QUALITY AND PALATABILITY OF BEEF STEAKS FROM SUBPRIMALS SUBJECTED TO VARIOUS FROZEN/REFRIGERATED STORAGE PARAMETERS

A Thesis

by

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ABSTRACT

Beef steaks from ribeye rolls and top sirloin butts were evaluated to determine how refrigerated and/or frozen storage impacted purge, color, cooking yields, tenderness, and consumer acceptability. Treatments included: frozen subprimals/frozen steaks; frozen subprimals/refrigerated steaks; refrigerated subprimals/frozen steaks; refrigerated subprimals/refrigerated steaks. For subprimals, treatment had minimal impact on purge, however, purge varied ($P < 0.0001$) among steak treatments with refrigerated/refrigerated being the lowest. For ribeye steaks, cook yield was highest ($P < 0.05$) for refrigerated/refrigerated. Refrigerated/refrigerated ribeye steaks had among the lowest WBS force values, and no differences ($P > 0.05$) in consumer ratings were observed for ribeye steaks. Frozen/frozen top sirloin steaks had the lowest ($P < 0.05$) consumer ratings for overall liking, flavor, and juiciness. Storage conditions played a greater role for quality and consumer acceptability for top sirloin steaks than ribeye steaks. Overall, freezing subprimals and steaks posed the greatest challenge in quality and palatability.

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NOMENCLATURE

%	percent
°	degree
°C	degrees Celsius
AMSA	American Meat Science Association
cc	cubic centimeter
cm	centimeter
g	grams
h	hours
IMPS	Institutional Meat Purchasing Specifications
in	inch
kg	kilograms
M.	muscle
m^2	square meter
min	minute
mm	millimeter
N	Newtons
R. H.	relative humidity
sec	seconds
SSF	slice shear force
USDA	United States Department of Agriculture
WBS	Warner-Bratzler shear

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1. INTRODUCTION

Purchasing decisions across all sectors of the beef industry can often be correlated to market signals and/or pressures. The cause of changing market conditions is often explained by drought, agricultural impacts, global shifts in consumer trends, seasonality, and holidays, while other shifts in price and available inventory may be less understood or expected. Purveyors, retailers, and/or foodservice operators may respond to changing market conditions by purchasing a greater quantity of subprimals than immediately needed and storing the excess for subsequent use. Therefore, a better understanding of the impact of various storage parameters on tenderness, color, and consumer acceptance could aid producers in developing storage strategies, managing inventory, and balancing changing marketing conditions to achieve optimal consumer acceptance.

While studies have been conducted to determine the effects of storage temperature on tenderness, a cohesive effort to evaluate the compound effect of subprimal and steak storage parameters on consumer acceptance and quality attributes has not been addressed. Therefore, this study was designed to determine if various combinations of refrigerated and frozen storage of subprimals and steaks impact product, color, purge, cook yield, tenderness, and overall consumer acceptability.

2. REVIEW OF LITERATURE

2.1. Meat tenderness

Meat tenderness is a determining factor in overall eating satisfaction. Tenderness is influenced by postmortem proteolysis, intramuscular fat, connective tissue, and the contractile state of the muscle (Belew, Brooks, McKenna, & Savell, 2003). Additionally, meat tenderness also can be impacted by pH, temperature, and breed type (Maltin, Balcerzak, Tilley, & Delday, 2003). Tenderness is an important attribute contributing to a consumer's perception of "taste" (Miller, Carr, Ramsey, Crockett, & Hoover, 2001; Morgan et al., 1991; Savell et al., 1987; Savell et al., 1989; Smith et al., 1987; Voges et al., 2007) and quality (Huffman et al., 1996; Miller et al., 2001). Boleman et al. (1997) found consumers were able to distinguish between three tenderness categories. Findings by Boleman et al. (1997) were in agreement with Miller et al. (1995) and Huffman et al. (1996), who found that consumers could detect differences in steaks of different Warner-Bratzler shear (WBS) force values both in-home and in a restaurant setting. Consumers also are willing to pay more for a product that is guaranteed tender (Boleman et al., 1997; Lusk, Fox, Schroeder, Mintert, & Koohmaraie, 2001; Miller et al., 2001).

2.1.1. Measurements of tenderness

Currently, objective tenderness measurements can be determined by utilizing WBS or slice shear force (SSF). When measuring WBS force values, the lower the value, the more tender the sample. While there are various factors impacting meat tenderness, Miller et al. (2001) found steaks transition from "tender" to "tough" within the WBS force range 4.3 to 4.9 kg. This agrees with the threshold set by Shackelford, Morgan, Cross, and Savell (1991), where retail steak tenderness decreased after a WBS force value of 4.6 kg. Belew et al. (2003) established tenderness categories based on the WBS force values of various muscles. WBS force values of less than 31.4 N (3.2 kg) are considered “very tender,” 31.4 N to 38.3 N (3.2 to 3.9 kg) are “tender,” 38.3 N to 45.1 N (3.9 to 4.6 kg) are “intermediate,” and greater than 45.1 N (4.6 kg) are considered “tough” (Belew et al., 2003). Supportive muscles, such as the *M. longissimus thoracis*, are more tender than locomotive muscles, such as the and *M. semitendinosus*, (3.50 kg vs 4.10 kg, respectively) according to Belew et al. (2003). While consumer panels are a subjective method for measuring tenderness, trained panelists are generally considered more of an objective method. Trained panelists are extensively trained and can identify slight changes in individual sensory characteristics. Consumer panels consisting of untrained panelists evaluate attributes, such as overall liking, tenderness, flavor, and juiciness, within a sample. Untrained consumer panelists evaluate samples without prior knowledge of certain sensory attributes. Utilization of consumer panels aid in determination of relative satisfaction or acceptability of the product (Munoz, 1998).

2.2. Factors influencing meat tenderness

2.2.1. Postmortem proteolysis

Specific proteases and cathepsins found within muscle can degrade myofibrillar proteins. Degradation of proteins results in increased tenderness as the structural integrity is compromised. The only identified proteases with the ability to breakdown myofibrillar proteins are calcium-dependent proteases (Koohmaraie, Whipple, Kretchmar, Crouse, & Mersmann, 1991). The rate of proteolysis of myofibrillar proteins influences postmortem tenderness. Koohmaraie et al. (1991) reported an accelerated rate of proteolysis or decreased amounts of calcium-dependent protease (CDP) may improve beef tenderness.

Koohmaraie, Crouse, and Mersmann (1989) found the activity of CDP inhibitor decreases with time as the temperature of meat decreases, however, the CDP inhibitor does not decrease while the meat is frozen. Therefore, freezing meat will halt the CDP activity, allowing the proteases to continue to degrade the myofibrillar proteins, which causes tenderization due to decreased structural integrity. Additionally, when the rate of proteolysis is limited or slowed, sarcomere length becomes a key determinant in WBS force values and tenderness (Hwang, Park, Cho, & Lee, 2004; Wheeler & Koohmaraie, 1999), as the shortening of sarcomeres results in a decrease in meat tenderness (Wheeler & Koohmaraie, 1994).

