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Evaluation of Fresh and Frozen Beef Strip Loins of Equal Aging Periods for Palatability Traits[1]

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Abstract: Although studies evaluating freezing are prevalent, most have used varied postmortem aging times to facilitate study design. The lack of a comprehensive study evaluating equally aged fresh and frozen steaks prevents a true understanding of the impact of freezing. Therefore, the objective of this study was to determine the eating quality and consumer perception differences between fresh and frozen beef steaks of 3 equal aging periods. Beef carcasses were selected from a processing plant on 2 kill dates 1 wk apart to allow for a 1-wk freezing period, fabricated, and aged for 21, 28, or 35 d. On the same day, all samples of equal aging periods were fed to consumer and trained sensory panelists, sheared for shear force, and powdered for lab assays. For consumer panels, the first 4 steaks were given with no additional information, whereas the last 4 steaks were served with the labels "previously frozen" or "fresh, never frozen." The consumer panelists rated the frozen samples as more tender ($P < 0.05$) than the fresh samples but found no other differences ($P > 0.05$). Even when given additional information, the perception of quality was not impacted ($P > 0.05$). Similarly, the trained panelists rated the frozen samples higher ($P < 0.05$) than the fresh counterparts for overall tenderness, but the fresh samples scored higher ($P < 0.05$) for initial and sustained juiciness. Supporting the sensory data, the frozen steaks had lower ($P < 0.05$) shear force values regardless of the aging period. However, the fresh samples resulted in lower ($P < 0.05$) purge and cook loss. Although some meat quality factors were impacted by freezing, the overall eating quality and perception of quality were not negatively impacted. Therefore, frozen meat should not be discounted due to the eating quality or perception of the quality of beef steaks.

Keywords: consumer, fresh vs. frozen, eating quality, beef, sensory, aging
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Introduction

Freezing meat is a common practice to alleviate pressure on cold chain management and to increase the consistency of the aging period (Iskandar et al., 2019). However, freezing is widely thought to not only negatively impact the overall quality of meat but also to negatively impact the consumer's perception of quality (Buckley et al., 1977). In retail, the label "previously frozen" is commonly believed to be a deterrent for some consumers, affecting their purchasing habits (Pietrasik and Janz, 2009). However, the notion that beef eating quality is reduced and the consumer's perception of quality is diminished through freezing has never been supported in scientific literature when comparing equally aged fresh and frozen products, leaving a significant gap in understanding (Pietrasik and Janz, 2009).

Although studies evaluating freezing are numerous, they have mostly evaluated the impacts of freezing on raw meat quality and ice crystal formations of frozen beef alone (Grayson et al., 2014; Aroeira et al., 2016). Ice crystals form while meat is freezing, and the size, location, and morphology of the ice crystal can play a large role in meat quality (Aroeira et al.,

2016; Botinestean et al., 2016). As the ice crystals form, they can rupture the muscle cell membrane, potentially leading to the release of prooxidants, metals, and water molecules (Zhang et al., 2023). The impact of ice crystal formation has been widely studied and accepted, impacting current perceptions of frozen beef quality (Martino and Zaritzky, 1988; Grayson et al., 2014; Aroeira et al., 2016).

Although the effects of freezing on the quality of beef have been studied widely in reference to ice crystal formation, purge loss, tenderness changes, and oxidation, no study has directly compared an equally aged fresh product against a frozen product to determine palatability changes. Other studies have compared the 2 cold storage methods but did so by aging the fresh treatment for substantially longer or by including aging periods after freezing (Wheeler et al., 1990; Farouk et al., 2003; Lagerstedt et al., 2008; Hergenreder et al., 2013; Grayson et al., 2014). By using different methodologies or comparing unequal aging periods, the palatability effects of freezing, especially tenderness, have been inconsistent (Hergenreder et al., 2013; Grayson et al., 2014). Although Grayson et al. (2014) and Aroeira et al. (2016) found tenderness to improve after freezing, the magnitude of the impact was drastically different because of inconsistent methods. Even more so, Hergenreder et al. (2013) found the frozen samples to be tougher than the fresh control with a significantly longer aging period. These discrepancies leave a gap in research and prevent any global statements to be made about the effect of freezing on meat quality, especially eating quality.

The lack of a comprehensive study evaluating equally aged fresh and frozen steaks prevents a true understanding of the impact of freezing. Because freezing is imperative for the meat industry, this comparison needs to be made. Additionally, although it is widely accepted in the meat industry that consumers deprioritize frozen meat (Pietrasik and Janz, 2009), no study has evaluated such claims. Therefore, the objectives of this study were to determine the eating quality and consumer perception differences between fresh and frozen beef steaks of 3 equal aging periods and to evaluate consumer perceptions of fresh versus frozen beef.

Materials and Methods

The Kansas State University (KSU) Institutional Review Board (IRB) approved all procedures for use of human participants in sensory panel evaluations (IRB #7440.8, October 2022).

