Meat and Muscle Biology™

Quality and Palatability of Beef Subprimals Subjected to Various Frozen/Refrigerated Storage Conditions

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Abstract: The objective of this study was to evaluate the impact of various combinations of refrigerated and frozen storage on quality and palatability attributes in ribeye roll and top sirloin butt subprimals and steaks. USDA Choice boneless ribeye rolls ($n = 40$) and top sirloin butts ($n = 40$) were aged under refrigeration for 21 d before being assigned to 1 of 4 treatments. Treatments included (1) Frozen subprimals/Frozen steaks, in which subprimals were frozen for 30 d, thawed for 7 d, and portioned into steaks that were frozen for 30 d, then thawed for 2 d before evaluation; (2) Frozen subprimals/Refrigerated steaks, in which subprimals were frozen for 30 d, thawed for 7 d, and portioned into steaks for evaluation; (3) Refrigerated subprimals/Frozen steaks, in which subprimals were portioned into steaks that were frozen for 30 d, then thawed for 2 d before evaluation; and (4) Refrigerated subprimals/Refrigerated steaks, in which subprimals were portioned into steaks for evaluation within 7 d of portioning. Beef steaks from the ribeye rolls and top sirloin butts were evaluated to determine the impact of storage treatments on purge, color, cooking yield, tenderness, and consumer acceptability. For both subprimals, purge varied ($P < 0.0001$) among steak treatments, with Refrigerated/Refrigerated being the lowest for both subprimals. For both steak types, cook yield was highest ($P < 0.05$) for Refrigerated/Refrigerated treatment. Refrigerated/Refrigerated ribeye steaks had among the lowest Warner-Bratzler shear force values, and similar ($P > 0.05$) consumer ratings were observed for ribeye steaks. Frozen/Frozen top sirloin steaks had the lowest ($P < 0.05$) consumer ratings for overall liking, flavor liking, and juiciness liking. Storage conditions played a greater role in quality and consumer acceptability for top sirloin steaks than ribeye steaks. Overall, freezing both subprimals and steaks posed the greatest challenge in quality and palatability.

Key words: beef, tenderness, frozen, refrigerated, consumer acceptability
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Introduction

Purchasing decisions across all sectors of the beef industry can often be correlated to market signals and/or pressures. Changes in market conditions are often explained by drought, global shifts in consumer trends, seasonality, and holidays, whereas other shifts in price and 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 freezing the excess for subsequent use.

Freezing is a commonly utilized method for food preservation of perishable foods. Freezing beef products, such as subprimals or steaks, allows for increased storage time and flexibility in inventory. However, freezing has also been associated with deteriorating quality attributes in meat products. Subsequent freeze/thaw methods have been shown to exhibit excess purge, lipid and protein oxidation, discoloration, and diminish texture, which is initially influenced by freezing rate (Leygonie et al., 2012). The literature has shown that freezing beef steaks increases tenderness or decreases shear force values (Tressler et al., 1932; Locker and Daines, 1973; Crouse and Koohmaraie, 1990; Wheeler et al., 1992; Grayson et al., 2014;

Kim et al., 2017), which is attributed to ice crystal formation during the freezing process (Bekhit et al., 2014). That being said, subprimals and steaks have differing freezing rates and can potentially impact quality attributes differently. Tindel et al. (2018) evaluated the impact of frozen and refrigerated storage of top sirloin butt subprimals on the palatability of the resulting steaks. Findings from the study revealed consumers' ratings did not differ with various subprimal storage conditions.

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 and Gilbert, 1969) to provoke alterations of the myofibrillar structure through proteolysis (Koohmaraie et al., 1991). In industry, the average aging time of beef has increased by 6.9 d (19.0 to 25.9 d) from 2000 to 2015, 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 Warner-Bratzler shear (WBS) force values as meat was aged from 1 to 21 d, with meat aged 21 d having the lowest WBS force values. Hanzelková et al. (2011) and Tindel et al. (2018) found aging to 14 d had a significant increase in tenderness, whereas samples aged longer than 14 d showed little improvement.

