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Evaluation of Beef Palatability Following Extended Storage at Low Temperature

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Abstract: Extending the shelf life of fresh meat without having an adverse effect on its quality attributes is critical to the meat industry to reduce waste, stabilize supply, and facilitate export. Low temperature (LT) storage of beef muscles at or slightly above their freezing point slows down microbiological spoilage while maintaining the product's fresh status. This study evaluated the impact of 60, 75, or 90 d of LT storage (−2.7°C ± 0.3°C) on the palatability characteristics of steaks from inside rounds (IR), bone-in ribeyes, and striploins (SL) from 10 ($n = 10$) upper two-thirds Choice beef carcasses. Two steaks fabricated from each subprimal were vacuum-packaged, wet-aged for 21 d (3°C), and frozen (−20°C) for Warner-Bratzler shear force (WBSF) and sensory analyses. These steaks served as the control with regard to storage condition and time. The remainder of each subprimal was fabricated into 3 portions, vacuum packaged, and randomly allocated to an LT storage time (60, 75, or 90 d). After each storage time, subprimals were fabricated into steaks, vacuum-packaged, and stored (−20°C) for WBSF and consumer sensory analyses. Consumers ($N = 238$) evaluated cooked samples for juiciness, tenderness, flavor liking, and overall liking. Data were analyzed using a mixed model with storage time as the fixed effect and individual carcasses as the random blocking factor. The WBSF values decreased ($P < 0.05$) with increased storage time for all the cuts. Similarly, consumer tenderness rating scores increased with the LT storage time, particularly in IR and SL steaks. However, storage time did not influence ($P \geq 0.05$) the juiciness, flavor, and overall liking of any of the cuts. The results of this study suggest it would be feasible to extend the storage time of beef while preserving or improving the sensory quality when held at optimal conditions above the freezing temperature.

Keywords: beef subprimals, extended storage, sensory evaluation, tenderness
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Introduction

With a fast-growing world population and increasing food demand, food systems must undergo transformations to ensure food security while complying with environmental, economic, and social objectives to meet global sustainability goals (Godfray et al., 2010; FAO, 2018). Extending the shelf life of fresh meat without any adverse effect on quality attributes is critically important to the meat industry to stabilize supply and facilitate export shipments. Meat is commonly preserved by storing it at chilled temperatures (2°C to 4°C). However, its shelf life under regular chilling conditions can be limited (on average 8 to 10 wk under vacuum packaging) primarily due to microbial spoilage (Coombs et al., 2017; Lu et al., 2019). Previous research has shown that the shelf life of fresh beef can be increased to up to 20 wk (140 d) when the product is vacuum-packaged and stored below regular chilling temperatures (around −0.5°C to −1.5°C) (Small et al., 2012; Chen et al., 2019). Furthermore, extended refrigerated storage/aging times can improve beef tenderness through the breakdown of muscle proteins by endogenous proteolytic enzymes (Casas et al., 2006; Ramanathan et al., 2020).

The 2015 National Beef Tenderness Survey reported that the average length of aging for steaks in retail and food service settings was 25.9 and 31.5 d, respectively (with a range of 3 to 102 d), and 11% of the steaks had less than 14 d of aging (Martinez et al., 2017). Such a variation in postmortem aging time could lead to inconsistency in tenderness between products (Dixon et al., 2012; Marino et al., 2013; Nair et al., 2019). In addition, during the peak steak consumption times of the year in the US, such as summer (Lusk et al., 2001; USDA-ERS, 2022), not all retailers and restaurants might have the supply of tender steaks needed to meet the demand, which could result in the use of steaks with low postmortem aging days or frozen beef. Additionally, beef market prices are seasonal and become highly inelastic during the summer months (Lusk et al., 2001), as consumers are willing to pay a higher price for specific cuts (Ardeshiri et al., 2019). Even when frozen beef can be used to stabilize the supply during the peak demand periods of the year, negative quality attributes associated with frozen beef, such as high purge, low color stability, poor tenderness, and high off-flavors, need to be considered (Wheeler et al., 1990; Lu et al., 2019; Wang et al., 2020).

Low temperature (LT) storage of beef subprimals slightly above their freezing point without the formation of ice crystals could slow down the growth of spoilage microflora and continue postmortem tenderization while maintaining the product's fresh status. This enables beef buyers to have a product held for weeks or even months (≤3 mo) delivered to them equivalent to a fresh product in terms of storage temperature. Previous studies have shown that extended postmortem aging of samples for more than 42 d can adversely affect beef flavor (Juárez et al., 2010; Garmyn et al., 2020; Karney et al., 2022). Nevertheless, research on the palatability characteristics of beef following LT extended storage is limited. Therefore, the objective of this study was to evaluate tenderness and palatability characteristics of beef inside round (IR), bone-in ribeye (RE), and striploin (SL) cuts following 60, 75, and 90 d of LT storage.