Sample collection and fabrication

Beef carcasses (N= 72; n = 36/collection; 12 per aging period) were selected from a Midwestern beef processing plant on 2 different kill dates 1 wk apart. The carcasses were all graded USDA Low Choice, were A maturity, and averaged 435.9 kg. Beef carcasses were selected to be uniform for yield and quality grades between the 2 kill dates and therefore were selected from the same rail designation, which was plant dependent. Trimmed strip loins (IMPS #180, NAMP, 2010) were collected from the right side of the carcasses. The collection was repeated twice for a total of 72 strip loins from 2 different kill dates. The strip loins were transported to KSU and were processed the day following the last collection. The strip loins were sliced into 12 steaks at a 2.5-cm thickness. Each steak was given a random 4-digit code and assigned to either 21, 28, or 35 d aging with one of the following designations: trained sensory panels, consumer sensory panels, shear force, or lab assays. All 36 loins from the first kill date represented the frozen samples, whereas the later kill date represented the fresh samples. All steaks were aged to their appropriate aging period at 2°C to 4°C in the absence of light. After aging, the frozen samples were blast frozen in a commercial freezer located at the KSU meat lab and held at −20°C for 1 wk before being placed in a 2°C to 4°C refrigerator to thaw 24 h before the time of use. At the time of thawing, the fresh samples were at the exact same aging period as the frozen samples at the time of freezing. This served as the direct comparison of fresh and frozen beef steaks for palatability traits and lab assays. The study timeline for each treatment is shown in Figure 1.

Trained sensory panels

At exactly 21, 28, and 35 d aged, the steaks were fed in trained sensory panels to 8 trained panelists at a time for a total of 3 panel sessions per day. Descriptive panelists were conducted, were trained, and used anchors similar to previous sensory panels conducted at KSU (Drey et al., 2019; Olson et al., 2019; Prill et al., 2019; Rice et al., 2019; Beyer et al., 2021; Farmer et al., 2022). Briefly, the full steaks were cooked on clamshell grills (Cuisinart Griddler Deluxe, Stamford, CT) according to the American Meat Science Association (AMSA) sensory guidelines (AMSA, 2015) to a medium degree of doneness (71°C), and peak internal temperatures were recorded. All samples were sliced on a slicing guide into 1-cm cubes, and 2 cubes were served to each panelist to reduce sample variation.

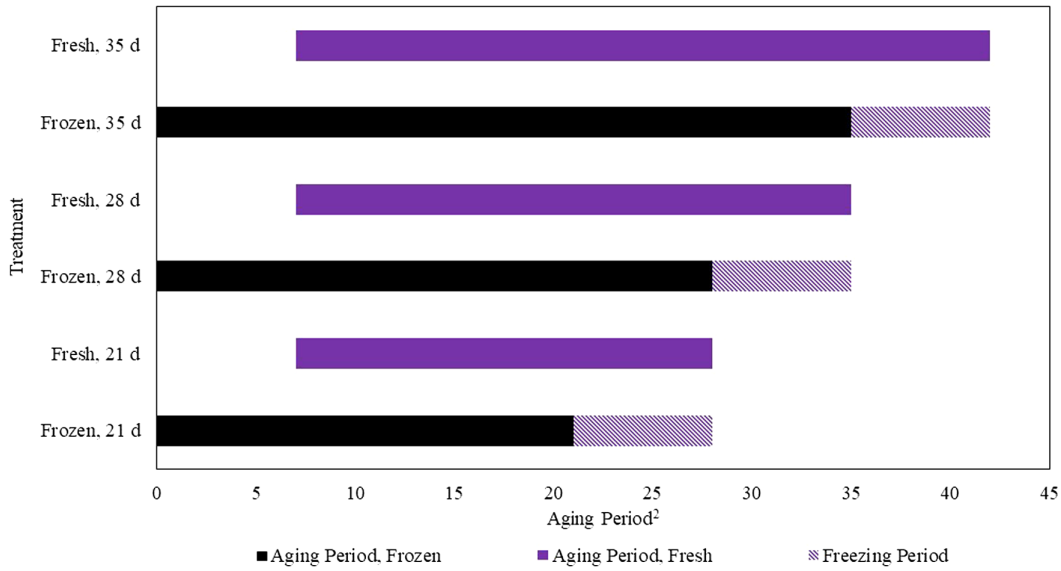

Figure 1. Timeline for the collection[1] and processing of each fresh vs. frozen and aging combination. [1]Harvest dates: 8/23/2022 (frozen), 8/30/2022 (fresh); [2]aging period axis based on day 0 of frozen collection.

Before each panel, trained sensory panelists were given one sample as a warmup to prevent panelist drift across different panel sessions. Additionally, trained sensory panels were conducted under red incandescent light, and each panelist was given deionized water, apple slices, and unsalted crackers for palate cleansing between samples. Each panelist received 8 samples, 4 from each treatment, and were asked to evaluate each sample for initial juiciness, sustained juiciness, myofibrillar tenderness, connective tissue amount, overall tenderness, beef flavor intensity, and off-flavor intensity. Each trait was evaluated on a 0 to 100 line scale with anchors described by Beyer et al. (2021). The trained sensory panel data were collected on electronic tablets (Lenovo TB-8505F, Morrisville, NC) using Qualtrics (v. 2417833; Qualtrics Software, Provo, UT).

Consumer sensory panels

On the same day as the trained descriptive panels, consumers ($n = 48$ aging period, $N = 144$ total) were fed 8 samples, 4 from each treatment. Consumer sensory panels were conducted and fed similarly to other panels held at KSU (Drey et al., 2019; Olson et al., 2019; Prill et al., 2019; Rice et al., 2019; Farmer et al., 2022). Samples were cooked as described previously following the AMSA sensory guidelines (AMSA, 2015). The consumers were asked to evaluate the samples for tenderness, juiciness, flavor liking, and overall liking as well as indicate if each sensory trait was acceptable or unacceptable. Each trait was evaluated on a 0 to 100 line scale with anchors described by Farmer et al. (2022). The consumers were also asked to classify the samples into 1 of 4 perceived quality categories (unsatisfactory, everyday quality, better than everyday quality, or premium quality). The consumer sensory panel data were collected similarly to the descriptive panel data on the same electronic tablets (Lenovo TB-8505F) using Qualtrics (v. 2417833; Qualtrics Software).