Although the combined effects of freezing, thawing, and/or aging on meat quality have been investigated, an effort to evaluate the compound effect of freezing 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 ribeye and top sirloin butt subprimals and their resultant steaks impacted product color, purge, cook yield, tenderness, and overall consumer acceptability. This information will improve the industry's ability to develop storage strategies, manage inventory, and balance changing marketing conditions without sacrificing consumer acceptance.

Materials and Methods

Raw material and treatment design

A collaborating beef purveyor obtained vacuum-packaged USDA Choice boneless ribeye rolls ($n = 40$) and top sirloin butts ($n = 40$), similar to IMPS 112A and 184 (USDA, 2014). The purveyor aged subprimals ($n = 80$) under refrigeration (−1.1°C) for 21 d. Following the initial postfabrication aging time, 10 ribeye rolls and 10 top sirloin butts were allocated to 1 of 4 treatment groups:

1. Frozen/Frozen subprimals were frozen (−28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (−1.1°C), and portioned into steaks, and steaks were placed in frozen storage (−15.2°C) for 30 d. After 30 d in frozen storage, steaks were thawed for 2 d under refrigerated conditions (−1.1°C) and evaluated within 7 d of thaw, totaling 98 d of storage.
2. Frozen/Refrigerated subprimals were frozen (−28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (−1.1°C), portioned into steaks, and evaluated within 7 d of cutting, totaling 65 d of storage.
3. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (−28.9°C) for 30 d. Then, steaks were thawed for 2 d under refrigerated conditions (−1.1°C) and evaluated within 7 d of thaw, totaling 60 d of storage.
4. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 d of cutting, totaling 28 d of storage.

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). Determination of subprimal net weight and subprimal purge weight was conducted as described by Laster et al. (2008) and purge percentage as described by Cassens et al. (2018).

Subprimal fabrication

After obtaining weights for purge quantification, all top sirloin butts ($n = 40$) were trimmed of excess surface fat and any discolored lean. 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 (NSL800; Albinea, Italy). Cut sections were identified as 1, 2, 3, 4, and 5 (cranial to caudal, respectively), with only sections 2 and 3 used in this study. Four steaks, weighing approximately 227 g, were hand cut from these 2 sections, producing 160 top sirloin steaks.

All ribeye rolls ($n = 40$) were weighed for purge quantification as described previously before having the "lip" (*M. serratus dorsalis* and *M. longissimus* *costarum*) removed and the fat trimmed to no more than 0.32-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 160 ribeye steaks.

All steaks were individually labeled and packaged under vacuum with a rollstock machine (Multivac R150; Multivac, Kansas City, MO) using CRYOVAC brand films, SEE (Charlotte, NC) (top web: Item No. T7230B, 3.0 mil with an oxygen transmission rate (OTR) of 4 [cc/m^2/day @ 23°C, 0% relative humidity (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 (−15.2°C) for 30 d. After completion of steak fabrication for 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 (160 steaks), one steak was assigned WBS force (80 steaks), and one steak was held as an extra (80 steaks). Steaks then were stored under refrigerated conditions (2°C to 4°C) for a minimum of 3 d and maximum of 7 d until subsequent analyses were performed. Treatments were scheduled such that all steak evaluations were performed on the same day as consumer sensory panels.

Instrumental color

Instrumental steak color (Commission Internationale de l'Eclairage [CIE] L^*, a^*, and b^* color space values) assessments were conducted after a 30-min bloom time in atmospheric oxygen. The color space values indicate lightness (L^*), redness (a^*), and yellowness (b^*). The values for L^* for the lightness range from black (0) to white (100). The values for a^* range from green (−) to red (+), and the values for b^* range from blue (−) to yellow (+). The higher the L^* value, the paler the meat. The higher the a^* value, the redder the meat. The higher the b^* value, the more yellow the color. Color measurements were obtained in 3 locations on each steak designated for WBS force using a Hunter MiniScan EZ (Model 4500L; HunterLab, 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 60th measurement using manufacturer-provided white and black reference tiles. Using the CIE L^*, a^*, and b^* values, hue angle and chroma values were calculated according to the American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023).

