Meat and Muscle Biology™

Double Freezing Beef Strip Loin Steaks at Blast or Consumer Freezing Temperatures in Vacuum and Overwrapped Packaging

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Abstract: Our objective was to evaluate the combined effect of blast freezing vacuum packaged USDA Low Choice *Longissimus lumborum* beef steaks followed by consumer freezing of retail overwrapped steaks upon objective and subjective measures of beef palatability. The experimental design utilized a randomized complete block with a 3 × 3 treatment structure of targeted freezing treatments initially in vacuum and secondly in overwrap packaging (unfrozen = NOT; blast frozen at −34.4°C = BF; consumer-frozen at −17.8°C = CF) to accomplish 9 treatment combinations. Descriptive sensory attributes were evaluated by trained panelists on a 100-point line scale. Slice shear force and expressible moisture were assessed. Data were analyzed via PROC GLIMMIX using a randomized complete block design with a 3 × 3 treatment structure. Of descriptive panel attributes, overall juiciness was the only interaction observed ($P = 0.006$). Though similar to steaks initially CF in the vacuum package and followed by a second freeze (CF/BF or CF/CF) in the overwrap package, steaks singly frozen to simulate a CF (CF/NOT and NOT/CF) resulted in the overall driest ratings by panelists ($P = 0.006$). Only bloody/serumy differed ($P = 0.002$) within the initial freeze, where steaks not frozen (NOT) in the vacuum package were rated higher than those that were frozen (BF or CF). During the second freeze in the overwrap package after retail display, steaks BF rated higher for oxidized ($P = 0.051$) off-flavor than steaks CF and higher than both CF and NOT steaks for refrigerator-stale ($P = 0.006$) off-flavor; all other attributes did not differ ($P \geq 0.155$). Although some freezing combinations that included CF were generally lower for overall juiciness, BF vacuum packaged steaks had no effect on palatability when compared to NOT steaks. The beef industry and consumers should feel confident using freezing as a means to extend shelf-life of beef steaks.

Key words: blast, consumer, freezing, overwrap, packaging, sensory
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Introduction

Seasonal changes in beef prices allow the industry to use cold storage to hold beef until the market trends towards a higher selling price. Although freezing has not been widely adopted or accepted in the beef industry, the pork and poultry industries have embraced allowing product to be frozen and then displayed as fresh. Previous research suggests that freezing and thawing of beef steaks impacts consumer palatability (Grayson et al., 2014), but the extent of change is not clearly understood. Because the majority of consumers' purchasing decisions of fresh beef steaks is based on color (Ponce et al., 2019), the industry has continued to provide beef in PVC overwrap packages, even though vacuum packaging is clearly more advantageous with regard to shelf-life and palatability (Ponce et al., 2019; Vierck et al., 2020). Although the amount of overwrapped meat packages in the retail case has declined over time, the National Meat Case Study in 2022 reported 28% of meat was sold in an overwrap package. If a consumer does not consume overwrapped fresh beef steaks within the USDA recommended 3 to 5 d period (USDA, 2024), they might choose to place that steak in the freezer to consume at a later date.

However, freezing meat has been perceived as a negative practice when compared to "fresh" or "never frozen" steaks (Zhang et al., 2023). Although consumers may believe "fresh" is superior to frozen, freezing and thawing has been reported to improve meat tenderness through ice crystal formation and disruption in the muscle (Grayson et al., 2014), as well as interim disruption of calpastatin activity while frozen (Whipple and Koohmaraie, 1992). Although tenderness has been shown to improve, some other attributes may perform negatively after freezing steaks. The degree of impairment on meat quality is influenced by both the size and location of ice crystal formation. Rapid freezing rates result in smaller, more uniform ice crystals when compared to slower freezing rates (Grujić et al., 1993; Petrović et al., 1993; Hergenreder et al., 2013). The industry can use rapid freezing of beef subprimals and steaks to counteract seasonal changes in price seen in the beef industry by holding beef in frozen storage until a profitable sell date. Subsequent consumer freezing of products has shown to overcome inherent toughness that may still occur, regardless of postmortem aging (Grayson et al., 2014).

Although changes occur, many consumers are unaware of palatability changes due to freezing and thawing beef or packaging type during frozen storage. Therefore, it is imperative the beef industry investigate the impact freezing and thawing of fresh beef steaks will have on consumer satisfaction. Therefore, the objective of this study was to evaluate the effect of double freezing using commercial blast freezing in vacuum packages, then consumer freezing and thawing of retail, overwrapped *Longissimus lumborum* beef steaks on objective and subjective measures of beef palatability.

Materials and Methods

Production collection and fabrication

Paired USDA Low Choice beef strip loins (IMPS #180; USDA, 2014; $n = 16$) were used in the study. Strip loins (*Longissimus lumborum*) were selected by trained West Texas A&M University personnel at a commercial beef processing facility in the Texas panhandle and transported to the West Texas A&M University Caviness Meat Science & Innovation Center. Strip loins were allowed to age (2 to 4°C) for 7 d in the original vacuum package prior to steak cutting and sample designation.

At the completion of aging, paired strip loins were fabricated into 9 pairs of 2.54 cm thick steaks for sample designation. The initial wedge steak and the vein steaks were eliminated from the study. For sample designation, the descriptive trained panel steak always preceded the objective test steak (i.e. slice shear force [SSF]; expressible moisture). Treatment distribution among paired strip loins was randomized. Table 1 illustrates the fabrication and allocation of samples within paired strip loins. Initial vacuum-packaged and second-overwrap packaged freeze treatments, as well as panel and serve orders, were randomly assigned along with the sample identification at the time of cutting.