Consumers were given 8 total samples with either no information or with the label "Previously Frozen" or "Fresh, Never Frozen." The first 4 samples were served without any additional information, whereas the last 4 samples were given with information before consumption. Within the identified samples, 1 steak from each treatment was labeled correctly, and the other was labeled with the opposite treatment to help understand the consumers' perception of fresh versus frozen beef steaks.

Shear force, cooking characteristics, and internal color

On the same day as the descriptive and consumer sensory panels, a steak from each treatment and from each strip loin was cooked for shear force and prepared for all other lab assays. The steak designated for shear force was used to determine slice shear force (SSF), Warner-Bratzler shear force (WBSF), purge loss, cook

loss, and Commission Internationale de l´Eclairage (CIE) L^*, a^*, and b^* internal cooked color readings. Before cooking, purge loss was determined. First, the full package was weighed and opened and the packaging was rinsed with water and dried with paper towels before being reweighed. The raw sample was weighed for purge loss and cook loss. Next, the steaks were cooked to an endpoint temperature of 71°C and immediately prepared and sliced for SSF using the protocol of Shackelford et al. (1999). A 2.54-cm-wide cut was made parallel to the muscle fibers in the lateral portion of the steak to measure the SSF and internal color using a HunterLab MiniScan Spectrophotometer (Illuminant A, 2.54 cm aperture, 10° observer, HunterLab Associates Laboratory, Reston, VA). After a 3-min bloom time measured with a timer, 3 readings were taken in different locations within the internal cut surface, and an average of L^*, a^*, and b^* values was recorded and the relative percentages of metmyoglobin (MetMb), oxymyoglobin (OMb), and deoxymyoglobin (DMb) were determined using spectral data according to the AMSA color guidelines (King et al., 2023).

The samples were sheared for SSF immediately following the color readings, and then the remaining steak was cooled for WBSF using the protocol in the AMSA sensory guidelines (AMSA, 2015). Both measures of tenderness were conducted using an Instron Model 5569 testing machine (Instron, Norwood, MA). Shear force values were represented as kilograms of force for SSF and WBSF.

Sample preparation and proximate analysis

The assigned lab assay steak from each treatment was sliced, cut into cubes, dipped in liquid nitrogen until completely frozen, and ground into a fine powder using a blender (Waring Commercial Products, Stamford, CT) before being stored at −80°C until use. The powdered sample was stored for surface hydrophobicity, lipid oxidation, and MetMb-reducing activity (MRA).

Surface hydrophobicity

Surface hydrophobicity is a measure used to determine the amount of hydrophobic groups exposed because of denaturation or damage to the muscle fiber. Surface hydrophobicity was determined using the protocol described by Dominguez-Hernandez and Ertbjerg (2021). Briefly, 0.3 g of meat powder and 1.5 mL of sodium phosphate buffer were added to a 1.5 mL tube with glass beads. The sample was homogenized for 30 s and centrifuged at 4,000 × g for 5 min. The supernatant was discarded and 1 mL of buffer was added and recentrifuged following the aforementioned parameters to wash away the remaining sarcoplasmic proteins. Myofibrillar proteins were extracted with sodium dodecyl sulfate and standardized to 2,000 µg/mL of protein. An aliquot of protein stock was added to 1 mg/mL concentration of bromophenol blue (BPB) and incubated for 10 min in the absence of light. The resulting sample was diluted to a 1/10 ratio with deionized water and added to a 96-well plate in duplicate. The absorbance was taken at 595 nm and used to calculate the BPB bound/mg of protein.

Metmyoglobin-reducing activity

The MRA was determined using the protocol from the AMSA color guidelines (King et al., 2023) modified to reduce the sample to a 0.3 g sample instead of a 5 g sample. Briefly, 0.3 g of the powdered sample and 1.2 mL sodium phosphate buffer were added and centrifuged at 14,000 × g for 30 min. A 96-well plate was prepared by adding 50 µL of 0.75 mM MetMb, 25 µL of 3.0 mM potassium ferrocyanide, 50 µL of deionized water, 25 µL of 5 mM ethylenediaminetetraacetic acid, and 25 µL of 3 mM sodium citrate buffer. Next, 50 µL of each sample was added in duplicate. After the sample was added, 25 µL of 1 mM nicotinamide adenine dinucleotide was quickly added, and the cells were agitated before being read at 580 nm every 60 s for 180 s. Beer's law was used to calculate the change in absorbance as the change from metmyoglobin to OMb (King et al., 2023).

Lipid oxidation

Lipid oxidation was determined using the thiobarbituric acid reactive substances assay following the procedures described by Ahn et al. (1998) and similar procedures done at KSU (Dahmer et al., 2022). Briefly, a 0.1 g sample of the powdered sample was weighed and added to 1.5 mL bead tubes with 0.7 mL of thiobarbituric acid and trichloroacetic acid and 50 µL of butylated hydroxy anisole. The samples were centrifuged at 2,000 × g for 5 min, and 0.6 mL of the supernatant was transferred into prelabeled glass tubes. After vortexing, the tubes were covered in aluminum foil and incubated in a 70°C water bath for 30 min. Then, the samples were cooled and centrifuged at 3,000 × g for 15 min. Lastly, 0.2 mL of the supernatant was pipetted into a 96-well plate in duplicate. The plate was evaluated at 532 nm absorbance, and a standard curve was used to determine the concentration of malondialdehyde (MDA).