Cooking procedures

Cooking procedures for steaks followed the procedures of Cassens et al. (2018) with minor adjustments. Steaks (240 total) were cooked on a Star commercial flat-top grill (Star-Max Model 536TGF; Star Manufacturing, Smithville, TN) preheated to 177°C ± 3°C. Internal steak temperatures were monitored during cooking using ThermaData Type T Thermocouple Loggers (Model THS-298-721; ThermoWorks, American Fork, UT) and 0.02-cm-diameter copper-constantan T-type thermocouple wire (Omega Engineering, Norwalk, CT) 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. Total cook times 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°C to 4°C) for 12 to 16 h. Cooked steaks assigned to consumer panels were held in an Alto-Shaam oven set at 60°C (Alto-Shaam, Menomonee 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]) × 100.

Warner-Bratzler shear force determination

One steak from each subprimal (40 steaks per subprimal type) was used to evaluate WBS force as described by Tindel et al. (2018) with slight modifications. Cooked and chilled steaks (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 handheld 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 Food Texture Analyzer (Food Technology Corporation, Sterling, VA) at a crosshead speed of 200 mm/min using a 250 N load cell and a

1.02-cm-thick V-shaped blade with a 60° angle and a half-round peak.

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 ($n = 80$; demographics in Table 1) were recruited from the Bryan/College Station area using an existing consumer database. Upon arrival at the sensory facility, panelists completed COVID-19 screening questions, and body temperature checks were performed. Those who passed then completed a demographic survey.

Table 1. Demographic attributes and consumer preferences of consumers who participated in the sensory panels

Item	*n*	%
Gender		
Male	39	48.75
Female	41	51.25
Age, years		
<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, USD		
<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

Consumer sensory panel steaks were cooked as described previously and identified with a random 3-digit code. Cooked steaks were cut into cuboidal portions (1.27 cm × 1.27 cm × 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 4 sessions and designed to have 5 groups of 4 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, Redmond, WA) and checked for duplicate numbers. Each group evaluated a uniform representation of treatments and subprimal types across panel days. Thus, each panelist assessed 8 samples, and each sample was evaluated by 4 panelists. Panelists evaluated the samples using a 9-point scale (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 the panel, each consumer was provided a $25 gift card for participating in this study.

Statistical analyses

Data were analyzed utilizing JMP Pro (v. 15.2.1; SAS Institute, Cary, NC). The Fit Y by X function was used for one-way analysis of variance, and mean comparisons were conducted using Student's t test and an alpha of <0.05. Data were generated and reported by subprimal/steak type. For Fit Y by X, the "Y, response" variable was the effect being analyzed, "X, factor" was the treatment, and "by" was subprimal/steak type.

Results and Discussion

Purge

Purge percentage was calculated for subprimals and steaks. Least-squares means for purge percentage stratified by subprimal type and treatment are depicted in Table 2. There was a difference ($P = 0.0067$) between top sirloin butt subprimal purge percentage

Table 2. Least-squares means of subprimal purge and steak purge percentage[1] of ribeye and top sirloin steaks stratified by storage treatment[2]

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

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

[1]Purge percentage = (purge (subprimal/steak) / net weight (subprimal/steak)) × 100.