2.2.2. Contractile state of the muscle

The contractile state of myofibrillar proteins influences meat toughness. Contractile state is determined by the rate and extent of the biochemical changes within the initial twenty-four hour period postmortem (Bowling, Dutson, Smith, & Savell, 1987). Depending on the rate of chilling, which is determined by the time and temperature the carcasses are held, differing contractile states such as cold shortening, heat shortening, and thaw rigor can occur. These contractile states have an effect on the contractile state of actomyosin or integrity of the Z-line also called the "actomyosin effect" (Smith & Carpenter, 1976). Smith, Arango, and Carpenter (1971) reported carcasses chilled to 16 °C for the initial 16 to 20 hours postmortem then at 2 °C for the remainder of the aging period, resulted in the greatest increase of tenderness (decrease in shear force values). Similarly, Bowling et al. (1987) concluded that steaks from rapid-chilled beef carcasses were more tender, and returned higher overall consumer palatability ratings than their conventionally chilled counterparts. Furthermore, depending on the way carcasses are suspended, muscles can enter rigor mortis in different states of contraction (Locker, 1959). Hostetler, Landmann, Link, and Fitzhugh (1970) investigated differing carcass suspension techniques and found an increase in tenderness when sarcomere length increased.

2.2.3. Connective tissue

Connective tissue is made up of elastin, collagen, reticulin, and ground substance. Factors influencing connective tissue amount and solubility include developmental stage, muscle type, muscle function, animal nutrition, animal breed, exercise, and injury (Purslow, 2005). The impact of connective tissue on muscle tenderness has been termed the “background effect” or “background toughness.” The composition and amount of connective tissue varies between muscles, species, breeds, and age (Purslow, 2005). Meat products that contain low amounts of connective tissue are in higher demand from consumers. For example, young, less mature beef is preferred to older, mature beef due to higher connective tissue content.

Collagen, the most abundant component of connective tissue, is influential in raw product tenderness (Dransfield et al., 2003) and contributes to connective tissue-related toughness (Cross, Carpenter, & Smith, 1973). Collagen solubility is dependent on the number of soluble crosslinks present. As an animal ages, the number of heat soluble collagen crosslinks decreases thus increasing the number of heat insoluble crosslinks present. The greater number of insoluble crosslinks, the tougher the meat becomes (Light, Champion, Voyle, & Bailey, 1985). Meat tenderness decreases as cooking temperature increases with a strong increase in toughness between 40 °C and 50 °C (Purslow, 2005). However, when cooking temperatures reach 60 °C, the contribution to tenderness decrease due to solubilization of connective tissue and gelatinization of collagen (Bouton, Harris, & Ratcliff, 1981), which results in improvements in tenderness. Thus, lower amounts of connective tissue, or a higher percentage of soluble collagen, is indictive of a more tender product.

2.2.4. Intramuscular fat content

Four theories - bite, strain, lubrication, and insurance - have been identified as ways intramuscular fat influences meat tenderness. The bite theory suggest that within a bite-sized portion, the prevalence of marbling decreases the mass per unit volume by replacing protein with lipid, which decreases bulk density. Because fat is less resistant to shear force than protein, the sample will have lower shear force values (Smith & Carpenter, 1976). Henry and Morrison (1915) concluded that marbling is deposited between the bundles of muscle fibers, causing separation of muscle fibers, resulting in increased tenderness, flavor, and juiciness values. This separation results in an improvement in tenderness ratings as fewer muscle fibers will be severed during consumer evaluation (chewing) or shearing. Strain theory relies on the amount of marbling deposited within the cell, which thins the connective tissue wall resulting in increased tenderness. The lubrication theory is based on the amount and distribution of intramuscular fat within and around muscle fiber, which influences tenderness by lubricating the muscle fibers and increasing juiciness (Smith & Carpenter, 1976). Research conducted by Berry, Smith, and Carpenter (1974) showed increased percentages of fat or decreased moisture percentage result in improved sensory ratings and tenderness values. Fat is less resistant to shear force values than protein, thus a decrease in bulk density results in an increase in tenderness. Lastly, the insurance theory provides protection of the muscle fibers from overcooking due to the lubrication between the muscle fibers from intramuscular fat (Smith & Carpenter, 1976).

USDA quality grades do not accurately predict meat tenderness (Smith et al., 1987). Marbling is poorly correlated with meat tenderness (Lusk et al., 2001), only accounting for five percent of tenderness variation (Wheeler, Cundiff, & Koch, 1994). Consistent variation amongst WBS force values and consumer panel ratings has been reported when evaluating beef products of different USDA quality grades (Davis, Smith, Carpenter, Dutson, & Cross, 1979; Morgan et al., 1991; Wheeler et al., 1994).

2.2.5. Aging and storage time

Aging has been shown to improve beef tenderness. Aging is the process of storing meat for an extended period of time above freezing temperatures (Davey & Gilbert, 1969) to provoke alterations of the myofibrillar structure through proteolysis (Koohmaraie et al., 1991). The extent of aging is impacted by the level of activation and inactivation of calpains during rigor (Dransfield, 1994).

In industry, the average aging time of beef has increased by 6.9 days (19.0 to 25.9 days) from 2000 to 2017, respectively (Brooks et al., 2000; Martinez et al., 2017). Many researchers have studied the effects of aging time on meat tenderness. Research conducted by Marino et al. (2013) found a significant decrease in WBS force values as meat was aged from 1 to 21 days, with meat aged 21 days having the lowest WBS force values. Hanzelková, Simeonovová, Hampel, Dufek, and Šubrt (2011) and Tindel et al. (2018) found aging for 14 days significantly increased tenderness, where samples aged longer than 14 days showed little improvements. Research by Bratcher, Johnson, Littell, and Gwartney (2005) found USDA Select steaks aged 14 days resulted in a 10% decrease in WBS force values compared to steaks aged 7 days. Brewer and Novakofski (2008) found WBS force values decreased 13% of the initial shear value during the first 7 days of aging and 17% after the next 7 days. In addition, consumer panelists' sensory ratings reveal an inability to detect differences in tenderness after 7 days of aging (Brewer & Novakofski, 2008). These results are similar to Tindel et al. (2018), where an increase in consumer sensory panel ratings or significant tenderness improvements were not found for steaks aged for 35 days compared to 14 days.

Extending storage time influences meat tenderness by lipid oxidation (Domínguez et al., 2019) and protein degradation (Van Laack, Stevens, & Stalder, 2001), especially in frozen products. During storage, proteolytic enzymes degrade proteins, diminishing structural integrity and increasing tenderness (Van Laack et al., 2001). Research conducted by Muela, Monge, Sañudo, Campo, and Beltrán (2016) revealed that steaks stored at 18 °C for 9 months had significantly increased trained panelists' tenderness ratings compared to storage times of fresh, 1 month, 15 months, and 21 months. Vieira, Diaz, Martínez, and García-Cachán (2009) identified steaks stored for 90 days also had significant decreases in WBS force values (7.40 kg vs 5.27 kg), compared steaks stored for 30 days. Increased frozen product storage time has been shown to decrease tenderness, increase shrinkage (Hanenian, Mittal, & Usborne, 1989) and exudation (Miller, Ackerman, & Palumbo, 1980).