Statistical analysis

The statistical analysis was conducted using SAS (v. 9.4; SAS Institute, Inc., Cary, NC) PROC GLIMMIX. Carcass served as the experimental unit. Data were analyzed as a 2×3 factorial design with the fixed effects of the fresh versus frozen state and aging period. There were no interactions ($P > 0.05$) found between the aging periods and the freezing method. Peak temperature was used a covariate when applicable. To determine the impact of "previously frozen" or "fresh, never frozen" labels, all combinations of information and freezing treatments were combined and evaluated as a completely randomized design. An α of 0.05 was set for a level of significance. The Kenward-Roger adjustment was used in all analyses.

Results

Consumer sensory evaluation

Consumer demographic information is displayed in Table 1. Men and women were equally represented. The majority of the consumers came from a 1 or 2 person household (64.5%) and were single (59.4%). Most (62%) of the participants either fell into the 20 to 29 y old or over 60 y old categories. A vast majority (83.9%) were Caucasian or of white ethnic origin, but African American, Asian, Latino, and Native American races were all represented. The majority (50.4%) of the consumers indicated they lived in a household earning $50,000 or more. Most of the consumers used for this study reported flavor to be the most important palatability trait, whereas tenderness was identified as the most variable by 42.6% of consumers, more than the other traits. The vast majority (78.1%) of consumers preferred a medium or a medium rare degree of doneness and consumed beef up to 5 d a week (74%).

Table 1. Demographic characteristics of consumers ($N = 144$) who participated in consumer sensory panels

Characteristic	Response	Percentage of consumers
Gender	Male	50.3
	Female	49.7
Household size	1 person	25.8
	2 people	38.7
	3 people	8.4
	4 people	13.5
	5 people	3.9
	6 or more people	5.8
Educational level	High school graduate	20.6
	Non-high school graduate	3.2
	Some college/technical school	45.2
	College graduate	18.1
	Post-college graduate	12.9
Marital status	Married	50.6
	Single	59.4
Age	Under 20	16.8
	20–29	32.3
	30–39	2.6
	40–49	7.1
	50–59	11.6
	Over 60	29.7
Ethnic origins	African American	2.6
	Asian	1.3
	Caucasian/White	83.9
	Latino	1.9
	Mixed race	4.5
	Native American	2.6
Income	Under $25,000	37.4
	$25,000–$34,999	8.4
	$35,000–$49,999	3.2
	$50,000–$74,999	16.8
	$75,000–$99,999	12.9
	$100,000–$149,999	9.7
	$150,000–$199,999	57.6
	>$199,999	10.1
Most important palatability trait when consuming beef	Tenderness	32.9
	Juiciness	11.6
	Flavor	54.8
Most variable palatability trait when consuming beef	Tenderness	42.6
	Juiciness	29.0
	Flavor	27.7
Preferred degree of doneness when consuming beef	Very rare	2.6
	Rare	3.9
	Medium rare	43.9
	Medium	34.2
	Medium well	11.6
	Well done	3.9
Weekly beef consumption	1–5 times	74.0
	6–10 times	23.9
	11 or more times	4.5

Table 2. Fresh beef steak purchasing motivators of consumers ($N = 144$) who participated sensory panels

Characteristic	Importance[1]
Price	73.0[a]
Color	72.6[ab]
USDA Grade	66.3[bc]
Nutrient content	64.5[cd]
Size, weight, and thickness	64.9[cd]
Marbling	59.9[de]
Familiarity with cut	58.1[e]
Animal welfare	56.6[ef]
Eating satisfaction claims	56.6[e]
Antibiotic use in animals	50.1[fg]
Fresh or frozen claim	49.4[g]
Growth hormone used in animals	49.4[g]
Animals fed a grass-based diet	48.2[gh]
Organic claim	44.8[ghi]
Animals fed a grain-based diet	42.7[hi]
Brand of product	40.2[i]
Packaging	39.9[i]
SEM[2]	3.2
P value	<0.01

[a–i]Means within the same column without a common superscript differ ($P < 0.05$).

[1]Purchasing motivators: 0 = extremely unimportant, 100 = extremely important.

[2]Standard error (largest) of the least-squares means.

Purchasing motivators are presented in Table 2. Overall, price was reported to have a larger ($P < 0.05$) role in purchasing decisions compared with all other options besides meat color. The fresh or frozen claim ranked in the lowest 7 traits for importance to consumers when purchasing meat at retail and was similar ($P > 0.05$) in importance to traits including many animal production claims.

The consumer sensory results found in Table 3 are similar to the trends found by the trained descriptive panelists. The consumers found no differences ($P > 0.05$) between the fresh and frozen samples for juiciness but did rate the frozen samples as more tender ($P < 0.05$). However, this tenderness difference did not impact ($P > 0.05$) the overall liking. Unlike the trained sensory results, the consumers found a difference ($P < 0.05$) in juiciness and tenderness for the different aging periods, with the 21 d–aged samples having lower ($P < 0.05$) juiciness and tenderness ratings in comparison with the other aging periods. Also, the 28 d–aged samples had the highest ($P < 0.05$) flavor and overall liking scores, whereas the 21 d–aged steaks had the lowest ($P < 0.05$) scores for the same traits.