Materials and Methods

Collection and sample processing

The Colorado State University Institutional Review Board approved the procedures used in this study (IRB exemption #2784, October 28, 2021). Beef subprimals (IR, RE, and SL) were collected from both sides of 10 ($n = 10$) upper two-thirds Choice beef carcasses from a commercial beef processing facility. All individually identified subprimals were transported in a refrigerated truck to the Department of Animal Sciences Global Food Innovation Center (GFIC) at Colorado State University (Fort Collins, CO). Upon arrival, two 2.5-cm steaks fabricated from each subprimal were vacuum-packaged, wet-aged for 21 d (3°C), and then frozen (−20°C) for Warner-Bratzler shear force (WBSF), cooking loss, and consumer sensory analyses. These samples served as the control treatment. The remainder of each intact subprimal was cut into sections, individually vacuum-packaged, and randomly assigned to 60, 75, or 90 d of LT storage (LT60, LT75, or LT90; −2.7°C ± 0.3°C). The packaged pieces were separated by subprimal cut and LT storage time, boxed, and transported overnight in a refrigerated truck (<4°C) to an LT storage facility. Following each LT storage period, the products were transported overnight in a refrigerated truck (<4°C) to the GFIC. Immediately after arrival, the sections were removed from their vacuum package, and 2 steaks of 2.5 cm were fabricated from each portion ($n = 10$). These steaks were individually vacuum-packaged and stored at −20°C for WBSF, cooking loss, and consumer sensory evaluations.

Cooking method

Before cooking, the frozen steaks were tempered for 24 h at 3°C to attain a raw internal temperature of 0°C to 4°C at the time of cooking. All excess external fat was trimmed off the raw steaks and then cooked in a combi-oven (Model SCC WE 61 E; Rational, Landsberg am Lech, Germany) set at 204°C, until a peak internal temperature of 71°C was achieved. A thermometer (Thermapen Mk4, Thermoworks Inc., American Fork, UT) placed in the geometric center of each steak was used to determine the peak internal temperature of the cooked steaks. For WBSF analysis, approximately 8 steaks from the same subprimal were cooked in the combi-oven and were grouped by raw weight without consideration of the treatment. For the sensory analysis, steaks from the same subprimal were cooked in their random serving order, with no more than 3 steaks at a time in the oven.

Cooking loss

The trimmed raw steaks were weighed on a food scale (V22XWE3T, Ohaus Corporation, Parsippany, NJ) prior to cooking. After cooking, the steaks were weighed again to calculate the percentage of cooking loss with the following formula: cook loss percentage = [(raw weight − cooked weight)/raw weight] × 100.

Warner-Bratzler shear force

Cooked steaks destined for WBSF determination were placed on trays, avoiding any overlap, and were covered with plastic wrap and refrigerated (3°C) overnight. The next day, cooked steaks were trimmed of visible connective tissue to expose muscle fiber orientation. Hand-held coring devices were used to remove at least six 1.2-cm diameter cores parallel to the muscle fibers from each steak. Cores were sheared once, perpendicular to the muscle fibers, using a universal testing machine (Instron Corp., Canton, MA) fitted with a Warner-Bratzler shear head (crosshead speed: 200 mm/min, load cell capacity: 100 kg). Peak shear force was recorded, and values from the cores taken from each steak were averaged to obtain a single WBSF value for each steak. The average peak shear force of the cores was used for statistical analysis.

Sensory evaluation

A total of 120 steaks ($n = 10$) identified with a four-digit number were randomly assigned by subprimal cut (i.e., IR, RE, SL) and storage time (i.e., 21 d wet-aged control, LT60, LT75, and LT90) to one of 30 panel sessions with 4 steaks evaluated per panel. Steaks were also randomly assigned a serving order within each panel session, and 8 panelists evaluated each steak. Frozen steaks were tempered for 18 to 24 h at 3°C before cooking, and the samples were cooked (as described previously) in the serving order. Cooked steaks were trimmed of all external fat and connective tissue and cut into cuboidal pieces (1-cm^2 × cooked steak thickness). Samples were served in order and warm to panelists, and portions comprised mainly of fat or heavy connective tissue were not utilized.

Panelists were recruited ($N = 238$) from Fort Collins, CO, and surrounding communities. Panels took place at Colorado State University in groups of 24 panelists. At the beginning of each panel, participants were given a brief orientation and ballot completion instructions. Then, participants signed a consent form, and demographic and beef consumption information was collected (Supplemental Table 1). Each panelist evaluated a total of 4 samples, with each sample representing a different storage time (i.e., 21 d wet-aged, LT60, LT75, and LT90). Each participant was given 2 cuboidal portions per sample in a plate identified with the random four-digit sample number. Panelists were provided unsalted saltine crackers (Nabisco Unsalted Tops Premium; Mondelez Global LLC, East Hanover, NJ), water, and 25% diluted unsweetened apple juice to use as palate cleansers between samples. For all palatability characteristics, samples were rated using a 100-point continuous line scale with anchors as follows: juiciness (0 = extremely dry, 50 = neither juicy nor dry, 100 = extremely juicy), tenderness (0 = extremely tough, 50 = neither tough nor tender, 100 = extremely tender), flavor (0 = dislike extremely, 50 = neither like nor dislike, 100 = like extremely), and overall liking (0 = dislike extremely, 50 = neither like nor dislike, 100 = like extremely). Additionally, consumers evaluated these 4 attributes for acceptability (juiciness acceptance, tenderness acceptance, flavor acceptance, and overall liking acceptance), including the presence or absence of off-flavors, with a "yes" or "no" answer, leaving perceived acceptance levels to consumers' interpretation. All data were collected using Qualtrics software (Provo, UT).