2.2.6. Freezing

Freezing is a common and efficient food preservation method utilized by processors and consumers. Freezing products, such as subprimals or steaks, allows for increased storage time and flexibility in inventory. Research has indicated that freezing increases tenderness (decrease the shear force value) of beef products (Crouse & Koohmaraie, 1990; Grayson, King, Shackelford, Koohmaraie, & Wheeler, 2014; Kim, Meyers, Kim, Liceaga, & Lemenager, 2017; Locker & Daines, 1973; Tressler, 1932; Wheeler, Crouse, & Koohmaraie, 1992). In contrast, Kim et al. (2017) showed freezing then thawing meat results in a lower numerical shear force value but the reduction was not detectable by consumers, similar to findings from Wheeler, Miller, Savell, and Cross (1990). Additionally, Locker and Daines (1973) found repeating a freeze-thaw cycle decreases the mean shear force value by 6 to 8% compared to unfrozen samples.

Tenderness is dependent on the rate of freezing (Hiner, Madsen, & Hankins, 1945), where an increased rate of freezing results in tenderization. When product is frozen at temperatures less than -1.5 °C, ice crystals begin to form. During rapid freezing, ice crystal formation is accelerated, inhibiting the chance to establish an osmotic gradient across the cell. This will prevent moisture migration and aids in maintaining the structural integrity of the cell wall. Consequently, for conventional freezing, ice formation is slow, allowing larger crystals to form outside the cell, which leads to an osmotic gradient and allows migration of moisture across the cell wall. This migration from the inside to outside of the cell causes dehydration and risks the structural integrity of the cell (Bekhit, Carne, Ha, & Franks, 2014). Consequently, a slower freezing rate diminishes structural integrity and upon thawing, reduces the quality of the product. Furthermore, freezing influences calpain and calpastatin activity. Calpastatin acts as an inhibitor of calpains. Freezing causes the activity of calpastatin to decrease resulting in improvements in tenderness (Whipple & Koohmaraie, 1992). Therefore, cellular disruption from freezing can cause increased meat tenderness.

2.3. Meat color

Product appearance and color are key determining factors assessed when purchasing meat products (Carpenter, Cornforth, & Whittier, 2001; Mancini & Hunt, 2005). Consumers tend to correlate product color with wholesomeness, freshness, and safety (Mancini & Hunt, 2005). The main colors seen in a retail setting for beef products are ranges of red, purple, and brown. According to Carpenter et al. (2001), consumers' likelihood to purchase a meat product decreases as the product color changes from red > purple > brown. Carpenter et al. (2001) emphasized the importance consumers place on color in their purchasing decisions.

Killinger, Calkins, Umberger, Feuz, and Eskridge (2004) found consumers prefer steaks that are bright, cherry red over dark red steaks. Whereas visual observation offers a subjective measurement of color, there are objective measurement tools that allow for numerical value to be assigned to lean color. Instrumentation, such as a colorimeter, can determine the CIE $L^*a^*b^*$ color space values of meat products (AMSA, 2012). The L^* value indicates the brightness of the product and ranges from $L0$ (black) to $L100$ (white). The b^* is associated with blue ($-b$) to yellow ($+b$), and a^* with green ($-a$) to red ($+a$) (AMSA, 2012). Munsell’s notation of color values - hue, chroma, and value - can be extrapolated using the color space values. Hue consists of multiple colors such as red, orange, yellow, and green. For hue value, if the CIE a^* value for the horizontal axis is positive then the hue is red-purple, and if it is negative, the hue correlates to a blue-green. For the vertical axis, b^*, a positive value indicates a yellow color and negative represents a blue color. Chroma is the level of saturation within the color away from gray (AMSA, 2012; McGuire, 1992). Value is similar to the CIE L^* value as it also measures lightness from black to white on a 0 to 10 scale (McGuire, 1992). These measures provide an unbiased platform to objectively assess color.

2.4. Factors affecting color

Muscles vary in color due to many endogenous and exogenous factors. McKenna et al. (2005) identified oxymyoglobin oxidation and discoloration as being dependent on muscle source. The quality of myoglobin present in a muscle can be influenced by muscle functionality, species, and animal age. Research by McKenna et al. (2005) found a higher quantity of myoglobin leads to a darker red color, as seen in the *M. gluteus medius*, while lower quantities contribute to a brighter red color, or higher *L** values such as the *M. semitendinosus*. Furthermore, as an animal ages, the quantity of myoglobin increases (Lawrie, 1950). For beef, veal has the lowest amount of myoglobin and beef from advanced maturity carcasses has the highest amount of myoglobin (Biswas & Mandal, 2019), thus veal will be a light-pale color and older beef will be a darker red color.

Muscle fiber type can also impact meat color and color stability. There are two broad categories for muscle fiber types: red and white. However, four types of muscle fibers have been identified and defined in skeletal muscle – Type I, IIA, IIX, and IIB. Type I fibers are red in color, have the highest myoglobin content, a higher oxidative metabolism, and the slowest contraction speed compared to Type IIA, IIX, and IIB fibers. Similarly, Type IIA fibers are red and have an equal affinity for both oxidative metabolism but have a faster contraction speed. Type IIX and IIB fibers are comparable in redness due to having the same myoglobin content and are less red or paler in color (Aberle, Forrest, Gerrard, & Mills, 2012).

2.4.1. Freezing

Product color undergoes biochemical changes when products are subjected to freezing. Freezing influences *L** values, where frozen/thawed samples exhibited lower *L** values (decreased brightness) than chilled (refrigerated) samples (Aroeira et al., 2017; Sales et al., 2020; Vieira et al., 2009). This is thought to be due to ice crystal formation during freezing, where water can migrate across to the extracellular environment increasing the concentration of heme protein in the intracellular space. The increased concentration allows for greater absorption of light resulting in a darker observed color. In addition, the darker surface color could be due to freezing/thawing products having less "bloom," potentially due to denaturation. Furthermore, frozen samples have a higher percentage of metmyoglobin, brown, and a lower percentage of oxymyoglobin, bright red (Ben Abdallah, Marchello, & Ahmad, 1999). Metmyoglobin is the brown pigmentation in meat and oxymyoglobin responsible for the bright, red pigmentation. Thus, samples with a high metmyoglobin percentage will display a darker color. McKenna et al. (2005) identified color stable muscles such as the *M. semitendinosus*, to exhibit lower metmyoglobin reducing activity and lower oxygen consumption rate. In contrast, muscles with higher rates of oxygen consumption (O'Keeffe & Hood, 1982) and higher rates of metmyoglobin reduction (McKenna et al., 2005) are color-labile. Oxygen consumption rate is the respiration rate of muscles over time, this competes with myoglobin for oxygen. If the oxygen consumption rate is high, metmyoglobin forms close to the surface of the muscle allowing color to deteriorate faster (Madhavi & Carpenter, 1993).