Table 3. Least-squares means ($n = 12$/age/treatment) of consumer sensory panelist palatability ratings[1] for fresh and frozen beef steaks of 3 aging periods

Treatment	Juiciness	Tenderness	Flavor liking	Overall liking
Freezing				
Frozen	64.5	65.1[a]	62.7	63.8
Fresh	66.0	61.4[b]	61.7	61.6
SEM[2]	1.46	1.65	1.42	0.45
***P* value**	0.30	0.03	0.47	0.16
Aging				
21 d	61.6[b]	58.0[b]	55.3[c]	56.5[c]
28 d	68.3[a]	67.6[a]	68.6[a]	68.4[a]
35 d	66.0[a]	64.0[a]	62.8[b]	63.2[b]
SEM[2]	1.82	2.05	2.05	1.95
***P* value**	<0.01	<0.01	<0.01	<0.01

[a–c]Means within the same section of the same column without a common superscript differ ($P < 0.05$).

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

[2]Standard error (largest) of the least-squares means.

Results for the percentage of samples rated as acceptable for each palatability trait are presented in Table 4. A greater ($P < 0.05$) percentage of consumers (89.3%) identified frozen samples as acceptable for tenderness in comparison with the fresh counterpart (83.9%). No other differences ($P > 0.05$) in the percentage of samples rated acceptable were found between the fresh and frozen samples. Among aging treatments, the 21 d–aged samples resulted in the lowest ($P < 0.05$) percentage of samples rated acceptable

Table 4. Least-squares means ($n = 12$/age/treatment) for the percentage of consumers who rated each palatability trait as acceptable

Treatment	Juiciness acceptability	Tenderness acceptability	Flavor acceptability	Overall liking acceptability
Freezing				
Frozen	86.6	89.3[a]	84.0	83.5
Fresh	87.4	83.9[b]	84.5	86.9
SEM[1]	0.18	0.19	0.17	0.17
***P* value**	0.70	0.01	0.85	0.13
Aging				
21 d	81.1[b]	78.1[b]	76.1[c]	76.8[b]
28 d	91.2[a]	88.4[a]	89.7[a]	89.4[a]
35 d	87.0[a]	91.3[a]	84.6[b]	87.4[a]
SEM[1]	0.22	0.25	0.22	0.23
***P* value**	<0.01	<0.01	<0.01	<0.01

[a–c]Means within the same section of the same column without a common superscript differ ($P < 0.05$).

[1]Standard error (largest) of the least-squares means.

Table 5. Least-squares means ($n = 12$/age/treatment) of the percentage of consumers who rated samples as each of the quality levels

Treatment	Unsatisfactory	Everyday quality	Better than everyday quality	Premium quality
Freezing				
Frozen	11.4	50.5	26.7	8.6
Fresh	14.2	53.5	23.7	5.5
SEM[1]	0.19	0.12	0.14	0.28
***P* value**	0.18	0.31	0.24	0.09
Aging				
21 d	22.1[a]	54.7	20.3[b]	2.6[c]
28 d	9.6[b]	48.4	26.9[a]	14.9[a]
35 d	9.4[b]	52.9	28.9[a]	8.2[b]
SEM[1]	0.25	0.15	0.17	0.39
***P* value**	<0.01	0.21	0.02	<0.01

[a,b]Means within the same section of the same column without a common superscript differ ($P < 0.05$).

[1]Standard error (largest) of the least-squares means.

for juiciness, tenderness, flavor, and overall liking. Additionally, consumers were asked to determine the quality level of each sample (Table 5). An equal ($P > 0.05$) percentage of fresh and frozen samples were classified as "unsatisfactory," "everyday quality," "better than everyday quality," and "premium quality." The 21 d–aged samples resulted in the highest ($P < 0.05$) percentage of steaks rated as "unsatisfactory quality" and the lowest ($P < 0.05$) percentage of steaks rated as "premium quality."

Following blinded sample evaluation, consumers were given additional samples with information about the preservation method for the final 4 samples. Two samples were correctly identified, and 2 samples were identified with the incorrect information. As reported in Table 6, these labels did not impact ($P > 0.05$) the eating quality of any attribute.

Trained sensory evaluation

The sensory evaluation scores from the trained sensory panels are presented in Table 7. Trained panelists determined the fresh samples were juicier ($P < 0.05$) within initial and sustained juiciness ratings compared with the frozen samples, whereas no differences ($P > 0.05$) were found among the different aging periods. The frozen samples were rated as more tender ($P < 0.05$) for overall tenderness in comparison with the fresh samples, whereas the treatments did not differ ($P > 0.05$) for myofibrillar tenderness. There was not a difference ($P > 0.05$) for myofibrillar or overall tenderness among the aging periods. However, the frozen

Table 6. Least-squares means ($n = 12$/age/treatment) of consumer sensory panelist palatability ratings[1] for fresh and frozen beef steaks of 3 aging periods when given no information, true information or false information about the cold storage method

Treatment information	Juiciness	Tenderness	Flavor liking	Overall liking
Fresh[2]				
None[3]	65.6	60.8	59.7	60.3
Fresh[3]	66.4	61.2	65.0	63.6
Frozen[3]	66.6	62.6	62.4	62.3
Frozen[2]				
None[3]	63.1	65.3	60.9	62.3
Fresh[3]	64.4	64.2	63.0	63.5
Frozen[3]	67.4	65.6	66.2	66.6
SEM[4]	2.95	3.40	2.81	3.16
***P* value**	0.54	0.38	0.08	0.34

[a–c]Means within the same section of the same column without a common superscript differ ($P < 0.05$).