Statistical analysis

All analyses were performed within each subprimal cut since it is known that different subprimals/muscles have different quality characteristics (Gruber et al., 2006). Data analysis was performed in R version 4.0.3 (R Core Team, 2020) using the lme4 package (Bates et al., 2015) as a mixed model, where storage time (i.e., 21 d wet-aged and LT storage time [LT60, LT75, LT90]) was set as a fixed effect and individual carcass as a random blocking factor. Least-squares means were calculated using the emmeans package (Lenth, 2020), and their differences are reported using a significance level of $\alpha = 0.05$ with Tukey's multiple comparison adjustment. Additionally, a mixed-effects binomial model was used to evaluate percentage acceptability of sensory trait and absence of off-flavor based on the storage conditions and times, where the carcass was set as a random blocking factor and storage time as a fixed effect.

Results

Cooking loss

The percentage of cooking loss by cut and storage days is shown in Figure 1. The different storage conditions (i.e., LT or 21 d wet-aged) and times had no effect ($P \geq 0.05$) on cooking loss irrespective of subprimal cut.

Warner-Bratzler shear force

The WBSF values of all 3 cuts generally decreased with an increase in storage time, as shown in Figure 2.

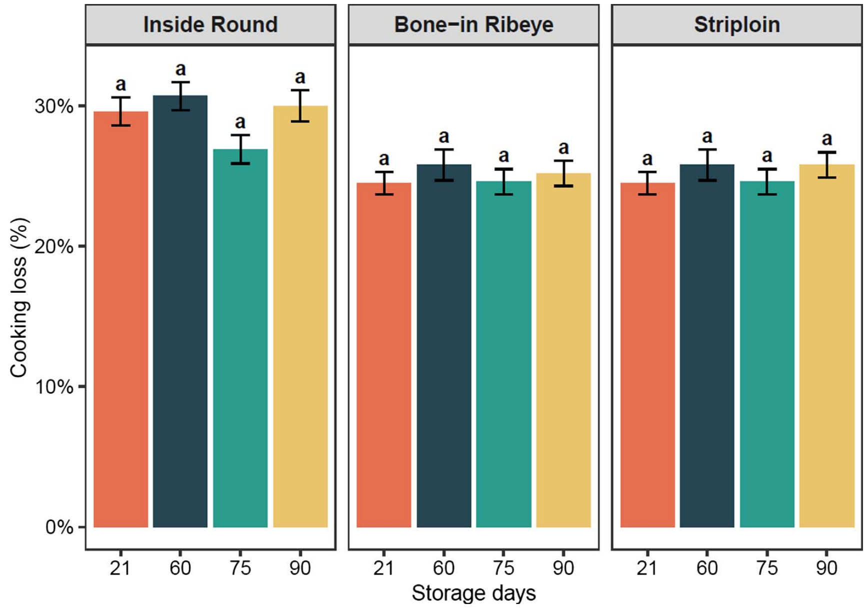

Figure 1. Effect of low temperature (−2.7°C ± 0.3°C) storage times (60, 75, or 90 d) or 21 d of wet aging on the percentage of cooking loss of inside round (IR), bone-in ribeye (RE), and striploin (SL) steaks ($n = 10$). Same letters (a) above the error bars indicate similarity ($P \geq 0.05$). Error bars represent the standard error of the mean.

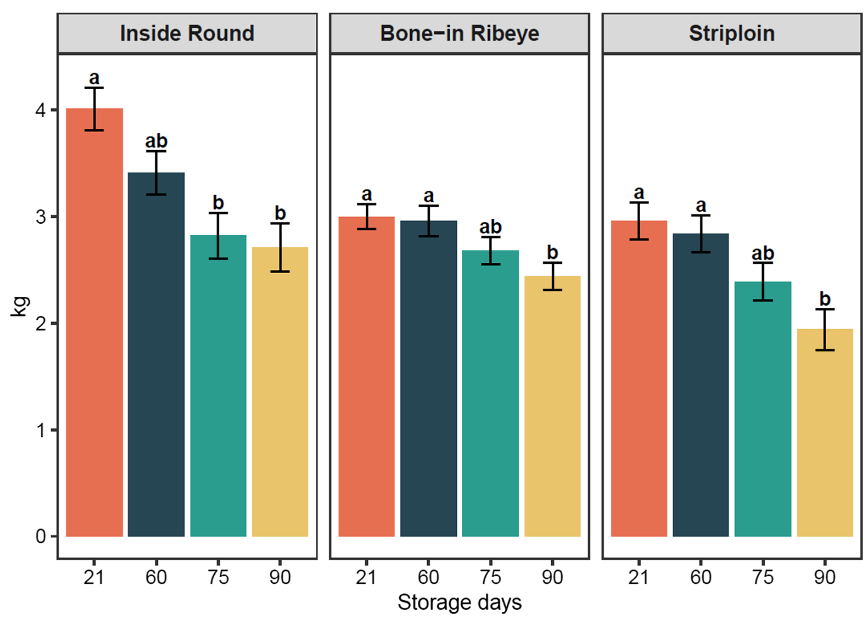

Figure 2. Effect of low temperature (−2.7°C ± 0.3°C) storage times (60, 75, or 90 d) or 21 d of wet aging on Warner-Bratzler shear force (kg) of inside round (IR), bone-in ribeye (RE), and striploin (SL) steaks ($n = 10$). Different letters (a-b) above the error bars indicate significant differences ($P < 0.05$). Error bars represent the standard error of the mean.