[2]Treatment: Frozen/Frozen subprimals were frozen (approximately −28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (approximately −1.1°C), and portioned into steaks, and steaks were placed in frozen storage (approximately −15.2°C) for 30 d. After 30 d in frozen storage, steaks were thawed for 2 d under refrigerated conditions (approximately −1.1°C) and evaluated within 7 d of thaw, totaling approximately 98 d of storage. Frozen/Refrigerated subprimals were frozen (approximately −28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (approximately −1.1°C), portioned into steaks, and evaluated within 7 d of cutting, totaling approximately 65 d of storage. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately −28.9°C) for 30 d. Then, steaks were thawed for 2 d under refrigerated conditions (approximately −1.1°C) and evaluated within 7 d of thaw, totaling approximately 60 d of storage. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 d of cutting, totaling approximately 28 d of storage.

and storage treatment. 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 had the highest ($P = 0.0067$) subprimal purge percentage compared with the other treatments. Results from top sirloin butt frozen samples exhibited a higher purge percentage than refrigerated, nonfrozen samples. Aroeira et al. (2016) concluded that freezing followed by thawing has a strong impact on water loss because of the formation of ice crystals within the muscle fibers, which disrupts the muscle fiber structure. Kim et al. (2015) also reported differences in freezing rates—fast and slow, in which faster freezing rates resulted in less purge loss, which was attributed to the disruption in muscle fiber structure.

There were differences ($P < 0.0001$) between storage treatments for steak purge percentage for both subprimal types. Frozen/Refrigerated ribeye and top sirloin steaks treatment had among the highest ($P < 0.05$) steak purge percentage, whereas Refrigerated/Refrigerated had the lowest. Similarly, Farouk et al. (2004) and Petrović et al. (1993) found similar results in which meat that was frozen and then thawed slowly had the greatest water loss because of larger ice crystal formation.

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 3. Ribeye and top sirloin steaks

Table 3. Least-squares means for cook yields[1] and times by storage treatment[2] for ribeye and top sirloin steaks

	n	Cook yield (%)	*n*	Cook times (s)
Ribeye				
Frozen/Frozen	10	74.02[c]	10	758.00
Frozen/Refrigerated	10	75.06[bc]	10	732.00
Refrigerated/Frozen	10	76.09[b]	10	750.00
Refrigerated/Refrigerated	10	80.02[a]	10	783.00
SEM		0.63		26.31
P value		<0.0001		0.5895
Top sirloin butt				
Frozen/Frozen	10	67.47[b]	10	1,142.00
Frozen/Refrigerated	10	68.64[b]	10	1,132.00
Refrigerated/Frozen	10	68.88[b]	10	1,160.00
Refrigerated/Refrigerated	10	72.21[a]	10	1,186.00
SEM		0.62		41.47
P value		<0.0001		0.8074

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

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

[2]Treatment: Frozen/Frozen subprimals were frozen (approximately −28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (approximately −1.1°C), and portioned into steaks, and steaks were placed in frozen storage (approximately −15.2°C) for 30 d. After 30 d in frozen storage, steaks were thawed for 2 d under refrigerated conditions (approximately −1.1°C) and evaluated within 7 d of thaw, totaling approximately 98 d of storage. Frozen/Refrigerated subprimals were frozen (approximately −28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (approximately −1.1°C), portioned into steaks, and evaluated within 7 d of cutting, totaling approximately 65 d of storage. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately −28.9°C) for 30 d. Then, steaks were thawed for 2 d under refrigerated conditions (approximately −1.1°C) and evaluated within 7 d of thaw, totaling approximately 60 d of storage. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 d of cutting, totaling approximately 28 d of storage.

from Refrigerated/Refrigerated resulted in the highest ($P < 0.0001$) cook yield compared with all other treatments. Refrigerated, never frozen steaks had a higher ($P < 0.05$) cook yield than frozen steaks, which is in agreement with Locker and Daines (1973), in whose study frozen beef had a higher cook loss than non-frozen/refrigerated beef. There were no differences ($P > 0.05$) in cook time among storage conditions for either steak type.