2.4.2. Aging

Studies have been conducted to determine the effect aging has on meat color. As aging time increases, color diminishes due to metmyoglobin formation from oxidation of oxymyoglobin. Mitchell et al. (1991) found steaks aged 3 days displayed significantly lower *a** values, with no difference in *L** or *b** values, and decreased consumer sensory ratings. A more recent study by King, Shackelford, Kalchayanand, and Wheeler (2012) found CIE *L** and *b** were not significantly impacted by aging time. However, aging time did influence steak display duration, as *b** values of steaks aged 35 days showed the most rapidly decrease from being displayed 1 to 7 days. The CIE *a** value (redness) was the most affected by aging and display time. Steaks aged 35 days had a more rapid decline in *a** values than steaks aged 14 days. Vieira et al. (2009) found after 10 days of aging with the color reduction, steaks were still within the desirable color threshold. Therefore, as aging duration increased, the desirability of the meat color decreases. Thus, aging for a duration that will cause maximum tenderness without diminishing the color is optimal to achieve consumer satisfaction.

2.4.3. Storage duration

Storing subprimals at freezing temperatures could benefit the foodservice industry on a financial and inventory basis, however, potential negative effects on meat quality are the main concern. Redness (*a**) is the color space value that is most affected by storage time. As storage time increases, consumer color ratings decreased rapidly (Muela et al., 2016), especially after nine months of frozen storage. Vieira et al. (2009) identified all CIE values (*L**, *a**, and *b**) of beef decrease significantly after 90 days of frozen storage. Research by Farouk and Swan (1998) suggest that the decrease in redness (*a**) after frozen storage is due to decreased metmyoglobin reducing activity. With increased storage duration, the concentration of metmyoglobin increases due to the inactivity of the reducing agent. Understanding the effects of storage duration on product color is imperative for consumer acceptance.

3. MATERIALS AND METHODS

3.1. Raw material and treatment design

USDA Choice boneless ribeye rolls (*n* = 40) and top sirloin butts (*n* = 40), similar to IMPS 112A and 184 (USDA, 2010), were vacuum packaged and shipped to a collaborating beef purveyor. All subprimals (*n* = 80) were aged under refrigeration (approximately -1.1 °C), for 21 days. Following the initial post-fabrication aging time, ten ribeye rolls and ten top sirloin butts were allocated to one of the four treatment groups:

1. Frozen/Frozen subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for seven days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and steaks were placed in frozen storage (approximately -15.2 °C) for 30 days. After 30 days in frozen storage, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 98 days of storage.
2. Frozen/Refrigerated subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for 7 days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and evaluated within seven days of cutting, totaling approximately 65 days of storage.
3. Refrigerated/Frozen subprimals were portioned into steaks, and steaks will be frozen (approximately -28.9 °C) for 30 days. Then, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 60 days of storage.

4. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 days of cutting, totaling approximately 28 days of storage.

Treatments were scheduled such that all steak evaluations were performed within a single 7-day window.

3.2. Purge determination

Purge was quantified for all subprimals by obtaining in-package subprimal, raw out-of-package subprimal, and dried package weights. All subprimal and package weights were measured using an Ohaus Valor 4000w digital scale (Model No. V41XWE15T; Ohaus Corporation, Parsippany, NJ). Subprimal net weight, subprimal purge, and purge percentage were calculated using the following equations:

1. Subprimal/steak net weight = In-package subprimal / steak weight – dried package weight
2. Subprimal/steak purge = In-package subprimal / steak weight – (Subprimal/steak raw weight + dried package weight)
3. Purge percentage = (purge (subprimal/steak) / net weight (subprimal/steak)) X 100

3.3. Subprimal fabrication

After obtaining weights for purge quantification, all top sirloin butts (n = 40) were trimmed of excess surface fat and discoloration. Once trimmed, all top sirloin butts were cut perpendicular to muscle fibers (dorsal to ventral) into five, 3.6-cm sections using a Grasselli slicer (NSL 800; Albinea, Italy). Cut sections were identified as 1, 2, 3, 4, and 5 (cranial to caudal, respectively), with only sections 2 and 3 were used in this study. Four steaks, weighing approximately 226.8 g, were hand-cut from these two sections producing a total of *n* = 160 top sirloin steaks.

All ribeye rolls (*n* = 40) were weighed for purge quantification as previously described before having the “lip” (*M. serratus dorsalis* and *M. longissimus costarum*) removed and being trimmed to leave no more than 0.3175-cm fat on each subprimal. Four steaks, approximately 2.54-cm thick, were hand cut from the caudal end of each ribeye roll to produce *n* = 160 steaks ribeye steaks.

All steaks were individually labeled and packaged under vacuum with a rollstock machine (Multivac R150; Kansas City, MO) using Sealed Air, Food Care Division (Charlotte, NC) films (top web: Item No. T7230B, 3.0 mil with an Oxygen Transmission Rate (OTR) of 4 [cc/ m^2 / day @ 23 °C, 0% R.H.] and bottom web: Item No. T7045B, 4.5 mil with an OTR of 3 [cc/ m^2 / day @ 23 °C, 0% R.H.].

Steaks designated for the Frozen/Frozen and Refrigerated/Frozen treatments were placed into frozen storage (approximately -15.2 °C) for approximately 30 days. Upon completion of steak cutting for the Frozen/Refrigerated and Refrigerated/Refrigerated treatments, all steaks (*n* = 320) were transported to Rosenthal Meat Science and Technology Center (College Station, TX) in insulated containers with refrigerant materials. Two steaks from each subprimal were assigned to consumer sensory panels (*n* = 160), one steak was assigned for Warner-Bratzler shear (WBS) force (*n* = 80), and one steak was assigned as an extra (*n* = 80). Steaks then were stored under refrigerated conditions (2 to 4 °C) for no longer than 7 days until analyses were performed.

3.4. Instrumental color

Instrumental steak color (CIE color space values L^*, a^*, and b^*) assessments were conducted after a 30-min bloom time in atmospheric oxygen. Color measurements were obtained in three locations on each steak designated for WBS force (n = 80) using a Hunter MiniscanXE (Model 4500L; Hunter Labs, Inc. Reston, VA; 31.8 mm aperture, Illuminant D65, 10° observer) colorimeter. Mean CIE L^*, a^*, and b^* color space values were derived for each steak. To ensure accuracy, the Hunter MiniScan EZ was calibrated at the beginning of each session and after every 60^{th} measurement using manufacturer provided white and black reference tiles. Using the CIE L^*, a^*, b^* values, hue angle, and chroma values were calculated according to the American Meat Science Association Meat Color Measurement Guidelines (2012).

3.5. Cooking procedures

Steaks (n = 240 total) were cooked on a Star International commercial flat-top grill (Max Model 536TGF, St. Louis, MO) pre-heated to 177 °C ± 3 °C. Internal steak temperatures were monitored during cooking using ThermData Type-T Thermocouple loggers (Model THS-298-721; ThermoWorks, American Fork, UT) and 0.02-cm diameter copper-constantan Type-T thermocouple wire (Omega Engineering) inserted into the geometric center of each steak. Steaks were cooked to 35 °C, flipped, and cooked to a final internal temperature of 70 °C. In-package weight, raw out-of-package weight, initial internal steak temperature, grill temperature, time on, final internal temperature, time off, and final cooked weight were collected for every steak. Cooked yield and total cook time were calculated. Cooked steaks assigned for WBS force evaluation were placed onto plastic trays in a single layer, covered with plastic film, and stored at refrigerated conditions (2 to 4 °C) for approximately 12 to 16 h. Steaks assigned to consumer panels were held in an Alto-Shaam oven set at 60 °C (Alto-Shaam Inc., Menomnee Falls, WI) for no more than 20 min before serving. Cook yield was calculated by the following equation:

Cook yield = (Final cooked weight / (Raw steak weight + purge)) X 100

3.6. Warner-Bratzler shear force determination

One steak from each subprimal was used for WBS force evaluation, (*n* = 40 steaks, per subprimal type). Cooked and chilled steaks (*n* = 80, total) were allowed to equilibrate to room temperature (approximately 1.5 h) before being trimmed of visible connective tissue to expose muscle fiber orientation. From each steak, at least six 1.3-cm cores were removed from the *M. longissimus thoracis* and *M. gluteus medius* parallel to the muscle fibers using a hand-held coring device. Cores were carefully prepared to avoid excess fat or connective tissue, and were sheared once, perpendicular to the muscle fibers, on a TMS-Pro Texture Analyzer (Mecmesin Ltd., Slinfold, UK) at a cross-head speed of 200 mm/min using a 250 N load cell, and a 1.02 cm thick V-shape blade with a 60° angle and a half-round peak.