However, WBSF values of LT60 steaks were similar ($P \geq 0.05$) to the control steaks subjected to 21 d of wet aging, regardless of the cut. WBSF values for LT90 RE and SL steaks were lower ($P < 0.05$) than their corresponding LT60 and 21 d wet-aged samples. For IR, LT75 and LT90 samples had lower ($P < 0.05$) WBSF values than steaks subjected to 21 d of wet aging but were similar ($P \geq 0.05$) to those of LT60 steaks.

Sensory evaluation

Consumer sensory ratings for juiciness, tenderness, flavor, and overall liking are presented in Figures 3, 4, and 5 for IR, RE, and SL, respectively, and the percentage of acceptance of these sensory traits and absence of off-flavor for all cuts are shown in Table 1. As presented in Figure 3, IR sample scores for juiciness, flavor, and overall liking were similar

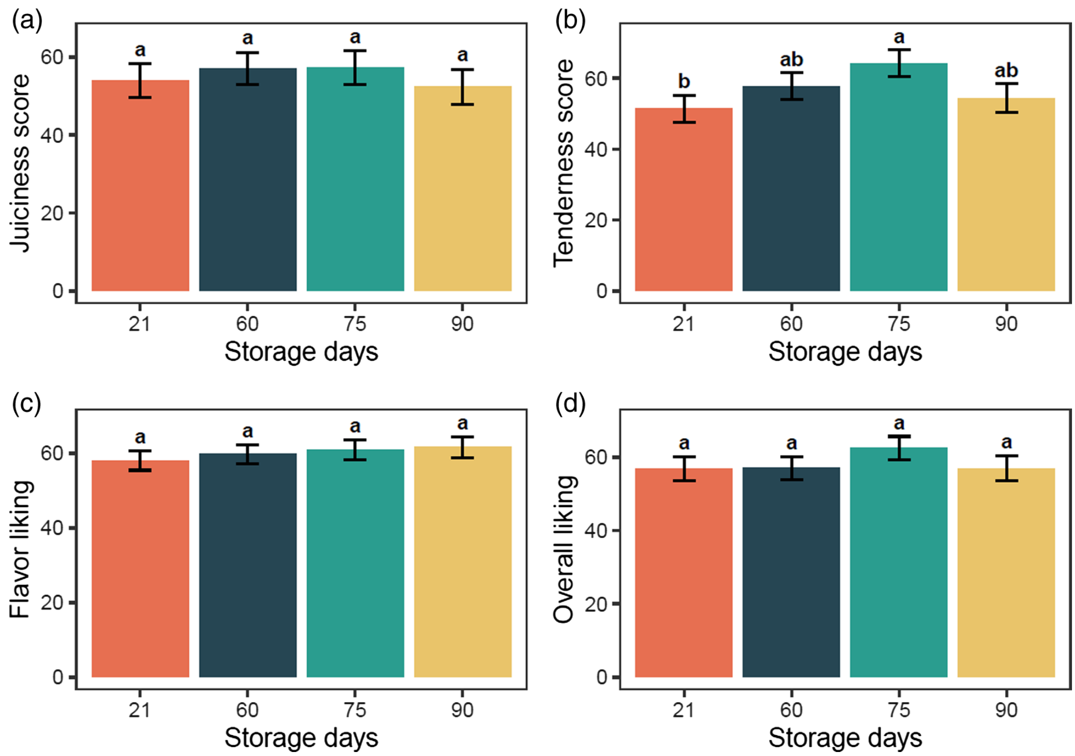

Figure 3. Consumer panelists ($N = 79$) sensory evaluation of inside round steaks (IR; $n = 10$) that were in low temperature (−2.7°C ± 0.3°C) storage (60, 75, or 90 d) or were wet-aged for 21 d. A: juiciness with a scoring scale from 0 to 100 was used, with 0 being labeled as extremely dry, 50 neither juicy nor dry, and 100 extremely juicy; B: tenderness with a scoring scale from 0 to 100 was used, with 0 being labeled as extremely tough, 50 neither tough nor tender, and 100 extremely tender; C: flavor liking; D: overall liking using scoring scale from 0 to 100 with 0 being labeled as dislike extremely, 50 neither like nor dislike, and 100 like extremely. Different letters (a-b) above the error bars indicate significant differences ($P < 0.05$). Error bars represent the standard error of the mean.