Table 1. Illustration of fabrication and sample[1] allocation within paired strip loins. [1]Panel = descriptive trained panel steak; SSF/EM = objective test steak. SSF, slice shear force; EM, expressible moisture.

	Strip Loin Pair	
Anterior end	Wedge	Wedge
	1-Panel	6-Panel
	1-SSF/EM	6-SSF/EM
	2-Panel	7-Panel
	2-SSF/EM	7-SSF/EM
	3-Panel	8-Panel
	3-SSF/EM	8-SSF/EM
	4-Panel	9-Panel
	4-SSF/EM	9-SSF/EM
	5-Panel	Extra-Panel
	5-SSF/EM	Extra-SSF/EM
Posterior end	Vein steaks	Vein steaks

Experimental treatments and study design

The experimental design consisted of 2 sets of targeted freezing treatments including an initial freeze within a vacuum package (unfrozen = NOT; blast frozen at −34.4°C = BF; consumer-frozen at −17.8°C = CF) and a second freeze within an overwrap package, of the same freezing parameters, in a 3×3 treatment structure (NOT/NOT; NOT/BF; NOT/CF; BF/NOT; BF/BF; BF/CF; CF/NOT; CF/BF; CF/CF).

Freezing samples at −34.4°C was designed to simulate a commercial BF, whereas samples frozen to −17.8°C were used to mimic the CF in a standard home-freezer. Furthermore, the initial freeze of the steaks occurred within the vacuum package shortly after product procurement (10 d postmortem) to mimic holding product in a frozen warehouse prior to transportation to a retail establishment or case-ready facility. The second freeze occurred within the overwrap package, after the retail display duration, to represent a consumer purchase of the steak, then freezing at home, in either a normal home-freezer or a blast freezer.

At the completion of steak cutting, steaks were weighed (Yamato PPC-300WP, Yamato Americas, Akashi, Japan; initial raw weight), vacuum packaged (3 mm thick vacuum pouches, UltraSource LLC, Kansas City, MO; Ultravac 2100 Double Chamber Vacuum Packaging Machine, UltraSource LLC, Kansas City, MO), allocated into treatment groups (NOT, BF, CF), and subjected to the initial vacuum freeze treatment. Samples of the BF treatment were placed in a commercial blast freezer (ThermalRite Blast Chiller, Rancho Cucamonga, CA) at a setpoint temperature of −34.4°C and the maximum fan speed of 10, whereas steaks frozen to simulate the CF were subjected to a setpoint temperature of −17.8°C and the minimum fan speed of 1. At the completion of the initial freeze, samples were relocated to a holding cooler (−1 to 3°C) and allowed 24 h to thaw. Steak and ambient temperature of coolers/freezers used were monitored and collected (Six Channel Handheld Rechargeable Temperature Data Logger, Omega Engineering, Inc., Norwalk, CT).

After the initial vacuum freeze and thaw, steaks were transported to Lubbock, TX to be unpackaged, weighed (post-initial freeze weight), overwrapped with the paired test steak (2 per package), and undergo a 96 h retail display. Steak pairs were placed on black expanded polystyrene trays (2S Black Foam Meat Trays, CFK Incorporated, Hantsport, NS, Canada), with absorbent pads (Meat, Poultry, Fish, Produce, & Fruit Pads, Tite-Dri Industries, Boynton Beach, FL), and overwrapped with polyvinyl chloride film using a Winholt Film Wrapper Machine (Model WHSS-1, Winholt Equipment Group, Dallas, TX).

At the completion of retail display, overwrapped, paired steaks were transported back to West Texas A&M University and subjected to the second freeze treatment (NOT, BF, CF) following the same freezing and thawing procedures as previous.

Purge and cook loss

Immediately following steak cutting and identification, individual steaks were weighed prior to vacuum packaging (*initial raw*). Following the completion of the initial freeze and thaw cycle, prior to retail display, steaks were removed from the vacuum package and weighed (*post-initial freeze*) before overwrapping. Steak weights were collected (*post-second freeze*) after removal from the overwrap package following the second freeze and thaw cycle, prior to cooking steaks for both objective and subjective tests. Cooked steak weights (*cooked*) were collected prior to cutting and serving. Overall loss was defined as the total weight loss from the *initial raw weight*, following the completion of cooking.

$$\text{Initial purge loss (\%)}: (\textit{Initial raw} - \textit{Post-initial freeze}) / \textit{Initial raw} \times 100$$

$$\text{Second freeze purge loss(\%)}: (\textit{Post-initial freeze} - \textit{Post-second freeze}) / \textit{Post-initial freeze} \times 100$$

$$\text{Total purge loss(\%)}: (\textit{Initial raw wt} - \textit{Post-second freeze wt}) / \textit{Initial raw wt} \times 100$$

$$\text{Cook loss(\%)}: (\textit{Post-second freeze wt} - \textit{Cooked wt}) / \textit{Post-second freeze wt} \times 100$$

$$\text{Overall loss(\%)}: (\textit{Initial raw wt} - \textit{Cooked wt}) / \textit{Initial raw wt} \times 100$$

Retail color evaluation

Steaks were placed under continuous fluorescent lighting in 2 multideck style, open-front cases (Model M3-8EA, Hussmann Corporation, Bridgeton, MO) at temperatures of 2 to 5°C for 96 h, and packages were rotated every 12 h within the 2 cases. Retail color evaluation parameters and perceptible color calculations were determined in reference to the *Display Guidelines for Meat Color Research* in the American Meat Science Association Guidelines for Meat Color Measurements (King et al., 2023). The L^*, a^*, and b^* values were determined at 3 locations per steak and recorded at 0 h and every 12 h during the entire display period. A Hunter MiniScan EZ 4500 (Hunter Associates Laboratory, Inc. Reston, Virginia) utilized an area with 45°/0° directional viewing geometry, with a 31.8 mm port and 25 mm viewed area. At the completion of retail display, steaks were removed from display cases and transported back to Canyon, TX for the second freeze and further analysis.