3.7. Consumer sensory panels

Consumer sensory panel procedures were approved by the Texas A&M Institutional Review Board for the Use of Humans in Research (Protocol number: IRB2019-1458M.) Panelists (*n* = 80) were recruited from the Bryan/ College Station area using an existing consumer database. Upon arrival at the sensory facility, panelists were asked to fill out a demographic survey and log their body temperature due to COVID-19 guidelines at the time of panel.

Consumer sensory panel steaks (n = 160) were cooked as described previously and identified with a random three-digit code. Cooked steaks were cut into cuboidal portions (approximately 1.27 cm x 1.27 cm x steak thickness) and served warm to panelists seated in individually partitioned spaces with red lighting to prevent panelist bias for degree of doneness. Consumer sensory panels were completed in four sessions and designed to have five groups of four panelists per session. Eight steaks (one from each treatment and subprimal type combination) were assigned in random order by a random number generator (Microsoft Excel; Microsoft Corp., Redmond WA) and checked for duplicate numbers to each group to achieve a uniform representation of treatments and subprimal types across panel days. Thus, each panelist assessed eight samples, and each sample was evaluated by four panelists. Panelists were asked to evaluate the samples using 9-point scales (1 = dislike extremely; 9 = like extremely) for overall liking, flavor liking, tenderness liking, and juiciness liking. Purified bottled water and individually packaged unsalted saltine crackers were provided for palate cleansing between samples. Upon conclusion of panel, consumers were provided a $25 gift card for participating in this study.

3.8. Statistical analyses

Data were analyzed utilizing JMP® Pro (Version 15.2.1; SAS Institute Inc., Cary, NC). Analysis of variance was performed to determine if differences occurred between treatments. Special attention was given when evaluating the variation in shear force and consumer sensory panel ratings along with determining those steaks that are considered “very tender,” “tender,” “intermediate,” or “tough” using thresholds developed by Belew et al. (2003).

4. RESULTS AND DISCUSSION

4.1. Purge

Purge is an important factor for consumers purchasing meat products as purge is accounted for in the net weight of the product and is lost when the product is being further processed. Least squares means for purge percentage stratified by subprimal type and treatment are depicted in Table 3.

There was a difference (*P* = 0.0067) between storage treatments for top sirloin butt subprimal purge percentage, however, no significant differences were found between storage treatments for ribeye rolls, which disagrees with Hergenreder et al. (2013) and Aroeira et al. (2016). For top sirloin butts, the Frozen/Frozen and Frozen/Refrigerated treatments (*P* = 0.0067) had the highest subprimal purge percentage compared to the other treatments. Results from top sirloin butt subprimals are similar to those reported Aroeira et al. (2016), where frozen subprimals exhibited a higher purge percentage than refrigerated subprimals. Aroeira et al. (2016) concluded freezing then thawing has a strong impact on water loss due to the formation of ice crystals within the muscle fibers, which disrupts the muscle fiber structure.

For both subprimal types, there were differences (*P* < 0.0001) between storage treatments for steak purge percentage. Frozen/Refrigerated ribeye and top sirloin steaks treatment had among the highest steak purge percentage, while Refrigerated/Refrigerated had the lowest. Similarly, Farouk, Wieliczko, and Merts (2004) and Petrovic, Grujic, and Petrovic (1993) found similar results where meat that was frozen then thawed slowly had the greatest water loss due to larger ice crystal formation.

4.2. Cook yield and cook time

Cook yield (%) and cook time data for ribeye and top sirloin steaks stratified by storage treatment can be found in Table 4. Ribeye and top sirloin steaks from Refrigerated/Refrigerated resulted in the highest ($P < 0.0001$) cook yield compared to all other treatments. Refrigerated, never frozen steaks had a higher cook yield than frozen steaks, which is in agreeance with Locker and Daines (1973), where frozen beef had a higher cook loss than non-frozen/refrigerated beef. There were no significant differences ($P > 0.05$) in cook time among storage conditions for either steak type.

4.3. Color evaluation

CIE color space values (L^*, a^*, *and* b^*) were measured and hue angle and chroma values were calculated to accurately evaluate the impact storage conditions had on steak color. Least squares mean of CIE color space values (L^*, a^*, *and* b^*) by steak type across storage treatments are shown in Table 5. For ribeye steaks, no differences ($P = 0.1824$) in L^* values were observed between storage treatments. For steaks from top sirloin butts, Refrigerated/Refrigerated had among the highest ($P = 0.0318$) lightness (L^*) value, indicative of a brighter lean color, and Frozen/Frozen had one of the lowest, indicating a darker lean color. For steaks from ribeye rolls, Frozen/Frozen and Refrigerated/Refrigerated resulted in higher ($P = 0.0148$) a^* (redness) values compared to Frozen/Refrigerated. For top sirloin butt steaks, Refrigerated/Frozen had the lowest (P

< 0.0001) *a** value compared to all other treatments. Refrigerated/Frozen for both steak types returned lower *b** values compared to the other storage treatments. Similar to the present study, Kim et al. (2017) found steaks from never frozen loins, comparable to Refrigerated/Refrigerated of the current work, exhibited a higher *L** and *a** value, but a lower *b** value than from frozen/thawed.

Least squares means for hue angle and chroma values are listed in Table 6. For ribeye steaks, Frozen/Refrigerated had the highest (P = 0.0153) hue angle compared to all other treatments. For top sirloin butt steaks, Frozen/Frozen and RefrigeratedFfrozen had higher (P = 0.0006) hue angle values compared to Frozen/Refrigerated and Refrigerated/Refrigerated. Higher hue angle values indicate less red color, meaning Frozen/Refrigerated ribeye steaks, and Frozen/Frozen and Refrigerated/Frozen top sirloin steaks displayed the least red color compared to the other treatments. For top sirloin steaks, Frozen/Refrigerated and Refrigerated/Refrigerated had the highest chroma values or exhibited a more vivid or saturated color. For ribeye steaks, Frozen/Frozen resulted amongst the highest chroma values, whereas Frozen/Refrigerated had among the lowest. For steaks from top sirloin butts, Refrigerated/Frozen exhibited the lowest chroma values compared to other treatments. The treatments that included a single freezing (frozen) step resulted in a less red and less saturated color. This is unexpected as both, subprimals and steaks, were frozen for Frozen/Frozen, but Frozen/Frozen displayed higher chroma values compared to treatments that were only subjected to one freezing step.

