll, lip-on, boneless (IMPS 112A; n = 22), striploin, boneless (IMPS 180; n = 25), and top sirloin butt, boneless (IMPS 184; n =

26). All subprimals were vacuum packaged and shipped via refrigerated truck to Rosenthal Meat Science and Technology Center (College Station, TX).

3.2. Cutting

Upon arrival, eight steaks were portioned from each subprimal using a Butcher Boy boneless saw (Model B16-F; Serial No. 7-19567, Butcher Boy Machines, International LLC, Selmer, TN). Aging period began the day of subprimal fabrication and were cut into individual steaks two days postmortem. Ribeye steaks were cut caudal-to-cranial end at the $12/13^{th}$ face and numbered in this manner. Strip loin steaks were cut from the $12/13^{th}$ face cranial-to-caudal and numbered in this manner. Ribeye and strip loin steaks were not to exceed 0.32-cm visible fat with no more than 2.54-cm length tail. Boneless top sirloin butt steaks, similar composition to IMPS 184 (primarily consisting of the *M. gluteus medius*, removing the *M. gluteobiceps*, the *M. gluteus profundus*, and *M. gluteus accessorius*) were cut into five, 2.54-cm-thick portions from each subprimal, cut cranial-to-caudal. Portions were identified as 1, 2, 3, 4, and 5. Only portions 2, 3, and 4 were used and cut into thirds to produce nine steaks for each subprimal. Portion 2 was sectioned into steaks 1, 2, and 3. Portion 3 was sectioned into steaks 4, 5, and 6. Portion 4 was sectioned into steaks 7, 8, and 9.

Each steak was randomly assigned to an aging treatment (2, 4, 6, 8, 10, 12, 14, 21 d postmortem), individually identified, vacuum-packaged in 2.0 mil Sealed Air Food Care vacuum bags (Item No. B2470, Sealed Air, Charlotte, NC) and sealed with an Ultravac Double Chamber Vacuum Packaging Machine (Model 2100-D; Kansas City, MO), and stored under refrigerated conditions. Steaks were not frozen prior to the analyses except for day treatment 6 and 8 in the second replication of this study due to Winter Storm Uri. Norton (2021) reported energy producers were unable to provide power to most of Texas due to power plants not optimized for freezing conditions. With the rapid surge of energy usage, the state's power grid malfunctioned, causing power failures without any option of channeling energy from outside sources (Norton, 2021). With the prolonged outages, a series of energy and water crises occurred that impacted facilities to shut down the week of February 13 – 17, 2021 (HARC, 2021). Without energy and running water, we were unable to cook and analyze these day treatments on their desired cooking day, however, steaks were allowed to age to their desired day treatment prior to being frozen. Steaks were cooked between the 14 and 21 d period so the study could continue during the desired age treatments. Frozen steaks were kept in their vacuum packaged bags, placed single layer in wire baskets to prevent stacking or overlapping, and placed in the -40 °C to freeze, although recording of temperature was unreliable with the power outages that occurred, until further notice to cook and analyze these treatments. Steaks were thawed at 2 to 5 °C for 48 h prior to cooking.

3.3. Dry-heat cookery

Upon completion of each aging treatment, raw steaks were weighed on a calibrated digital scale and internal temperatures were monitored using ThermoWorks omega readers and thermocouples (Model: THS-298-721; ThermoWorks, American Fork, UT 84003) with a 0.02-cm diameter, copper-constantan Type-T thermocouple wire, inserted in the geometric center of each streak, prior to cooking. During cooking, ThermoWorks pen readers were used as needed (Model: Thermapen Mk4;

ThermoWorks, American Fork, UT 84003). Steaks were cooked on two 2.54-cm-thick flat tops (Star Max 536TGF 91.44-cm Countertop Electric Griddle with Snap Action Thermostatic Controls and Star Max Electric Griddle Model 524TGF-DIV 1.91-cm, Star International Holdings Inc. Company, St. Louis, MO). Grills were preheated to 177 °C, ± 3 °C. Grill surface was checked with handheld instantaneous infrared thermometer (Model: IRT-2 Infrared, ThermoWorks, American Fork, UT 84003). Once the internal steak temperature reached 35 °C, steaks were flipped and removed from grill when final temperature reached 70 °C. Cook time, initial and final temperatures, raw weight, and final cooked weight were recorded for each steak. After the desired internal temperature was reached, steaks were removed, weighed, and placed on single layered plastic trays, covered with plastic wrap, and stored in refrigerated conditions (4 °C) for a minimum of 12 h, but no longer than 18 h to shear the following day.

3.4. Warner-Bratzler Shear Force

Chilled steaks were equilibrated to room temperature before coring. Steaks were trimmed free of visible connective tissue to expose muscle fiber orientation. Using a handheld coring device, six (1.27-cm diameter) cores were taken, when possible, from the *M. longissimus thoracis et lumborum* and a minimum of three cores were obtained from *M. gluteus medius*, avoiding connective tissue and excess fat deposits when possible. All cores were removed parallel to the muscle fiber orientation and sheared once, perpendicular to the muscle fibers, on a Warner-Bratzler shear machine (TMS – Pro Food Texture Analyzer, Model: Food Technology Corporation, (19-1001-06. SRS:N = 061900012810), Sterling, VA). A 10-kg load cell and 1.02-cm V-shape blade with 60-

degree angle, half round peak used, with a speed of 200 mm/min and calibration of the unit was conducted after every 60 shears or every 10 steaks. The peak force (kg) was recorded for each core and converted to Newtons (N), and the mean peak shear force value of cores from each steak were used for statistical analysis.