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

[2]Actual product type.

[3]Information given to consumers.

[4]Standard error (largest) of the least-squares means.

samples had a reduced ($P < 0.05$) connective tissue amount rating in comparison with the fresh samples, whereas the 21 and 35 d–aged samples resulted in lower ($P < 0.05$) connective tissue amount ratings compared with the 28 d samples. Lastly, there were no differences ($P > 0.05$) for beef flavor intensity between the freezing methods or among the aging periods.

Warner-Bratzler shear force and cooking characteristics

Objective measures of tenderness, moisture, aggregation, oxidation, and color were used to further understand the physiochemical changes that occur from the freezing process (Tables 8 and 9). Supporting the sensory data, the frozen samples resulted in a lower ($P < 0.05$) WBSF and SSF value than the fresh samples. Additionally, the 21 d–aged samples were the toughest ($P < 0.05$) as shown by the highest WBSF values. The fresh samples had lower ($P < 0.05$) cook loss and purge loss than the frozen samples. The 21 d–aged samples had the lowest ($P < 0.05$) cook loss of all aging periods; however, the same trend was not observed for purge loss, as the 35 d–aged samples resulted in the least purge loss ($P < 0.05$).

Table 7. Least-squares means ($n = 12$/age/treatment) of trained sensory panelist palatability ratings[1] for fresh and frozen beef steaks of 3 aging periods

Treatment	Initial juiciness	Sustained juiciness	Myofibrillar tenderness	Connective tissue amount	Overall tenderness	Beef flavor intensity
Freezing						
Frozen	60.7[b]	54.5[b]	70.6	4.0[b]	69.3[a]	33.4
Fresh	64.0[a]	58.5[a]	67.3	5.4[a]	65.2[b]	33.7
SEM[2]	1.42	1.60	1.70	0.45	1.75	0.65
***P* value**	0.02	0.01	0.06	<0.01	0.02	0.64
Aging						
21 d	61.6	55.8	67.2	4.2[b]	66.2	34.1
28 d	62.1	56.3	68.5	5.7[a]	65.5	32.4
35 d	63.3	57.4	71.2	4.3[b]	69.9	34.2
SEM[2]	1.74	1.91	2.05	0.55	2.15	0.79
***P* value**	0.63	0.67	0.15	<0.01	0.10	0.06

[a–c]Means within the same section of the same column without a common superscript differ ($P < 0.05$).

[1]Sensory scores: 0 = extremely dry/tough/bland/none, 50 = neither juicy/dry/tough/tender, 100 = extremely juicy/tender/abundant/intense.

[2]Standard error (largest) of the least-squares means.

Table 8. Least-squares means of Warner-Bratzler shear force (WBSF), slice shear force (SSF), cook loss, purge loss and surface hydrophobicity for fresh and frozen beef steaks of 3 aging periods

Treatment	WBSF, kg	SSF, kg	Cook loss, %	Purge loss, %	Surface hydrophobicity[1]
Freezing					
Frozen	3.1[b]	15.4[b]	17.1[a]	1.6[a]	4.6
Fresh	3.4[a]	19.0[a]	14.9[b]	0.8[b]	4.6
SEM[2]	0.14	0.86	0.45	0.12	0.78
***P* value**	<0.01	<0.01	<0.01	<0.01	0.97
Aging					
21 d	3.6[a]	18.9[a]	14.7[b]	1.3[a]	5.1
28 d	3.2[b]	17.0[ab]	16.4[a]	1.3[a]	4.7
35 d	3.0[b]	15.6[b]	16.9[a]	1.0[b]	4.0
SEM[2]	0.17	1.05	0.55	0.14	0.97
***P* value**	<0.01	<0.01	<0.01	0.03	0.51

[a–c]Means within the same section of the same column without a common superscript differ ($P < 0.05$).

[1]Surface hydrophobicity: μg bromophenol blue/mg protein.

[2]Standard error (largest) of the least-squares means.

Internal cooked color, color stability, lipid oxidation, and surface hydrophobicity

The fresh samples had higher ($P < 0.05$) L^* values in comparison with the frozen samples, appearing visually lighter; however, the 2 treatments did not differ ($P > 0.05$) in a^* values (redness). The relative percentages of MetMb, OMb, and DMb were similar ($P > 0.05$) for both cold storage treatments. However, the frozen steaks had significantly higher ($P < 0.05$) color stability, as indicated by a higher MRA. The 21 d–aged treatment had the highest ($P < 0.05$) a^* value and percentage of DMb while having a higher ($P < 0.05$) L^* value compared with the 35 d–aged treatment and a lower ($P < 0.05$) MetMb percentage as compared with the 28 d–aged treatment. Lastly, there were no ($P > 0.05$) differences in b^* values, lipid oxidation, and surface hydrophobicity for the fresh versus frozen treatments or among the aging periods.