4.4. Warner-Bratzler shear force evaluation

Mean WBS force values (N) stratified by steak type and storage treatment are shown in Table 7. No differences (*P* = 0.8190) in WBS force values were seen between storage treatments for top sirloin butts. For steaks derived from ribeye rolls, significant differences (*P* = 0.0040) in WBS force values between storage treatments were observed. Ribeye steaks from Frozen/Frozen had the highest WBS force values compared to the Refrigerated/Frozen and Refrigerated/Refrigerated treatments. These findings are interesting as they disagree with Shanks, Wulf, and Maddock (2002), that reported a tremendous decrease in WBS force value after freezing steaks. Furthermore, Grayson et al. (2014) investigated options to improve beef tenderness consistency and determined the effects of freezing, freezing then thawing, and aging have on tenderness. Grayson et al. (2014) determined various combinations of freezing and thawing resulted in an increase in meat tenderness and implied practices should be implemented into commercial processes to improve consistency.

WBS force classifications outlined by Belew et al. (2003) categorize “very tender” as less than 3.2 kg (less than 31.38 N), “tender” 3.2 – 3.9 kg (31.38 – 38.25 N), “intermediate” 3.9 - 4.6 kg (38.25 – 45.11 N), and “tough” greater than 4.6 kg (greater than 45.11 N). Table 8 displays the percentage of steaks per storage treatment categorized by Belew et al. (2003). For ribeye steaks, 70% of Frozen/Frozen could be classified as “very tender” with the other 30% was “tender”. All ribeye steaks in other treatments were found to be “very tender.” For top sirloin steaks, 100% of Frozen/Frozen and Refrigerated/Refrigerated, 80% of Frozen/Refrigerated, and 90% of

Refrigerated/Frozen were "very tender." The remaining top sirloin steaks, 20% of Frozen/Refrigerated and 10% of Refrigerated/Frozen, were classified as "tender." This is important as retailers and food service providers eating satisfaction, which includes tenderness, as one of their top quality concerns (Hasty et al., 2017).

4.5. Consumer panel evaluation

Consumer panelists' scores for four beef palatability attributes – tenderness, flavor, juiciness, and overall liking - stratified by steak type and treatment are shown in Table 9. For the steaks derived from ribeye rolls, there were no differences ($P > 0.05$) between storage treatments for any of the four beef palatability attributes. Frozen/Refrigerated ribeye steaks had the lowest consumer panel evaluations for three sensory attributes – overall liking, tenderness liking, and juiciness liking.

For steaks from top sirloin butt subprimals, there were differences ($P < 0.05$) between storage treatments for all four beef palatability attributes. Consumer panelists' rated Frozen/Frozen top sirloin butt steaks lower than other treatments for overall liking, flavor, and juiciness. However, evaluations showed a combination of refrigerated and frozen storage parameters had no detrimental effects on sensory attributes. With regard to the sensory performance of top sirloin butt steaks, this work disagrees with Obuz and Dikeman (2003) and Moody, Bedau, and Langlois (1978), which found freezing had no significant effects on panel ratings for juiciness, flavor, and tenderness attributes. Smith, Spaeth, Carpenter, King, and Hoke (1968) compared the effects of refrigerated, frozen, and thawed states of lamb roasts on sensory attributes and satisfaction and found roasts cooked from a frozen or fresh state, finding significant improvements in tenderness and satisfaction ratings, but no significant differences in juiciness.

5. CONCLUSIONS

Beef purveyors, retailers, and/or foodservice operators try to achieve optimal consumer satisfaction, including product availability and palatability. However, with marketing conditions fluctuations meeting consumer needs becomes more difficult due to price and availability of product. The objective of this study was to determine if tenderness and consumer acceptability of beef steaks are influenced by storage conditions (refrigerated versus frozen). Differences in purge, yield, color, WBS force values and sensory attributes were identified and documented for ribeye rolls and top sirloin butts. While some differences only impacted one subprimal, ribeye rolls were generally found to be less susceptible to the storage parameters than top sirloin butts. More factors were impacted by the treatments for top sirloins than for ribeyes. It should be noted that consumers found frozen then thawed top sirloin steaks that were derived from frozen and thawed subprimals (Frozen/Frozen) had the lowest ratings for all four beef palatability attributes evaluated. To allow for optimum yield, color, and consumer panel ratings, utilizing refrigerated top sirloin butt subprimals instead of frozen subprimals is recommended. However, a variation of storage conditions (refrigerated or frozen) can be implemented for ribeye rolls without negatively impacting palatability and yield. Findings from this research project could greatly impact the purchasing decisions made by companies to increase profitability, availability, and flexibility as market trends frequently fluctuate.

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APPENDIX A – TABLES

Table 1. Demographic attributes of consumers that participated in the sensory panels.

Item	*n*	%
Gender		
Male	39	48.75
Female	41	51.25
Age, yr		
< 20	7	8.75
21 to 25	11	13.75
26 to 35	24	30.00
36 to 45	12	15.00
46 to 55	9	11.25
56 to 65	10	12.50
≥ 66	7	8.75
Working status		
Not employed	11	13.75
Full-time	39	48.75
Part-time	7	8.75
Student	27	33.75
Income, US$		
< 25,000	16	20.00
25,000 to 49,999	20	25.00
50,000 to 74,999	13	16.25
75,000 to 99,000	10	12.50
≥ 100,000	21	26.25
Food allergy		
No	74	92.50
Yes	6	7.50
Food manufacturer		
No	79	98.75
Yes	1	1.25
Ethnicity		
Caucasian	43	53.10
Hispanic	15	18.50
Asian or Pacific Islander	11	13.60
Black	9	11.10
American Indian	0	0.00
Other	3	3.70
Consume meat		
No	0	0.00
Yes	80	100.00

Table 2. Consumer panelists' consumption patterns.

Item	*n*	%
Meat types consumed		
Chicken	76	87.40
Pork	75	86.20
Beef	79	90.80
Fish	70	80.50
No response	1	1.10
Overall beef consumption		
Daily	6	7.50
5 or more times per wk	17	21.25
3 or more times per wk	38	47.50
1 time per wk	14	17.50
1 time every 2wks	3	3.75
Less than once every 2 wks	2	2.50
At home beef consumption		
0 times per wk	2	2.50
1 time per wk	18	22.50
2 times per wk	22	27.50
3 times per wk	19	23.75
4 times per wk	10	12.50
5 or more times per wk	9	11.25
In restaurant beef consumption		
0 times per wk	4	4.90
1 time per wk	34	42.00
2 times per wk	19	23.50
3 times per wk	12	14.80
4 times per wk	8	9.90
5 or more times per wk	3	3.70
Not answered	1	1.20
Degree of doneness		
Rare	3	3.60
Medium rare	26	31.30
Medium	4	4.80
Medium well	36	43.40
Well done	14	16.90
Purchase tendencies		
Grass-fed	16	17.20
Traditional	65	69.90
Aged	5	5.40
Organic	7	7.50

Table 3. Least squares means of subprimal purge and steak purge percentage[a] of ribeye and top sirloin steaks stratified by storage treatment[b].

	n	Subprimal Purge (%)	*n*	Steak Purge (%)
Ribeye				
Frozen/Frozen	10	0.51	10	4.30b
Frozen/Refrigerated	10	1.38	10	5.04a
Refrigerated/Frozen	10	0.42	10	3.48c
Refrigerated/Refrigerated	10	0.66	10	2.36d
SEM		0.30		0.25
P-value		0.1130		<0.0001
Top sirloin butt				
Frozen/Frozen	10	2.51a	10	6.71a
Frozen/Refrigerated	10	2.57a	10	7.25a
Refrigerated/Frozen	10	1.27b	10	5.68b
Refrigerated/Refrigerated	10	1.36b	10	4.19c
SEM		0.32		0.35
P-value		0.0067		<0.0001

Least squares means within an attribute and main effect lacking common letter (a-d) differ ($P < 0.05$).