3.5. Statistical Analyses

Data analyses were performed using Statistical Analysis System (SAS Institute Inc., Cary, NC). Warner-Bratzler Shear Force, cook time, and cook yield were analyzed using PROC MIXED to perform analysis of variance (ANOVA) for three data analysis. Three sets of data were analyzed; fresh and frozen data, fresh only data excluding 6 and 8 d treatments from the second replication that were frozen and replicate 1 of the study. This was done to represent accurate aging to see if freezing steaks affected the tenderness of the current study. Fixed Effects Tests were used to determine significance in grade, age, and grade x age interaction. Main effects were categorized by quality grade (Top Choice, Choice, and Select), aging treatment days (2, 4, 6, 8, 10, 12, 14, and 21), and age and quality grade interaction. Cook temperature was included in the model as a covariate, animal ID and steak position were included as random effects, and age was a repeated measure. When significance was determined ($P < 0.05$), least squares comparisons were conducted when appropriate using a pairwise *t*-test with an alpha-level 0.05. Percentage distribution of WBSF values were analyzed in JMP to categorize tenderness according to Belew, Brooks, McKenna, and Savell (2003).

4. RESULTS AND DISCUSSION

4.1. Warner-Bratzler shear force

Aging ($P < 0.0001$) and quality grade ($P = 0.002$) affected Warner Bratzler Shear Force (WBSF) values for fresh and frozen strip loin steaks, but the interaction was not significant ($P = 0.7420$) (Table 2). The decline in WBSF was expected with extended postmortem aging treatments. Brooks et al. (2000) reported that little quality group effect on WBSF values in ribeye and strip loin steaks could be due to tender beef within quality grade. This contradicts the current findings in this study due to quality grade affected strip loin steaks (Tables 2 and 5). However, ribeye and top sirloin steaks were not affected. Quality grade ($P = 0.002$) and aging ($P < 0.0001$) affected fresh only strip loin steaks (Table 2). Choice was more tender than Top Choice and Select. Aging affected strip loin steaks in replicate 1 ($P < 0.0001$) (Table 8). All data for strip loin steaks had lowest WBSF on 21 d. Wheeler, Miller, Savell, and Cross (1990) reported fresh, chilled top loin steaks with 20 d or more of aging had lower WBSF values than frozen steaks with 14 d aging. However, there was no significant differences in tenderness between chilled steaks aged at 13 d compared to frozen 14 d top loin steaks (Wheeler et al., 1990). In the current study, freezing was not controlled, and storage conditions were inconsistent and not documented. Freezing most likely influenced tenderness for steaks aged 6 d and 8 d and subsequently frozen in replication 2. Data analyzed without frozen increased WBSF values nearly 2.7 and 3.4 N, for 6 and 8 d (Table 5). To thoroughly understand if freezing treatment was confounding results, replication 1 steaks that were not frozen were examined (Table 8). Aging time affected ($P < 0.0001$) WBSF for replicate 1 strip loin steaks. Strip loin steaks aged to 10 d had lower WBSF than strip loin steaks for shorter times. With increased aging to 21 d, WBSF continued to decrease. For inherently tender strip loin steaks, aging 10 d will provide optimal tenderness, or 21 d for maximum WBSF.

Aging affected WBSF for fresh and frozen ribeye steaks ($P < 0.0001$) (Table 1). The decline in WBSF values was expected with extended postmortem aging treatments. The interaction of aging time and USDA quality grade was not significant ($P = 0.59$). Frozen steaks aged 6 and 8 d had lower WBSF compared to all ribeye steaks regardless of quality grade or aging time. Lagerstedt, Enfält, Johansson, and Lundström (2008) reported freezing steaks from the *M. longissimus dorsi* had lower peak force values compared to fresh, chilled steaks. However, longer aging times and freezing steaks that were allowed to thaw, resulted in higher water loss percentage compared to chilled, fresh steaks that were aged to the same day (Lagerstedt et al., 2008). Jones, Jeremiah, Tong, Robertson, and Lutz (1991) indicated that marbling levels can cause significant changes in drip loss when thawing frozen ribeye steaks. This is a result of the level of fat content and moisture content within the meat. As marbling levels increase, the fat content increases and the moisture level decreases (Jones et al., 1991). This most likely influenced the purge loss in steaks that were frozen in the current study. Aging affected WBSF values for fresh only ribeye steaks ($P < 0.0001$) (Table 4). Aging steaks from 2 to 8 d had little influence on tenderness determined by WBSF and the lowest WBSF on 21 d (Table 4). As longer aging time occur, shear force values decline (Lagerstedt et al., 2008). Ribeye steaks were inherently tender, so the recommendation for steaks should be aged to 10 d for optimal WBSF and reduced cost of storage. Additional aging had little impact on improving tenderness, however, the maximum WBSF values were held at 21d.

Quality grade did not affect ribeye steak WBSF values for fresh and frozen (P = 0.09) and fresh only (P = 0.10) (Table 1 and 4). Brooks et al. (2000) and Wheeler, Shackelford, and Koohmaraie (1999) found that quality grade had little to no effect on steaks that were already considered very tender or tender. The effect of quality grade for fresh ribeye steaks from Replicate 1, quality grade (P = 0.009) affected WBSF (Table 7). Top Choice was more tender than Choice and Select.