Color evaluation

CIE L^* (lightness), a^* (redness), and b^* (yellowness) color values were measured and hue angle and chroma values were calculated to accurately evaluate the impact that storage conditions had on steak color. Least-squares means of CIE color values (L^*, a^*, and b^*) by steak type across storage treatments are shown in Table 4. 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 ($P < 0.05$) lightness (L^*) value, indicative of a brighter lean color, and Frozen/Frozen had one of the lowest ($P < 0.05$), indicating a darker lean color. For steaks from ribeye rolls, Frozen/Frozen and Refrigerated/Refrigerated resulted in higher ($P < 0.05$) a^* (redness) values compared with Frozen/Refrigerated. For top sirloin butt steaks, Refrigerated/Frozen had the lowest ($P < 0.05$) a^* value compared with all other treatments. Refrigerated/Frozen for both steak types returned lower ($P < 0.05$) b^* values compared with the other storage treatments. Similar to the present study, Kim et al. (2017) found steaks from never frozen loins, comparable with Refrigerated/Refrigerated of the current work, exhibited higher L^* and a^* values but a lower b^* value than frozen/thawed steaks.

Least-squares means for hue angle and chroma values are listed in Table 4. For ribeye steaks, Frozen/Refrigerated had the highest ($P = 0.0153$) hue angle compared with all other treatments. For top sirloin butt steaks, Frozen/Frozen and Refrigerated/Frozen had higher ($P = 0.0006$) hue angle values compared with 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 with the other treatments. For top sirloin steaks, Frozen/Refrigerated and Refrigerated/Refrigerated had the highest ($P < 0.0001$) chroma values or exhibited a more vivid or saturated color. For ribeye steaks, Frozen/Frozen returned among the highest ($P = 0.0157$) chroma values, whereas Frozen/Refrigerated had among the lowest. For steaks from top sirloin butts, Refrigerated/Frozen exhibited the lowest ($P < 0.0001$) chroma values compared with other treatments. Kim et al. (2017) concluded frozen/thawed steaks with lower a^* (redness) values and higher hue angles showed a greater amount of discoloration, which suggests frozen/thawed steaks are more susceptible to myoglobin oxidation compared with fresh, never frozen steaks. This could be due to ice crystal formation, which causes structural changes that impact meat color properties (Mateo-Oyague and Perez-Chabela, 2004), or myoglobin denaturation and accumulation of metmyoglobin or loss of metmyoglobin-reducing activity (Leygonie et al., 2012; Kim et al., 2015, 2017).

Table 4. Least-squares means of CIE L^*, a^*, b^* color values[1], hue angle, and chroma values of ribeye and top sirloin steaks stratified by storage treatment[2]

	n	L^*	a^*	b^*	Hue	Chroma
Ribeye steaks						
Frozen/Frozen	10	38.25	20.51[a]	19.86[a]	44.35[b]	28.58[a]
Frozen/Fresh	10	40.27	15.83[b]	17.3b[c]	47.90[a]	23.49[c]
Fresh/Frozen	10	39.67	17.61[ab]	16.8c	43.75[b]	24.35[bc]
Fresh/Fresh	10	41.46	20.15[a]	19.3[ab]	44.15[b]	27.99[ab]
SEM		1.02	1.11	0.78	0.97	1.29
P value		0.1824	0.0148	0.0202	0.0153	0.0157
Top sirloin steaks						
Frozen/Frozen	10	38.25[a]	16.54[b]	17.87[b]	47.25[a]	24.38[b]
Frozen/Fresh	10	40.66[ab]	19.77[a]	18.95[ab]	43.65[b]	27.41[a]
Fresh/Frozen	10	39.24[b]	14.00[c]	15.60[c]	48.74[a]	21.00[c]
Fresh/Fresh	10	41.71[a]	21.11[a]	20.04[a]	43.60[b]	29.13[a]
SEM		0.84	0.79	0.64	0.95	0.94
P value		0.0318	<0.0001	0.0002	0.0006	<0.0001

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

[1]CIE L^*, a^*, b^* color values: L^* for the lightness from black (0) to white (100), a^* from green (−) to red (+), and b^* from blue (−) to yellow (+). The higher the L^* value, the paler the meat. The higher the a^* value, the redder the meat. The higher the b^* value, the more yellow the color.