Cooked sample preparation

Before cooking, samples were thawed at 2°C to 4°C for 24 h to 26 h and weighed just prior to cooking. Paired steaks were evaluated by the descriptive trained panel as well and analyzed for objective tests on the same day. Steaks were cooked to a target internal temperature of 71°C using a clamshell grill with top and bottom plates set at 177°C (Cuisinart Griddler Deluxe, East Windsor, NJ); internal temperature was monitored using copper-constantan thermocouple

(Hermetically Sealed Tip Insulated Thermocouples, Omega Engineering, Norwalk, CT) and temperature monitoring device (Six Channel Handheld Rechargeable Temperature Data Logger, Omega Engineering, Inc., Norwalk, CT). Immediately following cooking, steaks were allowed to rest to reach a peak internal temperature and values were recorded. Cooked steaks were weighed prior to trimming any remaining external fat and connective tissue.

Descriptive sensory analysis

Descriptive sensory analysis was conducted at West Texas A&M University, and procedures were approved by the Institutional Review Board (WTAMU IRB#2023.04.004). Panelists were trained to detect multiple beef flavor characteristics according to the American Meat Science Association Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Meat (AMSA, 2016) via training methods and descriptive attribute anchor preparation as described by Ponce et al. (2019). Panelists used the lexicon developed by Adhikari et al. (2011) to objectively quantify the presence/absence of each flavor using a 100-point line scale, with a midpoint anchor (0 = slight; 50 = moderate; 100 = strong) on electronic tablets (iPad, Apple Inc., Cupertino, CA) using electronic surveys (Qualtrics, Provo, UT). Panelists were required to attend a minimum of 8 trainings over a period of 2 wk, and individual suitability was determined via training performance and accuracy.

Samples designated for sensory analysis were randomly assigned to sensory sessions so that all treatments were represented in each panel. Two or three panel sessions were conducted each day with 9 samples per session for a total of 8 panel sessions. Cooked and trimmed steaks were then portioned into 1.27 cm^3 pieces, and 2 pieces were immediately served to panelists in 2 oz sample cups with lids. One sample representing each of the 9 treatments per panel session was served to at least 6 to 8 trained panelists. Samples were served under red light-emitting diode light to mask color variation among samples during 1 h panel sessions.

Panelists were supplied with reverse-osmosis filtered water, unsalted crackers to cleanse their palates, and apple slices to serve as palate refreshers between samples. Panelists evaluated each sample for beef flavor identity, browned/roasted, bloody/serumy, fat-like, liver-like, fishy, oxidized, cardboard, rancid, refrigerator-stale, umami, bitter, sour, overall tenderness, and overall juiciness attributes on a 100-point line scale, with a midpoint anchor (0 = slight; 50 = moderate; 100 = strong). After each panel session, individual panelist ratings were averaged to obtain a single panel rating for each sensory attribute of each steak.

Expressible moisture and water holding capacity

Expressible moisture and water holding capacity (WHC) were based on a centrifugation method described by Pietrasik and Janz (2009). Single-piece subsamples (5.0 g), free of fat and visible connective or epimysial tissue, were obtained from the medial portion of SSF steaks prior to cooking. Subsamples were placed on top of 25 g of 4-mm glass beads (KIMAX Solid Borosilicate Glass Beads; Kimble Chase, Radnor, PA) and placed in the bottom of a 50-mL centrifuge tube (VWR Centrifuge Tubes with Flat Caps; VWR International). Tubes were then centrifuged (Sorvall RC6 Centrifuge; Thermo Scientific, Waltham, MA) at 900 × g for 10 min at 4°C. Following centrifugation, the sample was removed and reweighed. Expressible moisture (%) and WHC were calculated as described by Pietrasik and Janz (2009).

Slice shear force

Samples designated for SSF were thawed and cooked as previously described, and steaks were cooked on the same day as their designated paired descriptive panel steak. Peak internal and endpoint temperatures were recorded following cooking. Tenderness was evaluated by SSF as described by Shackelford et al. (1999). In brief, following the endpoint temperature reading, a 1–2 cm slice was removed across the width of the steak from the lateral end to square off the steak and expose the muscle fibers. Using a cutting guide, a 5-cm long × 1-cm thick section was obtained from the lateral end by cutting at a 45° angle, parallel to the muscle fiber orientation. The sample was center sheared perpendicular to the muscle fiber using an Instron Universal Testing System (Model Instron-5944, Instron, Norwood, MA) equipped with a load cell of 2 kN operating at a cross-head speed of 500 mm/min.

Statistical analysis

Statistical analyses were conducted using the procedures of SAS (Version 9.4; SAS Inst. Inc., Cary, NC). Treatment comparisons were tested for a significance using PROC GLIMMIX with $\alpha = 0.05$. Data were analyzed using a randomized complete block design with a 3 × 3 treatment structure. The individual steaks were the experimental unit, with paired strip loins (animal) as the individual block. Main effects were the initial and second freezing treatments. Random effects within trained sensory panel data were attributed to panel number and panel-serve order. Peak temperature was considered random within trained sensory data as well as SSF, whereas animal number and steak number within strip loins were considered random effects for all analyses. Color data (L^*, a^*, b^*) were analyzed as repeated measures using a compound symmetry covariance structure.