Aging affected WBSF values for fresh and frozen top sirloin steaks (P < 0.0001) (Table 3). The interaction of aging time and quality grade was not significant (P = 0.99). With extended aging, WBSF values decreased. It has been known that top sirloin steaks require longer aging times, compared to ribeye or strip loin steaks, to improve tenderness. Harris et al. (1992) reported overall tenderness improvements occurred for top sirloin steaks after 28 d compared to top loin steaks had muscle fiber tenderness improvements after 7 d postmortem with improved tenderness with extended aging. Frozen steaks decreased WBSF values on 8 d by 4.6 N (Table 3) compared to data from fresh only top sirloin steaks (Table 6). Additional postmortem aging results in improved tenderness, regardless of fresh, chilled treatments or freezing treatments (Wheeler et al., 1990).Wheeler et al. (1990) indicated fresh, chilled top sirloin steaks aged 20 d were most tender compared to frozen 7 d steaks that were least tender. In contrast, the present study found 6 d and 8 d steaks had lower WBSF values compared to the fresh, chilled steaks of the same age day. With continued aging, 21 d fresh steaks were considered the most tender (Table 3), in accordance with Wheeler et al. (1990) study. Aging affected fresh only top sirloin steaks ($P < 0.0001$) (Table 6) and Replicate 1 ($P < 0.0001$) (Table 9).

USDA quality grade did not affect top sirloin steaks. In a study done by Bratcher, Johnson, Littell, and Gwartney (2005) on various muscles from the chuck and round from Upper two-thirds Choice grade and USDA Select, the majority of WBSF value improvements occurred by 14 d postmortem for quality grades evaluated. In the current study, WBSF value improvements seemed to have occurred between 8 and 10 d, concluding that beef steaks became more tender within a shorter aging period. For optimal tenderness, top sirloin steaks should be aged to 10 d postmortem regardless of marbling level.

4.2. Tenderness thresholds

Tenderness thresholds according to Belew et al. (2003) were used to categorize "very tender," "tender," "intermediate," and "tough" based on WBSF values (Tables 10-18). Strip loin steaks from all replications and top sirloin steaks from Replicate 1 had the highest percentages of "very tender" steaks on 2 d, indicating steaks would have improved tender overtime within the current study. Top sirloin steaks had the highest percentages (32.1) in the "tender" category on 2 d, followed by ribeye steaks (25.6 and 28.2. On 21 d, strip loin steaks had the highest percentage (92.2 and 97.3) in the "very tender" category. Top sirloin steaks had the highest percentage (2.5 and 5.1) of the “intermediate” category on 21 d. All ribeye steaks were categorized as “tender” and “very tender” by 14 d. Ribeye did not have any steaks categorized as “tough” in any replications after 10 d, compared to top sirloin steaks had the highest percentage (1.3) in the “tough” category on 21 d.

Comparing the present study to Belew et al. (2003) study, at 14 d, Belew recorded WBSF values for *M. longissimus lumborum* to be 33.34 N, *M. longissimus thoracis* to be 34.32 N, and *M. gluteus medius* to be 35.59 N. These values were higher than the current study that recorded an average to be 24.67 N, 24.80 N, and 27.27 N, respectively. This concluded that the values in the current study would be categorized as “very tender” in contrast to Belew values would be categorized as “tender.” This concludes that beef steaks have become more tender over time with shorter aging times.

4.3. Cook data

Cook yield (%) and cook time (s) data across ribeye, strip loin, top sirloin steaks within fresh and frozen, fresh only, and replicate 1 analysis are shown in Tables 1-9. Data analyses including frozen steaks had significant differences in cook yield and cook time possibly due from the increased purge loss from frozen steaks. This resulted in lower cook yields and shorter cook times within the aging treatment. Wheeler et al. (1990) reported tissue damage from steaks being frozen can result in greater water loss and faster cooking times, thus resulting in greater cooking loss for frozen steaks. Lagerstedt et al. (2008) reported frozen steaks from the *M. Longissimus dorsi* had combined water loss significantly higher in frozen steaks that were thawed compared to fresh, chilled steaks. This indicated that frozen steaks acquired more purge loss than chilled steaks. Lagerstedt et al. (2008) also reported that over the aging period from 2 d to 14 d, the combined water loss decreased compared to the chilled steaks. At 7 d postmortem, there was a significant difference in combined water loss compared to at 14 d differences were not detected (Lagerstedt et al., 2008). The current study did not record this data; however, this data potentially could have provided evidence for determining the significant differences in tenderness from fresh and frozen steaks.

Quality grade affected cook yield and cook time, but there were no apparent trends. Choice seemed to have cooked at a faster cook time compared to the other quality grades, with Select taking the longest to cook. Although all steaks were cut as close to 2.54-cm as possible, if there are inconsistencies in thickness of steaks across ribeye, strip loin, and top sirloin steaks, cookery methods may need to be modified in order to keep consistency.

5. CONCLUSIONS

The objective of this study was to assess the effect of shortening aging times and USDA quality grades on ribeye, strip loin, and top sirloin steaks using Warner-Bratzler Shear Force (WBSF) determination. Beef is more tender than it has been prior to postmortem aging. The current challenge for the beef industry with inherently tender meat is does beef need to be aged as long as current recommendations suggest. Findings from our research indicate that steaks can be aged to 10 d postmortem for optimal tenderness, with little improvements in WBSF values up to 21 d. Strip loin and ribeye steaks had the lowest WBSF values and top sirloin steaks represented the highest WBSF values. Most steaks were initially considered tender at 2 d postmortem and had the lowest WBSF values at 21 d. Morgan et al. (1991) recorded an overall WBSF values for ribeye and strip loins to be 32.95 N and 31.09 N. The current study showed improved tenderness in WBSF values for ribeye and strip loin steaks to be 22.9 N and 22.6 N, respectively. These data demonstrate that aging ribeye, strip loin, and top sirloin steaks to 10 d postmortem will provide optimal tenderness levels for the foodservice industry to find comfort in utilizing without extended storage time and cost. If permitted, aging to 21 d will allow maximum tenderness. Future research could explore the tenderness differences within 14 and 21 d to ensure a minimum tenderness target.