($P \geq 0.05$) between the storage conditions and days. Tenderness scores for IR LT75 steaks were higher ($P < 0.05$) than those of 21 d wet-aged samples but were not different ($P \geq 0.05$) from the tenderness scores of LT60 and LT90 steaks (Figure 3B). The overall liking scores of all IR samples were similar ($P \geq 0.05$; Figure 3D). Additionally, all the sensory traits' acceptance percentages were similar ($P \geq 0.05$) for IR steaks within storage conditions and days (Table 1). However, tenderness of LT75 steaks had a percentage acceptability of 92.3% ($P = 0.1$), which is at least 7% higher than the rest of the treatments. This result for the IR steaks follows the same pattern as the tenderness score, where LT75 steaks had the highest tenderness rating.

The results of the consumer sensory evaluation of the RE steaks are shown in Figure 4. Consumers could not detect ($P \geq 0.05$) any difference in the sensory attributes of RE steaks, regardless of the storage time (Figure 4). Likewise, there were no differences ($P \geq 0.05$) in the absence of off-flavor and acceptability for juiciness, tenderness, flavor, and overall liking within each storage period (Table 1). As expected, the tenderness acceptability percentage of RE steaks was higher than 91%, regardless of the storage time (Table 1).

For the SL samples, there was no ($P \geq 0.05$) storage time effect on juiciness, flavor, and overall liking (Figure 5). However, consumers detected differences among the storage times for tenderness ratings of SL steaks. More specifically, tenderness scores of LT90 samples were greater ($P < 0.05$) than those of LT60 steaks but similar ($P \geq 0.05$) to tenderness scores of LT75 and 21 d wet-aged samples. Additionally, percentages of acceptance of all sensory traits evaluated and the absence of off-flavor on SL steaks did not ($P \geq 0.05$) differ by storage time (Table 1).

Discussion

Previous research has demonstrated that storage of beef below typical chilling temperatures (−0.5°C to −1.5°C) can extend its shelf life by up to 20 wk (Small et al., 2012; Chen et al., 2019; Yang et al., 2022). Beef quality attributes such as WBSF, cooking loss, and color, following storage at temperatures below 0°C without freezing have been evaluated previously

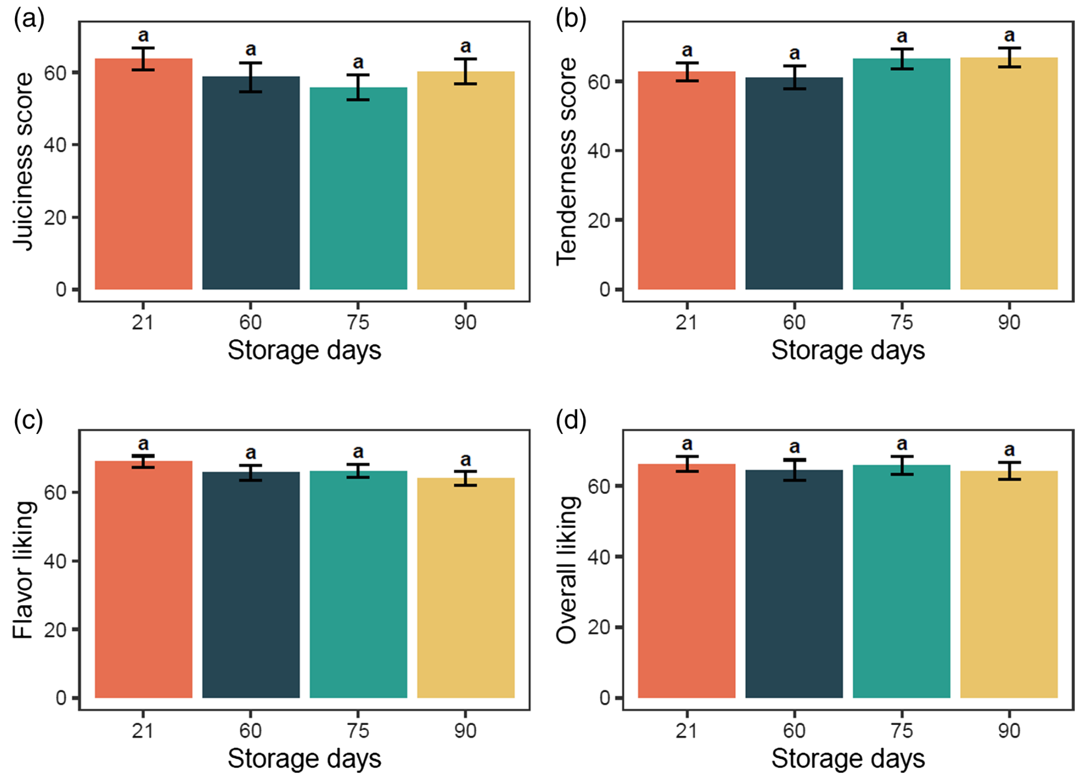

Figure 4. Consumer panelists ($N = 79$) sensory evaluation of ribeye steaks (RE; $n = 10$) that were in low temperature (−2.7°C ± 0.3°C) storage (60, 75, or 90 d) or were wet-aged for 21 d. A: juiciness with a scoring scale from 0 to 100 was used, with 0 being labeled as extremely dry, 50 neither juicy nor dry, and 100 extremely juicy; B: tenderness using a scoring scale from 0 to 100 was used with 0 being labeled as extremely tough, 50 neither tough nor tender, and 100 extremely tender; C: flavor liking; D: overall liking using scoring scale from 0 to 100 was used with 0 being labeled as dislike extremely, 50 neither like nor dislike, and 100 like extremely. Same letters (a) above the error bars indicate similarity ($P \geq 0.05$). Error bars represent the standard error of the mean.