[2]Treatment: Frozen/Frozen subprimals were frozen (approximately −28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (approximately −1.1°C), and portioned into steaks, and steaks were placed in frozen storage (approximately −15.2°C) for 30 d. After 30 d in frozen storage, steaks were thawed for 2 d under refrigerated conditions (approximately −1.1°C) and evaluated within 7 d of thaw, totaling approximately 98 d of storage. Frozen/Fresh subprimals were frozen (approximately −28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (approximately −1.1°C), portioned into steaks, and evaluated within 7 d of cutting, totaling approximately 65 d of storage. Fresh/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately −28.9°C) for 30 d. Then, steaks were thawed for 2 d under refrigerated conditions (approximately −1.1°C) and evaluated within 7 d of thaw, totaling approximately 60 d of storage. Fresh/Fresh subprimals were portioned into steaks to be evaluated within 7 d of cutting, totaling approximately 28 d of storage.

Warner-Bratzler shear force evaluation

Mean WBS force values (*N*) stratified by steak type and storage treatment are shown in Table 5. No differences ($P = 0.8190$) in WBS force values were seen between storage treatments for top sirloin butts. However, differences ($P = 0.0040$) in WBS force values between storage treatments were observed for steaks derived from ribeye rolls. Ribeye steaks from Frozen/Frozen had the highest ($P < 0.05$) WBS force values compared with the Refrigerated/Frozen and Refrigerated/Refrigerated treatments. These findings disagree with Shanks et al. (2002), who reported a decrease in WBS force value after freezing strip loin steaks. The impact of freezing on tenderness varies per research study. Shanks et al. (2002) and Grayson et al. (2014) reported that freezing improves meat tenderness, whereas Wheeler et al. (1990) did not. 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 and determined that various combinations of freezing and thawing resulted in an increase in meat tenderness and implied such combinations could be implemented into commercial processes to improve consistency. However, both studies (Shanks et al., 2002; Grayson et al., 2014) were conducted on beef steaks, not beef subprimals, unlike the present study, in which subprimals and subsequent steaks were subjected to freezing. Steaks and subprimals have different freezing rates because of the difference in mass and thickness, which alters cellular disruption from the freezing process (Ramsbottom and Koonz, 1939).

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 to 3.9 kg (31.38 to 38.25 N), "intermediate" 3.9 to 4.6 kg (38.25 to 45.11 N), and "tough" greater than 4.6 kg (greater than 45.11 N). Using these tenderness thresholds (data not reported in tabular form), for ribeye steaks, 70% of Frozen/Frozen was classified as "very tender" with the other 30% as "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 classified as "very tender." The remaining top sirloin steaks, 20% of Frozen/Refrigerated and 10% of Refrigerated/Frozen, were classified as "tender." This is important because retailers and food service providers rely on eating satisfaction, which includes tenderness as one of their top quality concerns (Hasty et al., 2017).

Table 5. Least-squares means of Warner-Bratzler Shear force values (*N*) for ribeye and top sirloin steaks stratified by steak type × storage treatment[1]

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

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

[1]Treatment: Frozen/Frozen subprimals were frozen (approximately −28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (approximately −1.1°C), and portioned into steaks, and steaks were placed in frozen storage (approximately −15.2°C) for 30 d. After 30 d in frozen storage, steaks were thawed for 2 d under refrigerated conditions (approximately −1.1°C) and evaluated within 7 d of thaw, totaling approximately 98 d of storage. Frozen/Refrigerated subprimals were frozen (approximately −28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (approximately −1.1°C), portioned into steaks, and evaluated within 7 d of cutting, totaling approximately 65 d of storage. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately −28.9°C) for 30 d. Then, steaks were thawed for 2 d under refrigerated conditions (approximately −1.1°C) and evaluated within 7 d of thaw, totaling approximately 60 d of storage. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 d of cutting, totaling approximately 28 d of storage.