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APPENDIX A

TABLES

Table 1
Least squares means for main effects associated with strip loin steaks (fresh and frozen)

Main Effects	WBSF (N)	Cook Yield (%)	Cook Time (s)
n	616	616	614
Cook Temp (*P*-Value)	0.98	0.97	0.55
Quality Grade[1] (*P*-Value)	0.002	0.04	0.01
Top Choice	$26.6^{b} \pm 0.91$	$81.7^{ab} \pm 0.71$	$837.6^{b} \pm 25.81$
Choice	$23.2^{a} \pm 0.91$	$82.6^{b} \pm 0.71$	$774.6^{ab} \pm 25.83$
Select	$27.6^{b} \pm 0.92$	$81.3^{a} \pm 0.71$	$811.6^{a} \pm 25.99$
Aging (day) (*P*-Value)	<0.0001	0.09	<0.0001
2	$28.8^{d} \pm 0.79$	82.4 ± 0.84	$774.3^{ab} \pm 30.84$
4	$28.4^{d} \pm 0.78$	81.5 ± 0.84	$849.1^{cd} \pm 30.61$
6	$27.4^{d} \pm 0.78$	81.0 ± 0.84	$805.0^{bc} \pm 30.49$
8	$23.9^{ab} \pm 0.78$	82.5 ± 0.84	$777.6^{abc} \pm 30.61$
10	$25.1^{bc} \pm 0.78$	81.3 ± 0.84	$900.1^{d} \pm 30.56$
12	$25.6^{c} \pm 0.78$	81.2 ± 0.83	$812.9^{bc} \pm 30.49$
14	$24.6^{bc} \pm 0.78$	81.8 ± 0.84	$802.1^{abc} \pm 30.51$
21	$22.7^{a} \pm 0.78$	83.0 ± 0.84	$742.2^{a} \pm 30.49$
Age x Quality Grade interaction (*P*-Value)	0.74	0.72	0.84

[1]Quality grade group = (USDA, 2016): (1) Top Choice (Modest and Moderate marbling scores and representative of the upper 2/3's Choice grade), (2) Choice (Small marbling scores and representative of the lower 1/3rd Choice grade), and (3) Select (Slight marbling).
Means within a column and within a category or method lacking a common letter (a-b) differ ($P < 0.05$).

Table 2
Least squares means for main effects associated with strip loin steaks (without frozen)

Main Effects	WBSF (N)	Cook Yield (%)	Cook Time (s)
n	538	538	536
Cook Temp (*P*-Value)	0.97	0.76	0.68
Quality Grade[1] (*P*-Value)	0.005	0.004	0.02
Top Choice	$26.9^{b} \pm 1.09$	$81.4^{a} \pm 1.06$	$861.3^{b} \pm 44.00$
Choice	$24.2^{a} \pm 1.09$	$82.4^{b} \pm 1.06$	$790.7^{a} \pm 44.01$
Select	$28.6^{b} \pm 1.10$	$80.7^{a} \pm 1.06$	$828.2^{ab} \pm 44.17$
Aging (day) (*P*-Value)	<0.0001	0.005	<0.0001
2	$28.8^{de} \pm 0.94$	$82.4^{bc} \pm 1.11$	$772.9^{ab} \pm 46.45$
4	$28.4^{de} \pm 0.94$	$81.5^{ab} \pm 1.11$	$849.4^{cde} \pm 46.29$
6	$30.1^{e} \pm 1.14$	$80.8^{ab} \pm 1.22$	$852.9^{cde} \pm 52.17$
8	$27.3^{cd} \pm 1.14$	$79.9^{a} \pm 1.22$	$883.1^{de} \pm 52.22$
10	$25.1^{b} \pm 0.94$	$81.3^{ab} \pm 1.11$	$899.3^{e} \pm 46.25$
12	$25.6^{bc} \pm 0.94$	$81.2^{ab} \pm 1.11$	$812.6^{bcd} \pm 46.21$
14	$24.6^{b} \pm 0.94$	$81.8^{bc} \pm 1.11$	$802.0^{abc} \pm 46.23$
21	$22.7^{a} \pm 0.94$	$83.1^{c} \pm 1.11$	$741.7^{a} \pm 46.22$
Age x Quality Grade interaction (*P*-Value)	0.46	0.36	0.88

[1]Quality grade group = (USDA, 2016): (1) Top Choice (Modest and Moderate marbling scores and representative of the upper 2/3's Choice grade), (2) Choice (Small marbling scores and representative of the lower 1/3rd Choice grade), and (3) Select (Slight marbling).
Means within a column and within a category or method lacking a common letter (a-b) differ ($P < 0.05$).

Table 3

Least squares means for main effects associated with strip loin steaks (replicate 1)

Main Effects	WBSF (N)	Cook Yield (%)	Cook Time (s)
N	304	304	303
Cook Temp (*P*-Value)	0.94	0.58	0.59
Quality Grade[1] (*P*-Value)	0.07	0.02	0.08
Top Choice	25.3 ± 1.26	82.4^{ab} ± 0.53	820.6 ± 26.75
Choice	24.5 ± 1.26	83.4^{b} ± 0.53	743.9 ± 26.75
Select	28.5 ± 1.32	81.6^{a} ± 0.55	797.9 ± 27.75
Aging (day) (*P*-Value)	<0.0001	<0.0001	<0.0001
2	28.2^{de} ± 0.98	85.9^{d} ± 0.74	643.4^{a} ± 36.15
4	25.7^{bc} ± 0.96	83.2^{c} ± 0.72	782.3^{bc} ± 34.55
6	29.7^{e} ± 0.97	81.8^{abc} ± 0.72	815.2^{bcd} ± 34.70
8	26.9^{cd} ± 0.97	80.8^{ab} ± 0.72	844.7^{cd} ± 34.80
10	24.5^{b} ± 0.97	82.4^{bc} ± 0.72	830.3^{cd} ± 34.60
12	26.7^{cd} ± 0.97	80.4^{a} ± 0.72	872.6^{d} ± 34.55
14	24.8^{b} ± 0.97	82.4^{bc} ± 0.72	775.9^{bc} ± 34.62
21	22.3^{a} ± 0.97	82.7^{c} ± 0.72	735.3^{b} ± 34.59
Age x Quality Grade interaction (*P*-Value)	0.11	0.81	0.95

[1]Quality grade group = (USDA, 2016): (1) Top Choice (Modest and Moderate marbling scores and representative of the upper 2/3's Choice grade), (2) Choice (Small marbling scores and representative of the lower 1/3rd Choice grade), and (3) Select (Slight marbling).