(Chen et al., 2019; Lu et al., 2019, 2020; Yang et al., 2022; Zhang et al., 2023). These studies have demonstrated that storage of vacuum-packaged beef below typical chilling temperatures can extend its shelf life while improving postmortem tenderization. However, the effect of this extended storage on palatability traits has not been examined extensively. Palatability traits such as tenderness, juiciness, and flavor are critical for consumer acceptance and repurchase decisions (Smith and Carpenter, 1974; Lyford et al., 2010). In the current study, palatability characteristics, including cooking loss, WBSF, and sensory evaluations of 3 major beef cuts (IR, RE, and SL) following LT storage, were assessed. In general, as storage time increased, WBSF values decreased, and tenderness rating increased, with no differences in cooking loss or juiciness, flavor, and overall liking.

Most of the weight loss that occurs during cooking is the result of water being expelled by protein degradation and muscle fiber contraction (Lepetit et al., 2000; Kondjoyan et al., 2013; Hughes et al., 2014). With extended storage time, a decrease in water holding capacity is expected, which can lead to an increase in cooking loss. However, in the current study, the storage condition and time did not influence the cooking loss of the IR, RE, and SL steaks (Figure 1). Cao et al. (2022) evaluated the cooking loss of beef *longissimus dorsi* steaks at 0, 4, 8, 12, 16, 20, and 24 d of vacuum storage at refrigerated (4°C) and superchilled temperatures (−1.5°C). These researchers reported that following storage, samples stored at 4°C had higher cooking loss than samples held at −1.5°C for the same length of time (Cao et al., 2022). Interestingly, under both storage conditions, cooking loss initially increased from 0 to 4 d and then decreased during the remainder of the storage time (Cao et al., 2022). In contrast, Lu et al. (2019) assessed the effect of extended storage at −4°C (0 to 24 wk) and 2°C (0 to 8 wk) on SL. Samples stored at −4°C had greater cooking loss than those held at 2°C (Lu et al., 2019). However, cooking loss of samples held at −4°C for 8, 12, and 24 wk was similar, suggesting that changes in cooking loss might not be significant after 8 wk (56 d) of storage (Lu et al., 2019).

Tenderness is considered the most critical factor in overall eating satisfaction and consumers' acceptability