Results and Discussion

Treatment freezing and thawing

BF steaks reached a minimum freeze temperature of −33.7°C recorded after approximately 3 h and 29 min, whereas steaks frozen via the consumer method reached −17.8°C within 4 h and 30 min (Figure 1). Once obtaining the minimum temperature goal, BF steaks thawed and breached freezing temperatures (−1.6°C) after 4 h and 51 min. Moreover, steaks subjected to CF thawed after 5 h. Unfrozen steaks sustained a temperature range of 2.4 to 4.8°C.

Retail color evaluation

Objective color (L^*, a^*, and b^* values) were obtained from steaks evaluated during 96 h of retail display after the initial freezing treatments. Expectedly, all color values were affected ($P < 0.001$) by hour of display. Mean L^* values (Figure 2) illustrated no difference ($P = 0.081$) was detected among initial freeze treatments at 0 h, whereas after 12 h and until 84 h, steaks not frozen (NOT) revealed higher ($P = 0.027$) L^* values, thus remaining brighter than steaks previously frozen (BF and CF). Steak L^* values were similar ($P \geq 0.164$) among BF and CF throughout display.

Likewise, a^* redness values (Figure 3) were greater ($P < 0.001$) and more saturated (higher chroma; $P < 0.001$) for steaks not frozen prior to display (NOT) compared to previously frozen steaks (BF and CF).

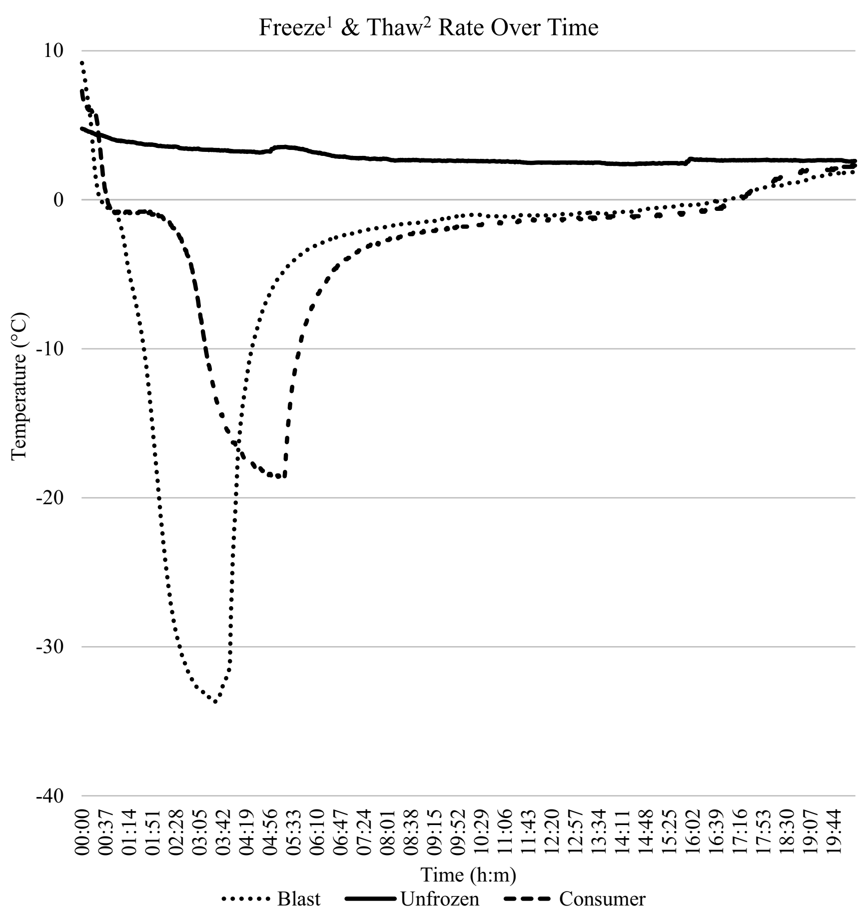
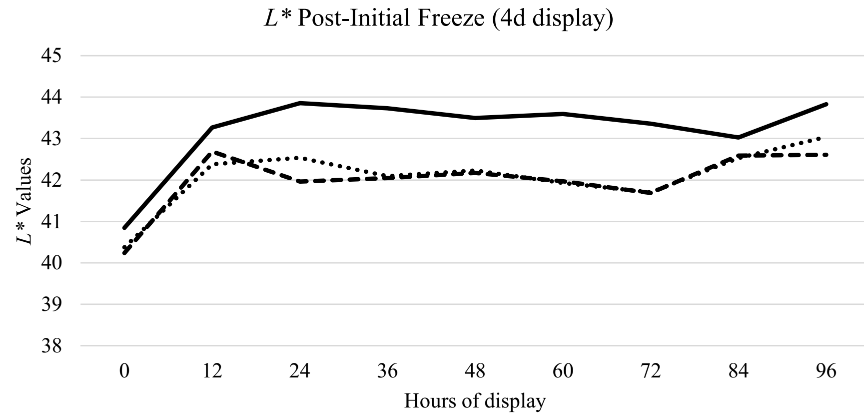