Means within a column and within a category or method lacking a common letter (a-b) differ ($P < 0.05$).

Table 4

Least squares means for main effects associated with ribeye steaks (fresh and frozen)

Main Effects	WBSF (N)	Cook Yield (%)	Cook Time (s)
n	592	592	591
Cook Temp (*P*-Value)	0.28	0.88	0.87
Quality Grade[1] (*P*-Value)	0.09	0.51	<0.0001
Top Choice	26.4 ± 0.88	80.3 ± 0.77	896.5^{b} ± 48.82
Choice	25.1 ± 0.87	80.8 ± 0.78	784.9^{a} ± 49.11
Select	27.5 ± 0.83	80.2 ± 0.77	881.2^{b} ± 48.82
Aging (day) (*P*-Value)	<0.0001	0.05	0.02
2	30.1^{d} ± 0.84	81.6^{b} ± 0.92	836.8^{a} ± 51.75
4	28.9^{cd} ± 0.84	80.2^{ab} ± 0.91	863.8^{a} ± 51.57
6	27.7^{c} ± 0.84	79.1^{a} ± 0.91	860.7^{a} ± 51.57
8	25.8^{b} ± 0.84	79.9^{a} ± 0.91	834.8^{a} ± 51.62
10	25.2^{b} ± 0.84	80.1^{ab} ± 0.91	936.7^{b} ± 51.58
12	25.2^{b} ± 0.84	80.4^{ab} ± 0.91	822.4^{a} ± 51.66
14	24.9^{b} ± 0.84	80.7^{ab} ± 0.91	848.7^{a} ± 51.64
21	23.0^{a} ± 0.84	81.8^{b} ± 0.91	829.9^{a} ± 51.56
Age x Quality Grade interaction (*P*-Value)	0.59	0.47	0.15

[1]Quality grade group = (USDA, 2016): (1) Top Choice (Modest and Moderate marbling scores and representative of the upper 2/3's Choice grade), (2) Choice (Small marbling scores and representative of the lower 1/3rd Choice grade), and (3) Select (Slight marbling).

Means within a column and within a category or method lacking a common letter (a-b) differ ($P < 0.05$).

Table 5

Least squares means for main effects associated with ribeye steaks (without frozen)

Main Effects	WBSF (N)	Cook Yield (%)	Cook Time (s)
n	522	522	521
Cook Temp (*P*-Value)	0.68	0.67	0.90
Quality Grade[1] (*P*-Value)	0.10	0.33	<0.0001
Top Choice	26.4 ± 0.96	80.3 ± 0.98	911.0^{b} ± 29.55
Choice	26.1 ± 0.95	80.8 ± 0.99	803.1^{a} ± 30.22
Select	28.3 ± 0.89	79.8 ± 0.98	915.6^{b} ± 29.37
Aging (day) (*P*-Value)	<0.0001	0.05	0.002
2	30.0^{c} ± 0.87	81.5 ± 1.09	837.9^{a} ± 33.73
4	28.9^{c} ± 0.85	80.2 ± 1.08	865.0^{a} ± 33.39
6	29.2^{c} ± 1.08	79.2 ± 1.26	938.3^{b} ± 41.65
8	29.1^{c} ± 1.08	78.5 ± 1.29	929.0^{b} ± 41.79
10	25.2^{b} ± 0.86	80.0 ± 1.08	937.9^{b} ± 33.41
12	25.2^{b} ± 0.86	80.4 ± 1.08	823.5^{a} ± 33.55
14	24.9^{b} ± 0.85	80.7 ± 1.08	850.2^{a} ± 33.49
21	22.9^{a} ± 0.85	81.8 ± 1.08	830.9^{a} ± 33.37
Age x Quality Grade interaction (*P*-Value)	0.05	0.35	0.16

[1]Quality grade group = (USDA, 2016): (1) Top Choice (Modest and Moderate marbling scores and representative of the upper 2/3's Choice grade), (2) Choice (Small marbling scores and representative of the lower 1/3rd Choice grade), and (3) Select (Slight marbling).

Means within a column and within a category or method lacking a common letter (a-b) differ ($P < 0.05$).

Table 6

Least squares means for main effects associated with ribeye steaks (replicate 1)

Main Effects	WBSF (N)	Cook Yield (%)	Cook Time (s)
n	312	312	312
Cook Temp (*P*-Value)	0.49	0.28	0.38
Quality Grade[1] (*P*-Value)	0.009	0.17	0.003
Top Choice	$24.2^{a} \pm 1.19$	81.4 ± 0.58	$932.9^{b} \pm 25.96$
Choice	$26.5^{ab} \pm 1.29$	81.6 ± 0.61	$822.1^{a} \pm 28.08$
Select	$29.2^{b} \pm 1.11$	80.4 ± 0.55	$942.2^{b} \pm 24.14$
Aging (day) (*P*-Value)	<0.0001	0.15	0.51
2	$29.3^{c} \pm 1.04$	82.5 ± 0.96	896.7 ± 38.34
4	$28.3^{c} \pm 1.01$	82.5 ± 0.93	879.9 ± 36.76
6	$29.0^{c} \pm 1.01$	79.9 ± 0.93	956.8 ± 36.74
8	$28.9^{c} \pm 1.01$	79.4 ± 0.93	943.9 ± 37.03
10	$24.3^{ab} \pm 1.01$	81.1 ± 0.93	899.6 ± 36.86
12	$25.8^{b} \pm 1.01$	80.8 ± 0.94	869.7 ± 37.18
14	$24.6^{ab} \pm 1.01$	81.2 ± 0.93	864.6 ± 36.74
21	$22.9^{a} \pm 1.01$	81.8 ± 0.93	881.0 ± 36.87
Age x Quality Grade interaction (*P*-Value)	0.36	0.09	0.20