Discussion

Sensory comparisons of fresh and frozen beef are sparse in published scientific literature, potentially because of the logistical issues of comparing fresh and frozen product of equal aging periods. Therefore, the current study serves as the best comparison to date of fresh versus frozen beef of equal aging periods. With equal aging periods, the current study found only a few differences within the consumer and trained

Table 9. Least-squares means of CIE L^*, a^*, MRA, and relative percentages of oxymyoglobin (OMb), deoxymyoglobin (DMb), metmyoglobin (MetMb), and MetMb-reducing activity (MRA) for bloomed internal cooked color of fresh and frozen steaks of 3 aging periods

Treatment	L^*[1]	a^*[2]	MetMb, %	OMb, %	DMb, %	MRA[3]	Lipid oxidation[4]
Freezing							
Frozen	56.8[b]	20.6	33.3	60.7	6.0	3.67[a]	0.66
Fresh	59.2[a]	20.2	33.1	61.3	5.6	3.08[b]	0.62
SEM[5]	0.57	0.73	1.29	1.37	0.91	0.27	0.06
***P* value**	<0.01	0.62	0.89	0.66	0.63	0.03	0.56
Aging							
21 d	59.0[a]	22.7[a]	31.0[b]	61.0	8.0[a]	3.64	0.67
28 d	58.2[ab]	18.7[b]	35.3[a]	61.0	3.8[b]	3.21	0.68
35 d	56.8[b]	19.7[b]	33.3[ab]	61.0	5.6[b]	3.26	0.58
SEM[5]	0.70	0.89	1.58	1.68	1.11	0.33	0.07
***P* value**	<0.01	<0.01	0.03	0.99	<0.01	0.37	0.30

[a–c]Means within the same section of the same column without a common superscript differ ($P < 0.05$).

[1]L^*: 0 = black, 100 = white.

[2]a^*: −60 = green, 60 = red.

[3]nmol/min/g.

[4]Lipid oxidation: malondialdehyde/mg meat tissue.

[5]Standard error (largest) of the least-squares means.

sensory ratings, with identified differences specifically in tenderness and juiciness.

It is well documented that freezing impacts tenderness in some capacity (Lagerstedt et al., 2008; Grayson et al., 2014; Aroeira et al., 2016). The impact of tenderness occurs through 2 potential mechanisms. First, the rupturing of the cell membrane, causing a physical improvement by decreasing the shear force (Rahelić et al., 1985) or from a post-freezing aging period (Aroeira et al., 2016). Our study illustrated freezing improved tenderness with an 18.9% decrease in SSF values and an 8.8% decrease in WBSF values as well as an increase of overall tenderness ratings within both the trained panel and consumer panel ratings by 6.3% and 6.0%, respectively. Other studies have researched the impact of freezing on tenderness and reported similar results (Lagerstedt et al., 2008; Grayson et al., 2014; Aroeira et al., 2016). Lagerstedt et al. (2008) used beef loins aged or frozen for 2, 7, or 14 d and determined that, even without equal aging periods, freezing still provided a 20% reduction in shear force at day 2 and a 14% reduction at day 14. Grayson et al. (2014) found a 42.3% decrease in SSF values from a 14 d fresh sample in comparison with a 14 d frozen sample with a 14 d aging period after freezing. However, a post-freezing aging period could also impact tenderness by potentially deactivating calpastatin through the freezing process, attributing to the greater percentage of change in shear force in comparison with the fresh sample (Koohmaraie, 1990; Grayson et al., 2013). It is hypothesized that freezing deactivates calpastatin activity, therefore allowing the calpains to be more active in a post-freezing system; however, the exact mechanism is unknown (Koohmaraie, 1990; Kristensen et al., 2006; Grayson et al., 2014; Aroeira et al., 2016). In every study that included a comparable aging period to the fresh sample, the frozen treatment resulted in decreased shear force values, similar to the present study (Grayson et al., 2014; Aroeira et al., 2016).

Although it is mostly accepted that freezing and thawing steaks decreases the shear force values of certain muscles, there have been conflicting reports (Wheeler et al., 1990; Farouk et al., 2003; Lagerstedt et al., 2008; Grayson et al., 2014; Aroeira et al., 2016). Hergenreder et al. (2013) found a 43.5% increase in WBSF values using a blast freezing treatment and a 35.5% increase in WBSF values using a conventional freezing treatment in comparison with a 21 d–aged fresh control. Similarly, because of the difference in design described previously, Aoreira et al. (2016) found WBSF values to decrease when freezing samples for 0 and 7 d of storage, but the fresh samples in their study resulted in lower WBSF values for 14 and 21 d of storage. These discrepancies were most likely the result of unequal refrigerated aging periods caused by differences in the project design (Grujić et al., 1993; Grayson et al., 2013; Aroeira et al., 2016). These design

differences make it challenging to compare the properties changed by freezing but do represent what is typically found in the industry and retail. Because of the large discrepancies in methods, the impact of freezing even within the published scientific literature remains unclear. However, from the current study, it can be concluded that within equal aging periods, the tenderness of beef steaks is improved with freezing.

Juiciness was also impacted by freezing within the trained sensory data of the present study, but it was not identified by the consumers. This may indicate the observed difference was too marginal to be detected by an untrained group of panelists. This was supported by Hergedreder et al. (2013), who used consumer panelists to evaluate palatability traits between the treatments described previously and found no differences for juiciness. Additionally, the attributes that are correlated to juiciness ratings such as cook loss and purge loss were also increased by freezing. These impacts have been of the highest scrutiny within the industry due to the economic loss related to moisture loss (Leygonie et al., 2012; Aroeira et al., 2016; Kim et al., 2018). However, the increase in purge found in this study was 0.8%, having little to no practical impact. In contrast, Aroeira et al. (2016) found up to a 6.6% increase in purge for a 21 d aged versus frozen steak. Although the 2 studies have differing freezing methods, the purge loss difference is substantial, illustrating the importance of the freezing method. It is also worth noting that in the current study and the Aroeira et al. (2016) study, purge loss was measured on a steak basis rather than a wholesale basis, which would be more common in industry. Moreover, cook loss for frozen samples resulted in approximately a 3% or less increase compared with the fresh counterpart in our study and others (Hergedreder et al., 2013; Aroeira et al., 2016). The decrease in water-holding capacity attributes can be tied back to the well-vetted mechanism of ice crystal formation (Leygonie et al., 2012; Aroeira et al., 2016; Kim et al., 2018). The rupturing of the cell membranes has been shown to release water, ions, enzymes, metals, and other molecules typically protected by the cell membrane (Sánchez del Pulgar et al., 2012). This loss of cellular integrity can be improved with improved freezing techniques, as potentially seen in the current study. Similarly, the changes in the water-holding capacity attributes, cook loss, and purge loss were not severe enough to elicit an impact on the juiciness ratings for the consumers.