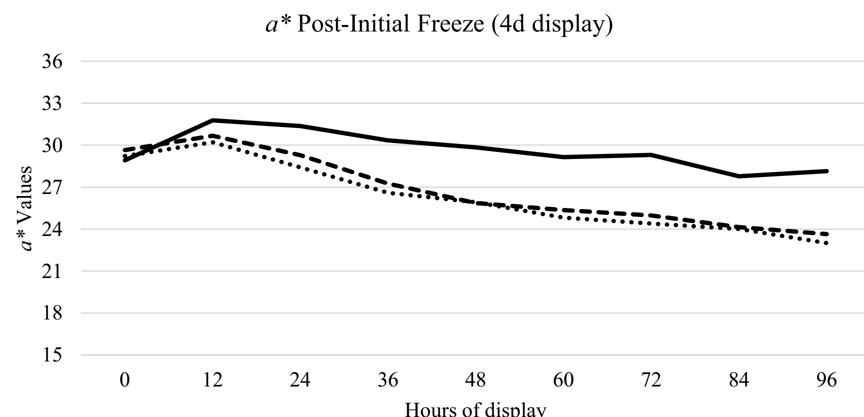
Figure 1. Freezing and thawing rates of beef strip loin steaks over time per freezing treatment. [1]Initial freeze = frozen before retail display in vacuum packaging; Blast = frozen to −34.4°C; Consumer = frozen to −17.8°C; Unfrozen = not frozen. [2]Thaw = −1 to 3°C for 24 h.



	SEM	P-value
Freeze	0.476	0.027
Hour	0.190	< 0.001
Freeze × Hour	0.822	0.021

BF CF NOT

Figure 2. Mean L^* values[1] collected of beef strip loin steaks per initial freeze[2] treatment during 96 h of continuous display. [1]L^* values = black to white (0 to 100). [2]Initial freeze treatments = frozen before retail display in vacuum packaging; Blast = frozen to −34.4°C; Consumer = frozen to −17.8°C; Unfrozen = not frozen. BF, blast frozen; CF, consumer frozen; NOT, not frozen; SEM, standard error of the mean.



	SEM	P-value
Freeze	0.453	< 0.001
Hour	0.181	< 0.001
Freeze × Hour	0.543	< 0.001

BF CF NOT

Figure 3. Mean a^* values[1] of beef strip loin steaks collected per initial freeze[2] treatment during 96 h of continuous display. [1]a^* values = red to green (+ to −). [2]Initial freeze treatments = frozen before retail display in vacuum packaging; Blast = frozen to −34.4°C; Consumer = frozen to −17.8°C; Unfrozen = not frozen. BF, blast frozen; CF, consumer frozen; NOT, not frozen; SEM, standard error of the mean.

Beginning at 12 h and 24 h, NOT steaks had the highest a^* and chroma values, respectively, remaining the reddest ($P \leq 0.004$) and most saturated ($P \leq 0.001$) color throughout the remainder of retail display, whereas steaks subjected to BF and CF did not differ ($P \geq 0.112$; $P \geq 0.146$). Beginning at 12 h, NOT steaks sustained the lowest ($P \leq 0.005$) hue angles compared to BF and CF, providing less deviation from initial redness. Notably, a^* and chroma values for all treatments declined ($P < 0.001$) over time, beginning at 12 h.

Lastly, mean b^* values (Figure 4) of initial freezing treatments are illustrated throughout the 96 h display. Similarly to the trend in a^* values, b^* values began declining over time ($P < 0.001$) and differed among treatments ($P < 0.001$) at 12 h, in which steaks initially NOT sustained higher b^* values than steaks previously frozen (BF and CF), whereas neither freezing treatment differed from one another ($P \geq 0.158$).

Similarly to L^* and a^* values of the current study, other studies (Hergenreder et al., 2013; Kim et al., 2015) have also reported unfrozen products to sustain the best color stability (brighter/redder), as freezing significantly impacts the meat surface color, leaving unfrozen steaks to sustain higher L^* and a^* values

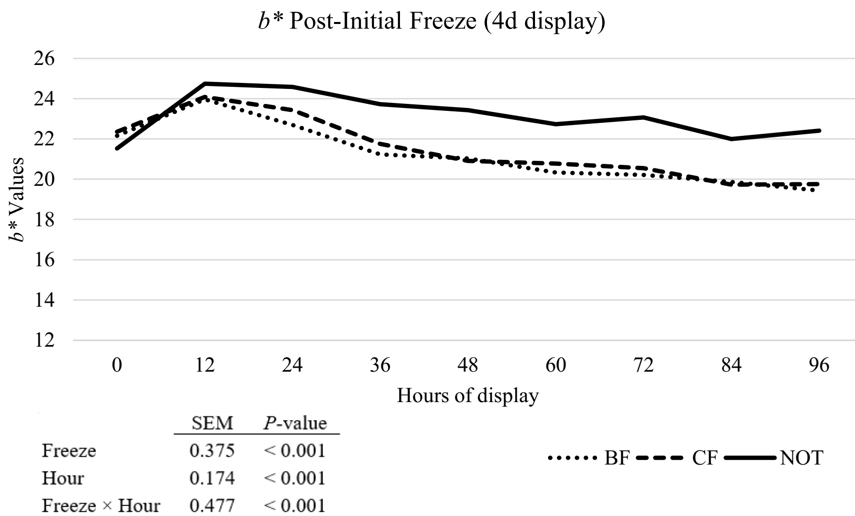


Figure 4. Mean b^* values[1] of beef strip loin steaks collected per initial freeze[2] treatment during 96 h of continuous display. [1]b^* values = yellow to blue (+ to −). [2]Initial freeze treatments = frozen before retail display in vacuum packaging; Blast = frozen to −34.4°C; Consumer = frozen to −17.8°C; Unfrozen = not frozen. BF, blast frozen; CF, consumer frozen; NOT, not frozen; SEM, standard error of the mean.

during retail display. It is expected for meat previously frozen to have a reduced ability and capacity for bloom and retention of red meat color due to the exhaustion of metmyoglobin reducing activity (MacDougall, 1982; Kim et al., 2015).