[1]Quality grade group = (USDA, 2016): (1) Top Choice (Modest and Moderate marbling scores and representative of the upper 2/3's Choice grade), (2) Choice (Small marbling scores and representative of the lower 1/3rd Choice grade), and (3) Select (Slight marbling).

Means within a column and within a category or method lacking a common letter (a-b) differ ($P < 0.05$).

Table 7

Least squares means for main effects associated with top sirloin steaks (fresh and frozen)

Main Effects	WBSF (N)	Cook Yield (%)	Cook Time (s)
n	624	624	622
Cook Temp (*P*-Value)	0.11	<0.0001	<0.0001
Quality Grade[1] (*P*-Value)	0.13	0.83	0.24
Top Choice	28.2 ± 0.84	75.1 ± 1.49	970.7 ± 25.20
Choice	27.6 ± 0.84	75.5 ± 1.49	998.4 ± 25.20
Select	29.6 ± 0.84	75.2 ± 1.49	1007.1 ± 25.17
Aging (day) (*P*-Value)	<0.0001	<0.0001	<0.0001
2	$30.1^{cd} \pm 0.91$	$77.4^{d} \pm 1.56$	$985.3^{bc} \pm 36.19$
4	$30.8^{d} \pm 0.90$	$75.7^{c} \pm 1.56$	$1069.9^{c} \pm 36.03$
6	$30.8^{d} \pm 0.90$	$72.9^{a} \pm 1.56$	$1040.3^{bc} \pm 35.85$
8	$26.7^{ab} \pm 0.91$	$75.9^{cd} \pm 1.56$	$860.1^{a} \pm 36.01$
10	$27.8^{b} \pm 0.91$	$74.9^{bc} \pm 1.56$	$1059.8^{c} \pm 35.97$
12	$28.7^{bc} \pm 0.91$	$73.9^{ab} \pm 1.56$	$992.7^{bc} \pm 35.89$
14	$27.3^{ab} \pm 0.90$	$75.3^{bc} \pm 1.56$	$971.8^{b} \pm 35.86$
21	$25.6^{a} \pm 0.91$	$76.0^{cd} \pm 1.56$	$956.6^{b} \pm 35.89$
Age x Quality Grade interaction (*P*-Value)	0.99	0.24	0.61

[1]Quality grade group = (USDA, 2016): (1) Top Choice (Modest and Moderate marbling scores and representative of the upper 2/3's Choice grade), (2) Choice (Small marbling scores and representative of the lower 1/3rd Choice grade), and (3) Select (Slight marbling).

Means within a column and within a category or method lacking a common letter (a-b) differ ($P < 0.05$).

Table 8

Least squares means for main effects associated with top sirloin steaks (without frozen)

Main Effects	WBSF (N)	Cook Yield (%)	Cook Time (s)
n	546	546	544
Cook Temp (*P*-Value)	0.42	<0.0001	0.0002
Quality Grade[1] (*P*-Value)	0.09	0.58	0.49
Top Choice	28.9 ± 1.44	74.7 ± 1.85	1018.5 ± 56.19
Choice	28.4 ± 1.44	75.3 ± 1.85	1015.9 ± 56.19
Select	30.8 ± 1.44	74.8 ± 1.85	1045.6 ± 56.17
Aging (day) (*P*-Value)	<0.0001	<0.0001	0.002
2	$30.0^{cd} \pm 1.42$	$77.4^{d} \pm 1.89$	$983.9^{a} \pm 60.82$
4	$30.7^{d} \pm 1.42$	$75.7^{e} \pm 1.89$	$1068.4^{c} \pm 60.71$
6	$33.7^{e} \pm 1.61$	$72.8^{a} \pm 2.00$	$1158.6^{b} \pm 68.97$
8	$31.3^{de} \pm 1.62$	$73.3^{ab} \pm 2.00$	$970.5^{a} \pm 45.86$
10	$27.7^{b} \pm 1.42$	$74.9^{bc} \pm 1.89$	$1059.2^{bc} \pm 60.68$
12	$28.7^{bc} \pm 1.42$	$73.9^{ab} \pm 1.89$	$992.9^{a} \pm 60.64$
14	$27.3^{ab} \pm 1.42$	$75.3^{bc} \pm 1.89$	$971.6^{a} \pm 60.62$
21	$25.6^{a} \pm 1.42$	$76.0^{cd} \pm 1.89$	$956.1^{a} \pm 60.64$
Age x Quality Grade interaction (*P*-Value)	0.98	0.42	0.18

[1]Quality grade group = (USDA, 2016): (1) Top Choice (Modest and Moderate marbling scores and representative of the upper 2/3's Choice grade), (2) Choice (Small marbling scores and representative of the lower 1/3[rd] Choice grade), and (3) Select (Slight marbling).

Means within a column and within a category or method lacking a common letter (a-b) differ (*P* < 0.05).