[a] Purge percentage = (purge (subprimal/streak) / net weight (subprimal/steak)) X 100.

[b] Treatment: Frozen/Frozen subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for seven days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and steaks were placed in frozen storage (approximately -15.2 °C) for 30 days. After 30 days in frozen storage, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 98 days of storage. Frozen/Refrigerated subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for 7 days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and evaluated within seven days of cutting, totaling approximately 65 days of storage. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately -28.9 °C) for 30 days. Then, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 60 days of storage. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 days of cutting, totaling approximately 28 days of storage.

Table 4. Least squares means for cook yields[a] and times by storage treatment[b] for ribeye and top sirloin steaks.

	n	Cook yield (%)	*n*	Cook times (s)
Ribeye steaks				
Frozen/Frozen	10	74.02c	10	758.00
Frozen/Refrigerated	10	75.06bc	10	732.00
Refrigerated/Frozen	10	76.09b	10	750.00
Refrigerated/Refrigerated	10	80.02a	10	783.00
SEM		0.63		26.31
P-value		<0.0001		0.5895
Top sirloin steaks				
Frozen/Frozen	10	67.47b	10	1142.00
Frozen/Refrigerated	10	68.64b	10	1132.00
Refrigerated/Frozen	10	68.88b	10	1160.00
Refrigerated/Refrigerated	10	72.21a	10	1186.00
SEM		0.62		41.47
P-value		<0.0001		0.8074

Least squares means within an attribute and main effect lacking common letter (a-d) differ ($P < 0.05$).

[a] Cook yield (%) = (Final cooked weight / (Raw steak weight + purge)) X 100.

[b] Treatment: Frozen/Frozen subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for seven days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and steaks were placed in frozen storage (approximately -15.2 °C) for 30 days. After 30 days in frozen storage, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 98 days of storage. Frozen/Refrigerated subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for 7 days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and evaluated within seven days of cutting, totaling approximately 65 days of storage. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately -28.9 °C) for 30 days. Then, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 60 days of storage. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 days of cutting, totaling approximately 28 days of storage.

Table 5. Least squares means of CIE *L**, *a**, *b** color space values for ribeye and top sirloin steaks stratified by storage treatment[a].

	n	*L**	*a**	*b**
Ribeye steaks				
Frozen/Frozen	10	38.25	20.51a	19.86a
Frozen/Refrigerated	10	40.27	15.83b	17.3bc
Refrigerated/Frozen	10	39.67	17.61ab	16.8c
Refrigerated/Refrigerated	10	41.46	20.15a	19.3ab
SEM		1.02	1.11	0.78
P-value		0.1824	0.0148	0.0202
Top sirloin steaks				
Frozen/Frozen	10	38.25b	16.54b	17.87b
Frozen/Refrigerated	10	40.66ab	19.77a	18.95ab
Refrigerated/Frozen	10	39.24b	14.00c	15.60c
Refrigerated/Refrigerated	10	41.71a	21.11a	20.04a
SEM		0.84	0.79	0.64
P-value		0.0318	<0.0001	0.0002

Least squares means within an attribute and main effect lacking common letter (a-d) differ ($P < 0.05$).

[a] Treatment: Frozen/Frozen subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for seven days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and steaks were placed in frozen storage (approximately -15.2 °C) for 30 days. After 30 days in frozen storage, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 98 days of storage. Frozen/Refrigerated subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for 7 days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and evaluated within seven days of cutting, totaling approximately 65 days of storage. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately -28.9 °C) for 30 days. Then, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 60 days of storage. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 days of cutting, totaling approximately 28 days of storage.

Table 6. Least squares means of calculated hue angle and chroma value of ribeye and top sirloin steaks stratified by storage treatment[a].

	n	Hue	Chroma
Ribeye steaks			
Frozen/Frozen	10	44.35b	28.58a
Frozen/Refrigerated	10	47.90a	23.49c
Refrigerated/Frozen	10	43.75b	24.36bc
Refrigerated/Refrigerated	10	44.15b	27.99ab
SEM		0.97	1.29
P-value		0.0153	0.0157
Top sirloin steaks			
Frozen/Frozen	10	47.25a	24.38b
Frozen/Refrigerated	10	43.65b	27.41a
Refrigerated/Frozen	10	48.74a	21.00c
Refrigerated/Refrigerated	10	43.60b	29.13a
SEM		0.95	0.94
P-value		0.0006	<0.0001

Least squares means within an attribute and main effect lacking common letter (a-d) differ ($P < 0.05$).

[a] Treatment: Frozen/Frozen subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for seven days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and steaks were placed in frozen storage (approximately -15.2 °C) for 30 days. After 30 days in frozen storage, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 98 days of storage. Frozen/Refrigerated subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for 7 days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and evaluated within seven days of cutting, totaling approximately 65 days of storage. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately -28.9 °C) for 30 days. Then, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 60 days of storage. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 days of cutting, totaling approximately 28 days of storage.

Table 7. Least squares means of Warner-Bratzler Shear force values (N) for ribeye and top sirloin steaks stratified by steak type × storage treatment[a].

	Ribeye steaks		Top sirloin steaks	
Treatment[a]	*n*	Mean (N)	*n*	Mean (N)
Frozen/Frozen	10	28.09a	10	23.57
Frozen/Refrigerated	10	25.28ab	10	25.52
Refrigerated/Frozen	10	22.31bc	10	24.75
Refrigerated/Refrigerated	10	20.68c	10	24.98
SEM		1.43		1.48
P-value		0.0040		0.819

Least squares means within an attribute and main effect lacking common letter (a-d) differ ($P < 0.05$).

[a] Treatment: Frozen/Frozen subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for seven days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and steaks were placed in frozen storage (approximately -15.2 °C) for 30 days. After 30 days in frozen storage, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 98 days of storage. Frozen/Refrigerated subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for 7 days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and evaluated within seven days of cutting, totaling approximately 65 days of storage. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately -28.9 °C) for 30 days. Then, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 60 days of storage. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 days of cutting, totaling approximately 28 days of storage.