Total purge and cook loss

The interaction of initial and second freezing treatments was obtained for purge losses, cooking losses, and overall losses (Table 2). As expected, freezing steaks increased ($P = 0.023$) purge losses; steaks frozen twice (BF/BF, BF/CF, CF/CF, CF/BF) experienced greater total purge losses when compared to steaks only frozen once. No difference ($P \geq 0.195$) was detected among steaks frozen twice. Within steaks frozen once, steaks frozen prior to retail display in the vacuum package (BF/NOT, CF/NOT) had greater total purge losses when compared to steaks frozen after retail display within the overwrap package (NOT/BF, NOT/CF). Steaks never frozen (NOT/NOT) resulted in less total purge losses than all other treatments.

Similarly, Hergenreder et al. (2013) detected differences in purge losses as a result of freezing and thawing subprimals; notably greater purge losses were discovered due to freezing when compared to unfrozen samples. Moreover, Kim et al. (2015) reported faster freezing rates significantly reduced purge and drip loss of strip loin sections, suggesting freezing rate may be a factor impacting the WHC of thawed meat. However, in the present study, purge losses were more affected by the number of times steaks were frozen in combination with the packaging type.

Cooking losses were greater ($P = 0.034$) for steaks subjected to one consumer freezing method regardless of if the freeze happened in the vacuum package

Table 2. Interaction between initial and second freezing treatments least-squares means of total purge loss, cook loss, and overall loss percentages of beef strip loin steaks

Freezing Treatment[1]				
Initial	*Second*	Total Purge Loss[2] (%)	Cook Loss[3] (%)	Overall Loss[4] (%)
Blast	Blast	5.758[a]	12.389[abc]	17.202[ab]
	Consumer	5.880[a]	13.099[ab]	17.943[a]
	Unfrozen	5.220[bc]	10.716[c]	15.254[cd]
Consumer	Blast	5.534[ab]	11.555[bc]	16.561[abc]
	Consumer	5.854[a]	12.670[ab]	17.718[ab]
	Unfrozen	4.995[c]	13.428[a]	17.651[ab]
Unfrozen	Blast	4.380[d]	12.175[abc]	15.972[bc]
	Consumer	4.281[d]	13.353[a]	17.137[ab]
	Unfrozen	2.753[e]	11.384[bc]	14.037[d]
SEM[5]		0.278	0.918	0.923
P-value		0.023	0.034	0.046

[1]Initial freeze = frozen before retail display in vacuum packaging; Second freeze = frozen after retail display in overwrap packing; Blast (BF) = frozen to −34.4°C; Consumer (CF) = frozen to −17.8°C; Unfrozen (NOT) = not frozen.

[2]Total purge loss (%) = (initial raw − post-second freeze)/initial raw × 100.

[3]Cook loss (%) = (post-second freeze − cooked weight)/post-second freeze × 100.

[4]Overall loss (%) = total purge loss + cook loss.

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

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

(CF/NOT) or after retail display in the overwrap package (NOT/CF) when compared to the unfrozen steaks (NOT/NOT) and steaks only frozen in the vacuum package (BF/NOT). This suggests consumers may experience greater cooking losses when freezing overwrapped steaks at home, regardless of if the steak was initially frozen or fresh prior to retail display. Steaks BF once in the vacuum package (BF/NOT) produced the lowest cooking loss percentages ($P = 0.034$) but remained similar ($P \geq 0.119$) in cooking loss percentages to fresh steaks (NOT/NOT), as well as double frozen steaks, first within a CF (CF/BF), and those only BF once in the overwrapped package (NOT/BF). Within steaks initially BF or not frozen in the vacuum package, steaks then subjected to consumer freezing methods in an overwrap package after retail display experienced greater cook loss ($P = 0.034$) than steaks not frozen, suggesting consumers that freeze steaks after retail purchase may increase further moisture loss during cooking.

Dissimilarly, Kim et al. (2015) reported unfrozen products to accumulate the greatest cooking losses when compared to other freezing treatments, with minimal differences in cooking losses among freezing treatments. Likewise, other studies (Grayson et al., 2014; Kim et al., 2015) have reported instances of frozen steaks resulting in lower cooking losses, presumedly because purge losses already occurred prior to cooking. Our findings closely align with studies that claim the greater cooking losses in slow frozen steaks is likely due to the disruption of the intracellular myofibrillar components during freezing caused by ice crystal formation, thus reducing the fiber's ability to hold water (Hergenreder et al. 2013; Grayson et al., 2014; Kim et al., 2015).

Overall loss (total purge losses + cooking losses) was greatly influenced by cooking losses. All double-freeze treatments (BF/BF, BF/CF, CF/CF, CF/BF), as well as steaks CF at least once (CF/NOT, NOT/CF) provided similar ($P \geq 0.115$) overall loss means that were greater ($P = 0.046$) than fresh steaks (NOT/NOT). No difference ($P \geq 0.179$) was detected among steaks CF in the vacuum package, regardless of the second freeze method. Within initially vacuum BF or NOT steaks, steaks not frozen (BF/NOT and NOT/NOT) in the overwrap package after retail display produced lower ($P = 0.046$) overall losses compared to those subjected to either freezing treatment within respective initial vacuum freeze treatments. However, the greatest difference in overall losses occurred in steaks never frozen (NOT/NOT), which was lower ($P = 0.046$) than all other freezing treatments but similar ($P = 0.170$) to steaks BF in the vacuum package only prior to retail display (BF/NOT).