Table 9

Least squares means for main effects associated with top sirloin steaks (replicate 1)

Main Effects	WBSF (N)	Cook Yield (%)	Cook Time (s)
n	312	312	311
Cook Temp (*P*-Value)	0.81	0.0009	0.003
Quality Grade[1] (*P*-Value)	0.12	0.94	0.35
Top Choice	26.3 ± 1.59	76.6 ± 0.68	999.2 ± 34.00
Choice	28.4 ± 1.59	76.9 ± 0.68	947.5 ± 33.93
Select	30.3 ± 1.59	76.8 ± 0.68	969.3 ± 33.93
Aging (day) (*P*-Value)	<0.0001	<0.0001	0.002
2	27.8^{a} ± 1.41	80.8^{c} ± 0.85	880.8^{a} ± 46.04
4	28.4^{ab} ± 1.41	78.8^{bc} ± 0.85	967.0^{ab} ± 46.46
6	32.8^{c} ± 1.41	74.7^{a} ± 0.85	1107.1^{c} ± 45.71
8	30.4^{bc} ± 1.41	75.1^{a} ± 0.85	972.6^{ab} ± 46.13
10	26.7^{a} ± 1.41	76.4^{a} ± 0.85	1029.8^{bc} ± 45.91
12	27.2^{a} ± 1.41	75.5^{a} ± 0.85	910.6^{a} ± 45.76
14	27.2^{a} ± 1.41	76.5^{a} ± 0.85	923.7^{ab} ± 45.73
21	26.1^{a} ± 1.41	76.7^{ab} ± 0.85	984.4^{ab} ± 45.98
Age x Quality Grade interaction (*P*-Value)	0.62	0.70	0.28

[1]Quality grade group = (USDA, 2016): (1) Top Choice (Modest and Moderate marbling scores and representative of the upper 2/3's Choice grade), (2) Choice (Small marbling scores and representative of the lower 1/3rd Choice grade), and (3) Select (Slight marbling).

Means within a column and within a category or method lacking a common letter (a-b) differ ($P < 0.05$).

Table 10

Percentage distribution of Warner-Bratzler Shear Force (WBSF) values for fresh and frozen ribeye steaks according to the tenderness categories based on Belew et al. (2003).

Aging	Very Tender, WBSF < 31.4 N (%)	Tender, 31.4 N < WBSF < 38.3 N (%)	Intermediate, 38.3 N < WBSF < 45.1 N (%)	Tough, WBSF > 45.1 N (%)
2	61.5	25.6	10.2	2.5
4	70.5	21.7	6.4	1.2
6	79.4	15.3	3.8	1.2
8	87.1	5.1	5.1	2.5
10	85.8	14.1	0	0
12	80.7	16.6	2.5	0
14	92.3	7.6	0	0
21	85.8	14.1	0	0

Table 11
Percentage distribution of Warner-Bratzler Shear Force (WBSF) values for fresh only ribeye steaks according to the tenderness categories based on Belew et al. (2003).

Aging	Very Tender, WBSF < 31.4 N (%)	Tender, 31.4 N < WBSF < 38.3 N (%)	Intermediate, 38.3 N < WBSF < 45.1 N (%)	Tough, WBSF > 45.1 N (%)
2	61.5	25.6	10.2	2.5
4	70.5	21.7	6.4	1.2
6	69.2	20.5	7.6	2.5
8	74.3	10.2	10.2	5.1
10	85.8	14.1	0	0
12	80.7	16.6	2.5	0
14	92.3	7.6	0	0
21	85.8	14.1	0	0

Table 12
Percentage distribution of Warner-Bratzler Shear Force (WBSF) values for replicate 1 ribeye steaks according to the tenderness categories based on Belew et al. (2003).

Aging	Very Tender, WBSF < 31.4 N (%)	Tender, 31.4 N < WBSF < 38.3 N (%)	Intermediate, 38.3 N < WBSF < 45.1 N (%)	Tough, WBSF > 45.1 N (%)
2	64.1	28.2	5.1	2.5
4	74.3	20.5	2.5	2.5
6	69.2	20.5	7.6	2.5
8	74.3	10.2	10.2	5.1
10	87.1	12.8	0	0
12	82.1	15.3	2.5	0
14	92.3	7.6	0	0
21	84.6	15.3	0	0

Table 13
Percentage distribution of Warner-Bratzler Shear Force (WBSF) values for fresh and frozen strip loin steaks according to the tenderness categories based on Belew et al. (2003).

Aging	Very Tender, WBSF < 31.4 N (%)	Tender, 31.4 N < WBSF < 38.3 N (%)	Intermediate, 38.3 N < WBSF < 45.1 N (%)	Tough, WBSF > 45.1 N (%)
2	68.8	18.1	10.3	2.5
4	72.7	16.8	6.4	3.8
6	72.7	18.1	5.1	3.8
8	90.9	6.4	1.2	1.2
10	89.6	7.7	2.5	0
12	81.8	14.2	2.5	1.2
14	89.6	9.1	1.2	0
21	92.2	6.4	1.3	0

Table 14
Percentage distribution of Warner-Bratzler Shear Force (WBSF) values for fresh only strip loin steaks according to the tenderness categories based on Belew et al. (2003).

Aging	Very Tender, WBSF < 31.4 N (%)	Tender, 31.4 N < WBSF < 38.3 N (%)	Intermediate, 38.3 N < WBSF < 45.1 N (%)	Tough, WBSF > 45.1 N (%)
2	68.8	18.1	10.3	2.5
4	72.7	16.8	6.4	3.8
6	63.1	23.6	7.8	5.2
8	84.2	10.5	2.6	2.6
10	89.6	7.7	2.5	0
12	81.9	14.2	2.5	1.2
14	89.6	9.1	1.2	0
21	92.2	6.5	1.2	0

Table 15
Percentage distribution of Warner-Bratzler Shear Force (WBSF) values for replicate 1 strip loin steaks according to the tenderness categories based on Belew et al. (2003).