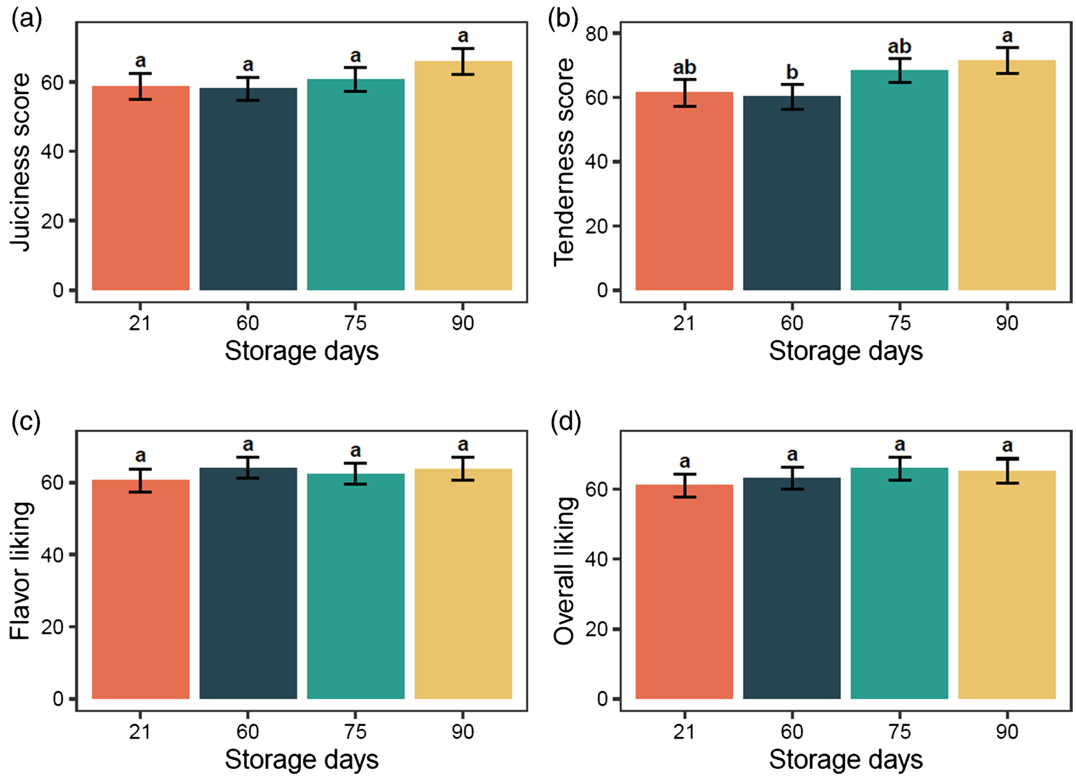

Figure 5. Consumer panelists ($N = 80$) sensory evaluation of striploin steaks (SL; $n = 10$) that were in low temperature (−2.7°C ± 0.3°C) storage (60, 75, or 90 d) or were wet-aged for 21 d. A: juiciness with a scoring scale from 0 to 100 was used, with 0 being labeled as extremely dry, 50 neither juicy nor dry, and 100 extremely juicy; B: tenderness using a scoring scale from 0 to 100 was used with 0 being labeled as extremely tough, 50 neither tough nor tender, and 100 extremely tender; C: flavor liking; D: overall liking using scoring scale from 0 to 100 was used with 0 being labeled as dislike extremely, 50 neither like nor dislike, and 100 like extremely. Different letters (a-b) above the error bars indicate significant differences ($P < 0.05$). Error bars represent the standard error of the mean.

Table 1. Least-squares means for the percentage of consumers ($N = 238$) who indicated acceptability for juiciness, tenderness, flavor, overall liking, and absence of off-flavor of inside round (IR), bone-in ribeye (RE), and striploin (SL) steaks ($n = 10$) that were in low temperature (−2.7°C ± 0.3°C) storage (60, 75, or 90 d) or wet-aged for 21 d

Cut	Days of storage	Juiciness acceptability	Tenderness acceptability	Flavor acceptability	Absence of off-flavor	Overall acceptability
IR	21	78.2	78.8	81.8	80.7	81.2
	60	82.0	84.7	83.6	83.8	78.0
	75	85.3	92.3	90.2	83.3	89.3
	90	71.9	80.5	90.5	76.2	81.5
	SE	7.7	7.3	4.7	5.6	5.4
	P value	0.28	0.10	0.33	0.67	0.33
RE	21	88.7	93.3	95.6	95.8	92.5
	60	83.3	92.0	94.2	86.5	83.3
	75	81.0	94.1	90.8	93.0	92.1
	90	76.2	91.0	89.3	93.7	87.3
	SE	5.4	4.2	4.3	6.3	5.4
	P value	0.27	0.92	0.48	0.25	0.35
SL	21	81.9	90.2	89.1	87.9	92.4
	60	81.7	90.6	91.3	89.2	91.8
	75	86.7	95.0	91.3	85.5	92.9
	90	85.0	95.3	84.4	84.9	86.7
	SE	5.1	4.5	4.6	4.8	5.3
	P value	0.80	0.43	0.53	0.85	0.55

SE: standard error.

of beef (Miller et al., 2001; Shackelford et al., 2001). In the present study, WBSF values of all 3 cuts decrease with an increase in storage time, as shown in Figure 2. In general, initial tenderness (21 d wet-aged) for all the cuts met the Minimum Tenderness Threshold Value of less than 4.4 kg WBSF (ASTM, 2011). Furthermore, WBSF values of RE and SL steaks after 21 d of wet aging could be considered "very tender" (ASTM, 2011), and WBSF values of IR steaks achieved this threshold after LT60. The WBSF results of this study agree with previous studies that have observed a decrease in shear force with an increase in aging time (Gruber et al., 2006; Dixon et al., 2012; Colle et al., 2015; Karney et al., 2022). However, the results can vary depending on parameters such as storage temperature and muscle evaluated (Lu et al., 2019; Nair et al., 2019; Lu et al., 2020). For example, Lu et al. (2019) assessed the effect of extended storage at −4°C (0 to 24 wk) and 2°C (0 to 8 wk) on SL and reported that WBSF values of SL steaks after 12 wk of storage at −4°C were lower than those stored for 4 wk at −4°C. The authors further reported that WBSF values of steaks after 8 wk of chilled storage (2°C) were lower than those after 4 wk of storage at the same temperature (Lu et al., 2019). However, WBSF values of samples after 4 wk of chilled storage (2°C) were significantly lower than those of samples held for 12 wk at −4°C, indicating that the time and temperature of storage can have an impact on tenderness. Similarly, Karney et al. (2022) performed WBSF analyses on SL that had been wet-aged at 0°C for 14, 21, 28, 35, 49, or 63 d and reported that 49 and 63 d aged samples had the lowest WBSF values, while 21, 28, and 35 d aged steaks had similar values.

Consumers' eating satisfaction is crucial when new technologies are being evaluated to extend beef shelf life since it is documented that consumers are willing to pay more for beef that meets their eating expectations (Lyford et al., 2010). Generally, beef palatability is attributed to juiciness, tenderness, and flavor (Smith and Carpenter, 1974), and these primary sensory traits were evaluated in the current study, along with overall liking. The term "juiciness" describes the sensation that occurs when meats have higher levels of juices, and it is positively associated with consumer preference (Maughan et al., 2012). The changes in the juiciness of steaks from the different LT storage periods varied depending on the cut evaluated. However, regardless of the cut, consumers could not detect differences in juiciness among any of the storage treatments. These results agreed with cooking loss, where no differences were observed. The lack of differences in juiciness, regardless of the storage time, could be because all samples were from upper two-thirds Choice carcasses, where the amount of marbling is moderate (Emerson et al., 2013). Laster et al. (2008) performed consumer sensory evaluations on RE and SL steaks that were wet-aged at −0.6°C ± 1.8°C for 14, 21, 28, and 35 d (after initial aging for 9 d during shipment) and reported no differences in the juiciness levels of RE and SL steaks over the aging periods.