Our findings that never frozen steaks were lowest for overall moisture loss agreed with Lagerstedt et al. (2008) where combined water loss was reported to be greatest in meat products previously frozen.

Objective attribute evaluation

Expressible moisture, used as a predictor for WHC, was not affected by an initial vacuum freeze (Table 3; $P = 0.123$); however, a tendency ($P = 0.079$) was observed in the second freeze treatment, in which steaks subjected to the CF method in the overwrap package tended to experience a greater percentage loss in expressible moisture than steaks BF or NOT.

No difference ($P = 0.855$) occurred in assessment of objective tenderness using the SSF method in the initial vacuum frozen treatment. SSF differences ($P = 0.039$) occurred within second freeze treatments, in which steaks BF in the overwrap package during the second freeze treatment were more tender when compared to steaks frozen via the consumer method or not frozen.

As discovered in the initial freeze of vacuum packaged steaks in the current study, no difference in objective tenderness evaluation of steaks derived from subprimals subjected to blast and conventional (low velocity) freezing was detected by Hergenreder et al.

Table 3. Least-squares means for percent expressible moisture and slice shear force (SSF) of beef strip loin steaks subjected to varying initial and/or second freezing treatments

	Freezing Treatment[1]				
	Blast	Consumer	Unfrozen	SEM[2]	*P*-value
Expressible Moisture (%)[3]					
Initial Freeze	5.005	5.278	6.008	0.509	0.123
Second Freeze	5.335	5.999	4.958	0.461	0.079
SSF (kg)					
Initial Freeze	10.008	10.063	9.791	0.521	0.855
Second Freeze	9.191[b]	10.450[a]	10.221[a]	0.508	0.039

[1]Initial freeze = frozen before retail display in vacuum packaging; Second freeze = frozen after retail display in overwrap packing; Blast (BF) = frozen to −34.4°C; Consumer (CF) = frozen to −17.8°C; Unfrozen (NOT) = not frozen.

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

[3]Means expressed as a percentage of moisture (water) lost.

[a,b]Least-squares means in the same row without a common superscript differ ($P < 0.05$).

(2013). Likewise, Kim et al. (2015) did not detect differences in steak shear force among various freezing rates of vacuum packaged, strip loin sections.

Other studies (Timm et al., 2002; Lagerstedt et al., 2008; Hergenreder et al., 2013; Grayson et al., 2014) froze products in vacuum packaging and reported freezing of meat products decreased objective tenderness values of steaks, thus increasing tenderness. This was similar to the findings of the current study, with the decreased SSF values for BF overwrapped steaks during the second freeze after retail display. The increased tenderness, suggested by reduced SSF values, is likely due to ruptured intracellular myofibrillar structures, and connective tissue stretching compared to the intact myofibrillar structure of unfrozen steaks.

Descriptive panel analysis

No interaction between the initial vacuum freeze and second overwrapped freeze treatment was observed for trained panel descriptive attributes ($P \geq 0.114$), except overall juiciness ($P = 0.006$; Table 4). No difference was observed between unfrozen steaks and steaks initially BF for overall juiciness ($P \geq 0.548$). Steaks that were BF once, regardless of initial or second freeze, rated higher ($P = 0.006$) in overall juiciness than steaks frozen via the consumer method (CF) once, regardless of initial or second freeze. The impact of double freezing steaks only tended to impact ($P \geq 0.072$) overall juiciness ratings by trained panelists when compared to the treatments only frozen in the overwrapped package within the same type of initial freeze. Though similar to steaks initially CF in the vacuum package and followed by a second freeze (CF/BF or CF/CF) in the overwrap package, steaks that encountered a CF at least once (CF/NOT and NOT/CF) resulted in the overall driest ratings by panelists ($P = 0.006$).

Table 4. Interaction between initial and second freezing treatments of least-squares means on overall juiciness of beef strip loin steaks

Freezing Treatment[1]		
Initial	*Second*	Overall Juiciness[2]
Blast	Blast	63.834[abc]
	Consumer	63.420[abc]
	Unfrozen	64.693[ab]
Consumer	Blast	60.147[cd]
	Consumer	60.900[bcd]
	Unfrozen	57.310[d]
Unfrozen	Blast	66.797[a]
	Consumer	57.846[d]
	Unfrozen	63.391[abc]
SEM[3]		2.287
P-value		0.006

[1]Initial freeze = frozen before retail display in vacuum packaging; Second freeze = frozen after retail display in overwrap packing; Blast (BF) = frozen to −34.4°C; Consumer (CF) = frozen to −17.8°C; Unfrozen (NOT) = not frozen.

[2]Evaluated on a 100-point line scale, with midpoint anchor (0 = slight; 50 = moderate; 100 = strong).

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

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

The effect of double freezing on overall juiciness becomes controversial with previous data, as unfrozen steaks remained similar to most freezing combinations, both initially, prior to retail display, as well as after the second freeze. Data reported by Lagerstedt et al. (2008) reported unfrozen steaks to retain improved juiciness ratings when compared to steaks frozen to −20°C, whereas in the present study, all steaks frozen to −34.4°C (BF) during the initial and/or second freeze were rated similar in overall juiciness. Generally, the inclusion of a CF, within either the initial vacuum freeze or the second overwrap freeze, provided lower overall juiciness ratings by panelists.