Aging	Very Tender, WBSF < 31.4 N (%)	Tender, 31.4 N < WBSF < 38.3 N (%)	Intermediate, 38.3 N < WBSF < 45.1 N (%)	Tough, WBSF > 45.1 N (%)
2	68.4	18.4	13.1	0
4	86.8	10.5	2.6	0
6	63.1	23.6	7.8	5.2
8	84.2	10.5	2.6	2.6
10	89.4	10.5	0	0
12	76.3	18.4	5.2	0
14	89.4	10.5	0	0
21	97.3	2.6	0	0

Table 16
Percentage distribution of Warner-Bratzler Shear Force (WBSF) values for fresh and frozen top sirloin steaks according to the tenderness categories based on Belew et al. (2003).

Aging	Very Tender, WBSF < 31.4 N (%)	Tender, 31.4 N < WBSF < 38.3 N (%)	Intermediate, 38.3 N < WBSF < 45.1 N (%)	Tough, WBSF > 45.1 N (%)
2	57.7	32.1	6.4	3.8
4	61.5	25.6	7.6	5.1
6	60.2	30.7	5.1	3.8
8	76.9	14.1	7.6	1.3
10	74.3	20.5	5.1	0
12	66.7	28.2	5.1	0
14	79.4	12.8	7.6	0
21	85.9	10.3	2.5	1.3

Table 17
Percentage distribution of Warner-Bratzler Shear Force (WBSF) values for fresh only top sirloin steaks according to the tenderness categories based on Belew et al. (2003).

Aging	Very Tender, WBSF < 31.4 N (%)	Tender, 31.4 N < WBSF < 38.3 N (%)	Intermediate, 38.3 N < WBSF < 45.1 N (%)	Tough, WBSF > 45.1 N (%)
2	57.7	32.1	6.4	3.8
4	61.5	25.6	7.6	5.1
6	53.8	30.7	7.6	7.6
8	61.5	20.5	15.3	2.5
10	74.4	20.5	5.1	0
12	66.7	28.2	5.1	0
14	79.5	12.8	7.7	0
21	85.6	10.2	2.5	1.3

Table 18
Percentage distribution of Warner-Bratzler Shear Force (WBSF) values for replicate 1 top sirloin steaks according to the tenderness categories based on Belew et al. (2003).

Aging	Very Tender, WBSF < 31.4 N (%)	Tender, 31.4 N < WBSF < 38.3 N (%)	Intermediate, 38.3 N < WBSF < 45.1 N (%)	Tough, WBSF > 45.1 N (%)
2	71.8	20.1	2.5	5.1
4	76.9	15.4	2.5	5.1
6	53.8	30.8	7.7	7.7
8	61.5	20.5	15.4	2.5
10	82.1	12.8	5.1	0
12	74.4	20.5	5.1	0
14	74.4	15.4	10.2	0
21	82.1	12.8	5.1	0

Table 19
Means, SD, minimum and maximum values for USDA carcass grade[1] traits

Trait	N	Mean	SD	Minimum	Maximum
Top Choice					
REA cm^2	23	89.5	19.29	74.30	102.88
Adjusted fat thickness, cm^2	23	1.6	0.43	1.11	2.56
KPH, %	23	2.0	0.29	1.58	2.55
HCW, kg	23	392.7	33.26	342.72	457.99
USDA grade yield	23	3.2	0.74	2	5
Marbling score[2]	23	574.7	139.13	466	775
Choice					
REA cm^2	26	87.8	7.87	71.53	100.75
Adjusted fat thickness, cm^2	26	1.4	0.35	0.86	2.14
KPH, %	26	1.8	0.15	1.42	2.13
HCW, kg	26	406.5	18.49	377.68	443.60
USDA yield grade	26	2.8	0.73	2	4
Marbling score[2]	26	453.7	33.84	383	523
Select					
REA cm^2	22	88.4	9.99	72.89	118.62
Adjusted fat thickness, cm^2	22	1.2	0.28	0.69	1.72
KPH, %	22	1.8	0.24	1.46	2.39
HCW, kg	22	394.3	46.80	324.11	477.93
USDA yield grade	22	2.54	0.80	1	4
Marbling score[2]	22	385.5	22.41	353	455

[1]Quality grade group; 100 = Canner^{00}; 400 = Commercial^{00}; 600 = Select^{00}; 700 = Choice^{00}; 800 = Prime^{00} (USDA, 2016).
[2]100 = Practically devoid^{00}; 200 = Traces^{00}; 300 = Slight^{00}; 400 = Small^{00}; 500 = Modest^{00}; 700 = Slightly Abundant^{00}; 900 = Abundant^{00} (USDA, 2016).

APPENDIX B

FIGURES

Figure 1. Cook datasheet

NCBA WBS Short Aging - Stayci **WBS Cooking Record** Recorded By: _______________
Date: ______________________

Age Day	Subprimal	Steak ID	Raw Weight (g)	Raw Temp (°C)	Grill Surface Temp (°C)	Start Time (military)	Removal Time (military)	Final Temp (°C)	Final Weight (g)

Entered by:________________________
Entered Date: ____________________

Page ___ of ___

Checked by:__________________________
Checked Date: ______________________

Figure 2. WBSF datasheet

NCBA WBS Short Aging - Stayci **WBS Force Record (kg)** Recorded By: _______________
Date: ______________________

Age Day	Subprimal	Steak ID	Shear 1	Shear 2	Shear 3	Shear 4	Shear 5	Shear 6

Entered by:_______________________ Checked by:____________________________
Entered Date: ____________________ Page ___ of ___ Checked Date: _______________________