Table 8. Percentage of ribeye and top sirloin steaks stratified by storage treatment[a] according to classifications[b] by Belew, Brooks, McKenna, and Savell (2003).

	n	"Very Tender"	"Tender"	"Intermediate"	"Tough"
Ribeye steaks					
Frozen/Frozen	10	70.0	30.0	0.0	0.0
Frozen/Refrigerated	10	100.0	0.0	0.0	0.0
Refrigerated/Frozen	10	100.0	0.0	0.0	0.0
Refrigerated/Refrigerated	10	100.0	0.0	0.0	0.0
Top sirloin steaks					
Frozen/Frozen	10	100.0	0.0	0.0	0.0
Frozen/Refrigerated	10	80.0	20.0	0.0	0.0
Refrigerated/Frozen	10	90.0	10.0	0.0	0.0
Refrigerated/Refrigerated	10	100.0	0.0	0.0	0.0

[a] Treatment: Frozen/Frozen subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for seven days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and steaks were placed in frozen storage (approximately -15.2 °C) for 30 days. After 30 days in frozen storage, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 98 days of storage. Frozen/Refrigerated subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for 7 days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and evaluated within seven days of cutting, totaling approximately 65 days of storage. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately -28.9 °C) for 30 days. Then, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 60 days of storage. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 days of cutting, totaling approximately 28 days of storage.
[b] Classifications: "very tender" is less than 3.2 kg (less than 31.38N), "tender" is 3.2 – 3.9 kg (31.38 – 38.25 N), "intermediate" is 3.9 - 4.6 kg (38.25 – 45.11 N), and "tough" is greater than 4.6 kg (greater than 45.11 N).

Table 9. Least squares means of consumer panelists' scores[a] for attributes of ribeye and top sirloin steaks stratified by storage treatment[b].

	n	Overall liking	Flavor liking	Tenderness liking	Juiciness liking
Ribeye steaks					
Frozen/Frozen	10	6.10	6.25	5.71	5.85
Frozen/Refrigerated	10	5.90	6.30	5.41	5.14
Refrigerated/Frozen	10	6.89	6.86	6.58	6.14
Refrigerated/Refrigerated	10	6.73	6.46	6.64	6.44
SEM		0.29	0.23	0.39	0.37
P-value		0.0579	0.2396	0.0715	0.0915
Top sirloin steaks					
Frozen/Frozen	10	5.16b	5.48b	4.86b	4.55b
Frozen/Refrigerated	10	6.26a	6.40a	6.19a	5.90a
Refrigerated/Frozen	10	5.99a	6.21a	5.66ab	6.03a
Refrigerated/Refrigerated	10	6.19a	6.14a	5.68ab	6.01a
SEM		0.22	0.22	0.30	0.28
P-value		0.0039	0.0259	0.0307	0.0010

Least squares means within an attribute and main effect lacking common letters (a-d) differ ($P < 0.05$).
[a] Consumers used the following scales: overall liking (1 = dislike extremely; 9 = like extremely), flavor liking (1 = dislike extremely; 9 = like extremely), tenderness liking (1 = dislike extremely; 9 = like extremely) and juiciness liking (1 =dislike extremely; 9= like extremely).
[b] Treatment: Frozen/Frozen subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for seven days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and steaks were placed in frozen storage (approximately -15.2 °C) for 30 days. After 30 days in frozen storage, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 98 days of storage. Frozen/Refrigerated subprimals were frozen (approximately -28.9 °C) for 30 days, thawed for 7 days under refrigerated conditions (approximately -1.1 °C), portioned into steaks, and evaluated within seven days of cutting, totaling approximately 65 days of storage. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately -28.9 °C) for 30 days. Then, steaks were thawed for two days under refrigerated conditions (approximately -1.1 °C) and evaluated within seven days of thaw, totaling approximately 60 days of storage. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 days of cutting, totaling approximately 28 days of storage.

APPENDIX B – FIGURES

Figure 1. Demographics ballot.

Date:
Session Time:

INSTRUCTIONS

Thank you for your participation in this study. Your assistance is very much appreciated. The objective of this study is to carefully evaluate beef samples. Please take your time and evaluate the samples served to you carefully.

This sampling will take about an hour. Please answer the following questions as completely as possible. If you have any questions, please ask the monitor for assistance.

Begin by filling out the basic demographic questions on the first page. This information is confidential and will not be used in publication, or have your name associated with it in any way.

After completing the demographic information, you are ready to begin the sample evaluation. Instructions at the top of each questionnaire will provide guidance on how to complete the evaluation.

Thank you very much for your help with this study.

DEMOGRAPHICS BALLOT

Please circle each appropriate response:

1. Please indicate your gender:

   Male Female

2. Which of the following best describes your age?

   20 years or younger 46-55 years
   21-25 years 56-65 years
   26-35 years 66 years and older
   36-45 years

3. Please indicate your current working status:

   Not employed Part-time
   Full-time Student

4. Which of the following best describes your household income?

   Below $25,000 $75,000 - 99,999
   $25,001 - 49,999 $100,000 or more
   $50,000 - 74,999

5. Do you have any known food allergies or dietary restrictions?

   No Yes

6. Do you or any of your immediate family work for a market research firm, advertising firm, or food

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manufacturing company?

No Yes

7. Please indicate your ethnic background:
   - White
   - Black
   - Hispanic
   - American Indian
   - Asian or Pacific Islander
   - Other

8. Do you eat meat?

   No Yes

9. Which of the following meats do you eat?

   - Chicken
   - Beef
   - Pork
   - Fish

10. You said that you eat beef. Approximately how often do you eat beef?

    - Daily
    - Once per week/weekly
    - 5 or more times per week
    - Once every 2 weeks
    - 3 or more times per week
    - Less than once every 2 weeks

11. Please mark the number of times a week you consume beef (including ground beef):

At Home:	0	1	2	3	4	5 or more
Restaurant or Fast-food Establishment:	0	1	2	3	4	5 or more

12. Please indicate your preferred degree of doneness for beef:

    - Rare (cool red center)
    - Medium Rare (warm red center)
    - Medium (hot pink center)
    - Medium Well (slightly pink center)
    - Well Done (no pink)

13. When purchasing beef, what do you typically buy?

    - Grass-fed
    - Aged
    - Traditional
    - Organic

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Figure 2. Consumer panelist ballot.

Date ___________________ **Participant No.**

Session Time ____________ **Sample No.**

INTRUCTIONS

Prior to tasting each sample, please take a bite of a cracker followed by a sip of water. After tasting each sample, place a mark in the box that best represents your answer for each of the following questions. The final two questions will be open ended, please answer them as completely as possible.

1. Indicate by placing a mark in the box your **OVERALL LIKE/DISLIKE** of the meat sample.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely — No Preference — Like Extremely

2. Indicate by placing a mark in the box your **LIKE/DISLIKE** for the **FLAVOR** of the meat sample.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely — No Preference — Like Extremely

3. Indicate by placing a mark in the box your **LIKE/DISLIKE** for the **TENDERNESS** of the meat product.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely — No Preference — Like Extremely

4. Indicate by placing a mark in the box your **LIKE/DISLIKE** for the **JUICINESS** of the meat product.

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely — No Preference — Like Extremely

5. Please describe what you **LIKED MOST** about this meat sample.

____

6. Please describe what you **LIKED LEAST** about this meat sample.

____

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