No differences ($P \geq 0.083$; Table 5) in descriptive panel attributes (beef flavor identity, browned/roasted, fat-like, liver-like, oxidized, fishy, cardboard, rancid, umami, bitter, sour, overall tenderness) were observed during the initial freeze, except within the bloody/serumy attribute ($P = 0.002$).

Steaks that initially were not frozen (NOT) in the vacuum package rated higher for bloody/serumy ($P = 0.002$) than those that were frozen (BF or CF). Bloody/serumy is considered to be one of the major attributes in beef flavor notes as reported by Adhikari et al. (2011). Likewise, in a study conducted by Wheeler et al. (1990), panelists also detected lower flavor intensity in frozen steaks, though beef flavor notes were not specifically reported in the study. Similarly to the ratings of bloody/serumy in the current study, Lagerstedt et al. (2008) also reported unfrozen meat to have retained sensory qualities, including a higher intensity rating of meat taste.

Additionally, steaks first subjected to BF in the vacuum package tended to rate higher ($P = 0.083$) for refrigerator-stale than CF and NOT. During the second freeze in the overwrapped package, no differences in descriptive panel attributes (beef flavor identity, browned/roasted, bloody/serumy, fat-like, liver-like, fishy, cardboard, rancid, umami, bitter, sour, overall tenderness) were observed ($P \geq 0.155$), except for within oxidized and refrigerator-stale. Steaks BF in

Table 5. Least-squares means for descriptive panel attributes of beef strip loin steaks of initial and second freeze main effects

Descriptive Panel Attributes[2]	Freezing Treatments[1]									
	Initial Freeze					*Second Freeze*				
	Blast	Consumer	Unfrozen	SEM[3]	*P*-value	Blast	Consumer	Unfrozen	SEM[3]	*P*-value
Beef Flavor ID	63.332	63.106	63.332	1.157	0.538	62.855	63.193	62.514	1.177	0.835
Brown/Roasted	51.397	49.352	50.093	2.031	0.593	49.974	52.170	48.699	1.976	0.209
Bloody/Serumy	17.389[b]	16.304[b]	21.953[a]	1.589	0.002	18.023	18.933	18.691	1.469	0.805
Fat-Like	17.105	18.533	17.599	1.145	0.448	16.832	18.023	18.832	1.150	0.383
Liver-Like	0.000	0.019	0.000	0.018	0.465	0.000	0.000	0.020	0.018	0.399
Oxidized	0.326	0.243	0.350	0.191	0.843	0.559[a]	0.078[b]	0.281[ab]	0.192	0.051
Rancid	0.113	0.075	0.000	0.066	0.235	0.051	0.027	0.111	0.063	0.390
Refrigerator-Stale	1.264	0.824	0.605	0.294	0.083	1.435[a]	0.478[b]	0.779[b]	0.292	0.006
Umami	12.805	12.807	13.333	0.998	0.825	12.488	13.677	12.780	1.009	0.454
Bitter	0.058	0.000	0.045	0.052	0.518	0.046	0.044	0.013	0.053	0.770
Sour	1.122	0.743	0.958	0.228	0.258	0.737	1.025	1.061	0.233	0.327
Overall Tenderness	72.833	70.468	71.234	1.404	0.242	73.145	70.650	70.740	1.428	0.155

[1]Initial freeze = frozen before retail display in vacuum packaging; Second freeze = frozen after retail display in overwrap packing; Blast (BF) = frozen to −34.4°C; Consumer (CF) = frozen to −17.8°C; Unfrozen (NOT) = not frozen.

[2]Attributes were evaluated on a 100-point line scale, with midpoint anchor (0 = slight; 50 = moderate; 100 = strong); fishy and cardboard attributes were also assessed but were not detected by panelists.

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

[a,b]Least-squares means in the same row without a common superscript differ ($P < 0.05$).

the overwrap package after retail display rated higher for oxidized ($P = 0.051$) than steaks CF in the overwrap package and higher than both CF and unfrozen steaks for refrigerator-stale ($P = 0.006$) attributes. Also, after the second freeze occurred in the overwrap package, no difference was observed between CF and NOT steaks for oxidized ($P = 0.293$) and refrigerator-stale attributes ($P = 0.303$).

Although BF steaks were objectively more tender ($P = 0.039$), the difference was not detectable by trained panelists ($P \geq 0.155$). Means of all remaining descriptive attributes (beef flavor identity, browned/roasted, fat-like, liver-like, fishy, cardboard, rancid, umami, bitter, sour, overall tenderness) did not differ ($P \geq 0.155$) for either the initial and/or the second freeze. Both sensory and objective measures of tenderness assessed by Wheeler et al. (1990) were not different between chilled and frozen steaks, whereas Lagerstedt et al. (2008) detected differences among sensory tenderness, in which unfrozen steaks were reported to be more tender as previously described in the second freeze SSF data.

Ultimately, many of the reported differences among descriptive attributes evaluated were very minor and could lose practicality when assessing the reality of the consumers' ability to detect a difference among mean descriptive panelist ratings. Therefore, similar to the findings of this study, Hergenreder et al. (2013) also reported sensory attributes to be very comparable to those of fresh, unfrozen steaks in assessing the impact of freezing subprimals, and in this case double freezing beef strip loin steaks.

Conclusions

The results of this study suggest consumers should not be deterred by frozen beef steaks, as tenderness and flavor were unaffected, and juiciness was minimally affected. Additionally, not freezing steaks prior to retail display/purchase promotes preferred color life extension, with steaks remaining brighter and redder within the retail case. The industry can use these findings to educate consumers on the important benefits of using freezing practices to increase shelf-life of beef steaks, thereby increasing sustainability of beef without jeopardizing eating quality.

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