Consumer panel evaluation

Consumer panelists' scores for 4 beef palatability attributes—tenderness, flavor, juiciness, and overall liking—stratified by steak type and treatment are shown in Table 6. For the steaks derived from ribeye rolls, there were no differences ($P > 0.05$) between storage treatments for any of the 4 beef palatability attributes. Frozen/Refrigerated ribeye steaks had the lowest ($P < 0.05$) consumer panel evaluations for 3 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 4 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 that a combination of refrigerated and frozen storage parameters had no detrimental effects on sensory attributes. These results disagree with Hergenreder et al. (2013), who found freezing had no significant effects on panel ratings

Table 6. Least-squares means of consumer panelists' scores[1] for attributes of ribeye and top sirloin steaks stratified by storage treatment[2]

	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	5.16[b]	5.48[b]	4.86[b]	4.55[b]
Frozen/ Refrigerated	10	6.26[a]	6.40[a]	6.19[a]	5.90[a]
Refrigerated/ Frozen	10	5.99[a]	6.21[a]	5.66[ab]	6.03[a]
Refrigerated/ Refrigerated	10	6.19[a]	6.14[a]	5.68[ab]	6.01[a]
SEM		0.22	0.22	0.30	0.28
P value		0.0039	0.0259	0.0307	0.0010

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

[1]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).

[2]Treatment: Frozen/Frozen subprimals were frozen (approximately −28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (approximately −1.1°C), portioned into steaks, and steaks were placed in frozen storage (approximately −15.2°C) for 30 d. After 30 d in frozen storage, steaks were thawed for 2 d under refrigerated conditions (approximately −1.1°C) and evaluated within 7 d of thaw, totaling approximately 98 d of storage. Frozen/Refrigerated subprimals were frozen (approximately −28.9°C) for 30 d, thawed for 7 d under refrigerated conditions (approximately −1.1°C), portioned into steaks, and evaluated within 7 d of cutting, totaling approximately 65 d of storage. Refrigerated/Frozen subprimals were portioned into steaks, and steaks were frozen (approximately −28.9°C) for 30 d. Then, steaks were thawed for 2 d under refrigerated conditions (approximately −1.1°C) and evaluated within 7 d of thaw, totaling approximately 60 d of storage. Refrigerated/Refrigerated subprimals were portioned into steaks to be evaluated within 7 d of cutting, totaling approximately 28 d of storage.

for juiciness and tenderness attributes for *M. gluteus medius*. However, the study by Hergenreder et al. (2013) is different from the present study because subprimals were subjected to the freezing process, then steaks were collected and evaluated. In the present study, steaks were also subjected to the freezing process depending on the random treatment assignment. However, Lagerstedt et al. (2008) found that chilled meat, which was subjected to the freezing method after fabrication of sample size, was significantly higher in juiciness and flavor evaluations compared with frozen meat, which agrees with the current study. With regard to the sensory performance of top sirloin butt steaks, this work disagrees with Obuz and Dikeman (2003) and Moody et al. (1978), who found freezing had no significant effects on panel ratings for juiciness, flavor, and tenderness attributes. Additionally, Smith et al. (1968) compared the effects of refrigerated, frozen, and thawed states of lamb leg roasts on sensory attributes and satisfaction and found that freezing leg roasts significantly decreased tenderness and overall satisfaction ratings, whereas freezing lamb chops resulted in increased shear force values.

Conclusions

Beef purveyors, retailers, and/or foodservice operators try to achieve optimal consumer satisfaction, including product availability and palatability. However, with marketing condition fluctuations, meeting consumer needs becomes more difficult because of 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. Although some differences only impacted one subprimal, ribeye rolls were generally found to be less susceptible to 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 4 beef palatability attributes evaluated. To allow for optimum yield, color, and consumer panel ratings, refrigerated top sirloin butt subprimals should be utilized in place of frozen subprimals. 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 beef purchasing decisions made by companies to increase profitability, availability, and flexibility as market trends frequently fluctuate.

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