In the current study, consumers were able to detect differences in tenderness with the storage time for IR and SL samples. However, they could not detect differences in tenderness for RE steaks, regardless of the storage time. This result is also in agreement with Laster et al. (2008), where consumers were unable to detect the differences in tenderness of RE after wet aging. The percentage of acceptance of tenderness did not vary by storage time, irrespective of the cut (Table 1). Moreover, these observations in consumer evaluations were consistent with the WBSF results, where WBSF values of LT90 IR and SL steaks were more than 1 kg lower compared to IR and SL steaks aged for 21 d. Specifically, the WBSF values of LT75 and LT90 IR steaks were lower than those of 21 d wet-aged samples, and WBSF values of LT90 SL steaks were lower than those of LT60 samples. Although there was a statistical difference between WBSF values of LT90 RE steaks and WBSF values of LT60 and 21 d wet-aged RE samples, the change was less than 1 kg, which could explain why consumers could not perceive the difference (Miller et al., 1995).

Several studies have demonstrated that flavor is of great importance when tenderness is acceptable (Goodson et al., 2002; Killinger et al., 2004; Behrends et al., 2005), and a recent study indicated that it could have more influence than tenderness on overall consumer eating satisfaction of beef (O'Quinn et al., 2018). In the current study, as storage time increased, flavor scores numerically increased for IR and SL steaks (Figure 3C and 5C), whereas flavor scores numerically decreased for RE steaks (Figure 4C); however, none of these changes were statistically significant. The overall liking scores of samples were similar for all storage times, regardless of the cut evaluated (Figure 3D, 4D, and 5D). Similar to the present study, Colle et al. (2015) assessed the flavor and overall liking of SL steaks aged (2, 14, 21, 42, and 63 d) at 0°C and reported no differences in either attribute across the different aging periods. In contrast, Garmyn et al. (2020) evaluated flavor and overall liking every 7 d of SL aged at 2°C from 21 to 84 d and reported a significant decrease as postmortem aging time increased.

Differences in results from the current study compared to others, where overall liking decreased with aging time, could be due to the lower temperature used during storage. Previously, Juárez et al. (2010) demonstrated that storage temperature could affect the off-flavor intensity, with SL and IR steaks stored at 5°C having a greater off-flavor compared to steaks stored at 1°C. A recent study (Hernandez et al., 2023) evaluated the influence of storage temperature (−2°C, 0°C, or 4°C) and duration (14, 28, 42, or 56 d) of vacuum-packaged beef SL on palatability, and it was reported that off-flavors, such as sour notes, were higher on samples aged for 56 d at 4°C compared with those stored for the same time at the lower temperatures.

Conclusions

Tenderness and palatability attributes are important when new processes are being evaluated as they affect consumers' eating satisfaction and repurchase decisions. In the current study, the WBSF values of IR, RE, and SL steaks decreased over LT storage time (up to 90 d), and perceived tenderness by consumers increased with no adverse effect on juiciness, flavor, and overall liking. These results suggested that storage temperatures lower than typical chilling temperatures could extend the storage life of beef while preserving or even improving sensory performance. With seasonality in beef price and consumption, these results can be useful to the meat industry to stabilize supply.

Acknowledgments

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Supplemental Table 1: Demographic characteristics of consumers (N = 238) who participated in the consumer sensory panels.

Characteristic	Response	Percentage of consumers
Gender	Male	50%
	Female	48%
	Other	2%
Age group	Under 20 years old	11%
	20 to 29 years old	49%
	30 to 39 years old	21%
	40 to 49 years old	7%
	50 to 59 years old	8%
	Over 60 years old	4%
Ethnic origin	African-American	1%
	Asian	6%
	Caucasian/white	65%
	Hispanic	21%
	Native American	1%
	Mixed race	2%
	Other	5%
Marital status	Single	65%
	Married	35%
Household size	1 person	29%
	2 people	36%
	3 people	17%
	4 people	10%
	5 people	4%
	6 people	3%
Annual household income	Under $25,000	37%
	$25,000 to $34,999	5%
	$35,000 to $49,999	10%
	$50,000 to $74,999	12%
	$75,000 to $99,999	10%
	$100,000 to 149,999	16%
	$150,000 to $199,999	4%
	> $199,999	5%
Education level	Non-high school graduate	2%
	High school graduate	7%
	Some college/technical school	26%
	College graduate	34%
	Post-college graduate	31%
Preferred beef degree of doneness	Very rare	2%
	Rare	6%
	Medium rare	49%
	Medium	26%
	Medium well	12%
	Well done	4%
	Very well done	2%

Supplemental Table 1: (*Continued*)

Characteristic	Response	Percentage of consumers
Beef consumption per week	Every other week	4%
	Weekly	15%
	2 to 3 times a week	37%
	4 to 5 times a week	19%
	Daily	25%