The physiochemical properties that were evaluated supported the sensory data, finding few differences between the fresh and frozen samples. Freezing decreased L^* values but had no impact on a^* values or the relative percentages of MMb, OMb, or DMb for cooked color. As expected, an increased aging period decreased L^* and a^* values because of the gradual decline in color stability throughout aging (English et al., 2016; Ramanathan et al., 2020). However, cooked color has not been measured between different aging periods, but the same relationship has been found while using raw steaks (English et al., 2016). Although cooked color has also not been evaluated within fresh and frozen steaks, larger color differences have been found in previous studies evaluating the color of the raw product prior to cooking (Jeong et al., 2011). These results indicated that although raw color might be affected by freezing, it does not translate to changes in cooked color or potentially the thermal stability of myoglobin.

The MRA assay was used in the current work to determine the ability of the pigment to bloom after being oxidized or as an objective measure of raw color stability (Bekhit and Faustman, 2005). Surprisingly, the frozen samples resulted in a greater MRA than the fresh samples, indicating the frozen sample would have a greater ability to reduce MMb to OMb. This is the opposite of the previous hypothesis from Suman et al. (2014) stating that freezing meat decreases color stability. It is documented that freezing typically decreases color stability in a retail display starting at 4 d of the display, but the impact is dependent on the previous aging period (Hergenreder et al., 2013). However, a different methodology was used in our study in comparison with others because of the need to use powdered samples (Jeong et al., 2011; Nair et al., 2017). A potential explanation could be that the inevitable rupturing of the cell membranes through the thawing process could release a surge of enzymes able to perform enzymatic MRA initially but potentially depleting the longevity of the MRA system. However, this hypothesis needs to be evaluated in subsequent work.

Lipid oxidation was not impacted by freezing or the aging parameters used. Lipid oxidation has produced conflicting results based on the protein source, time of freezing, number of freeze cycles, and freezing temperature (Rahman et al., 2015; Setyabrata and Kim, 2019; Al-Dalali et al., 2022). Consistently, multiple freeze-thaw cycles can cause a significant increase of lipid oxidation and deterioration of other quality parameters (Rahman et al., 2015; Setyabrata and Kim, 2019). The sublimation of the ice crystals can increase the release of prooxidants such as metals and heme proteins by disrupting the cell membrane stability, thereby

increasing the rate of protein and lipid oxidation (Zhang et al., 2023). Protein oxidation and denaturation have also been tied to freezing if storage or a display period was included after thawing (Xia et al., 2009; Bao et al., 2021). Oxidation can increase throughout multiple freeze-thaw cycles, leading to changes in flavor, color, and potentially overall acceptability within sensory evaluations (Xia et al., 2009). Regardless, the MDA concentration in our study was far too low to be perceived by trained panelists (Zhang et al., 2019). Therefore, the freezing parameters chosen for the current study could have eliminated enough cellular damage to prevent detectable oxidation.

The effects of freezing on meat quality proved to be much less substantial within the current study in comparison with previous works (Leygonie et al., 2012; Aroeira et al., 2016; Kim et al., 2018). Although marginal differences were found for juiciness and tenderness within the consumer and trained sensory data, the overall liking ratings were similar for the 2 treatments. These results were supported by the physiochemical assays evaluated. Additionally, the consumers' ratings were not changed when given information about the cold storage method used within the samples evaluated. This is in direct contradiction to the dogma that consumers deprioritize frozen meat. However, it has been previously noted that this dogma has never been evaluated in scientific literature (Pietrasik and Janz, 2009). The current study can serve as the foundation for the comparison of palatability traits and the consumers' perception of fresh versus frozen beef of equal aging periods.

Conclusions

Overall, the impact of freezing on eating quality and physiochemical properties of beef steaks resulted in minimal differences. The consumer panelists found few differences between the fresh and frozen treatments. Even though the frozen sample was considered more tender and the fresh sample was considered juicier, and the overall liking was not impacted. This final assessment of eating quality is the most important. Although it was previously believed that the eating quality of frozen beef is lower than its fresh counterpart, especially as viewed by consumers, the current study fails to support this claim. Although some meat quality factors are impacted by freezing, the overall eating quality is not negatively impacted. Similarly, informing consumers of the frozen/fresh state of the product prior to evaluation did not alter their assessment, providing evidence that for consumers, "fresh, never frozen" labeling may not be impactful. Based on this study, the actual eating quality and perception of quality is not impacted by freezing beef steaks of equal aging periods. Therefore, frozen meat should not be discounted because of the eating quality or perception of the quality of beef steaks. This study can provide guidance for the industry to make supported decisions on cold chain management strategies.

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