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Effect of Extended Postmortem Aging on Beef Muscles of Differing Quality Grade during Retail Display

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Abstract: Aging of beef subprimals is a common industry practice to improve tenderness. However, the effect of extended aging (up to 63 d) on retail shelf life, tenderness, and eating quality of beef strip loin and sirloin of differing quality grades is not clearly understood. Therefore, in the current study, *longissimus dorsi* (strip loin) and *gluteus medius* muscles (sirloin) were collected from USDA Choice or Select carcasses and fabricated into 6 portions. Each of these portions was designated to an assigned time of wet aging (14, 21, 28, 35, 45, or 63 d) in vacuum bags. After aging, samples were fabricated into steaks and placed into a multideck retail display case for 72 h. Steaks were evaluated for color (instrumental and color panelists) every 8 h during retail display, and Warner-Bratzler shear force and sensory analysis were conducted after retail display. The results were analyzed using the PROC MIXED procedure of SAS with repeated measures for the color data. Among the effects evaluated (aging, quality grade, and aging × quality grade), quality grade was not significant ($P > 0.05$) for either strip loin or sirloin steaks. An aging × display hour interaction was identified ($P < 0.05$) for the color measurements. In general, as aging time increased over the display period, color was negatively impacted. Although tenderness improved ($P < 0.05$) with aging, the incidence of off-flavors also increased, especially in sirloin steaks, suggesting that beef processors need to consider flavor changes during extended aging.

Key words: aging, color, tenderness, quality grade, sensory evaluation
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Introduction

Beef tenderness is one of the most important sensory characteristics determining overall acceptance and consumer eating satisfaction (Huffman et al., 1996; Platter et al., 2003; O'Quinn et al., 2018). Postmortem aging, especially wet aging of subprimals under vacuum packaging, is an essential and effective management technique commonly employed by the beef industry to improve tenderness. The recent National Beef Tenderness survey indicated that there is substantial variation in the aging time of beef muscle cuts (Martinez et al., 2017). The postfabrication storage or aging times of subprimals ranged from 6 to 102 d at retail establishments with an average of 25.9 d, whereas at the food service level, the range was from 3 to 91 d with an average of 31.5 d (Martinez et al., 2017). Moreover, tenderness is a muscle-specific attribute (Belew et al., 2003; Von Seggern et al., 2005), with tenderness variations observed among different muscles from the same carcass. In addition, the tenderness improvement with aging varies between muscles (Gruber et al., 2006; Nair et al., 2019). Gruber et al. (2006) further reported that the quality grade of the muscles (upper two-thirds Choice vs. Select) influenced the tenderness improvement with aging, with much slower improvement in the Select muscles.

Similar to tenderness, the maintenance of fresh beef color is the primary factor in determining retail display life and influences consumer purchase decisions at the retail marketplace (Carpenter et al., 2001; Troy and Kerry, 2010; Ramanathan et al., 2020). However, aging can adversely affect the cellular and biochemical mechanisms influencing meat color (Nair et al., 2018). King et al. (2012) reported that *longissimus* steaks aged for 35 d and packaged in polyvinyl chloride had lower redness (a^* value) compared with 14 d aged samples. Similarly, lower redness was reported for USDA Select steaks (*gluteus medius* and *longissimus lumborum*) aged for 62 d compared to those aged for 21 or 42 d during retail display (Colle et al., 2015).

Flavor is another important attribute that could be influenced by aging. Garmyn et al. (2020) reported that consumer flavor liking, overall liking, juiciness, and overall eating quality declined in steaks with increase in aging time of *longissimus lumborum* muscle wet-aged for 21 to 84 d, but their tenderness was not improved by aging beyond 21 d. In contrast, Colle et al. (2015) reported no difference in acceptability or juiciness but observed an improvement in tenderness with extended aging times.

An important factor in reducing food waste is increasing both storage times and the amount of time a product can still be acceptable on retail display (Eriksson et al., 2016). Therefore, it is important to understand how extended aging time impacts meat color, palatability, and ultimately retail display time. Retail beef products that do not meet quality standards can result in discarded products, resulting in a potential economic loss estimated to be over $1 billion yearly in the United States alone (Smith et al., 2000).

Even though the concept of aging beef has been well received and is heavily utilized by the beef industry, extended aging is not standardized or commonly implemented. Therefore, a clear understanding of the effects of postmortem aging on retail display life of USDA Choice and Select, the 2 quality grades of beef that are most likely to appear in retail supermarkets, could lead to more extensive implementation of aging, which could ultimately decrease the incidence of unacceptably tough steaks at retail. Nonetheless, the effect of extended aging period on retail display life and eating quality has not been well documented. Therefore, the objective of this study was to identify the impact of extended postmortem aging times on retail shelf life, tenderness, and eating qualities of beef top sirloin and strip loin steaks (Choice vs. Select).

Materials and Methods

Paired (from the same carcass) beef strip loins (IMPS/NAMP #180; Strip Loin) and top sirloin butts (IMPS/NAMP #184; Top Sirloin Butt) were obtained approximately 48 h postmortem from either USDA Choice ($n = 15$; marbling scores ranging from Small^{00} to Small^{50}) or USDA Select ($n = 15$; marbling scores ranging from Slight^{50} to Slight^{99}) from a commercial beef processing plant (Table 1). The samples were then transported under refrigeration (0°C to 2°C) to Colorado State University Meat Laboratory for further processing.

Muscle fabrication and steak allocation

The *biceps femoris*, *gluteus accessorius*, and *gluteus profundus* were removed from the top sirloin butts to isolate the *gluteus medius* muscle (sirloin). The sirloin was then fabricated into 3 parts by cutting anterior to posterior approximately parallel with the muscle fiber orientation to create 3 equal portions of the *gluteus medius* muscle. These portions were then halved to result in a total of 6 portions. The paired strip loins also were fabricated into 6 portions, 3 from each strip loin, by cutting perpendicular to the length of each strip loin and excluding the most posterior portion of each strip loin containing the *gluteus medius* (vein portion). One of the 6 portions from each set of paired primals was then randomly allocated to 1 of 6 postmortem aging periods (14, 21, 28, 35, 45, or 63 d). All portions were then individually vacuum sealed in a nonoxygen-permeable package (standard barrier nylon polyethylene bags with 0.6 cm^3 O_2/645.16 cm^2/24 h at 0°C) and stored at 0°C (±1°C) in the absence of light

Table 1. Simple means for carcass traits of the sample collected ($n = 15$; $N = 30$) by quality grade

Quality grade[1]	Fat (cm)	HCW (kg)	REA (cm^2)	KPH (%)	Yield grade	Lean maturity[2]	Marbling[3]
USDA Choice	0.9 ± 0.1	374.9 ± 29.3	87.7 ± 7.1	2.5 ± 0.2	2.7 ± 0.5	173.0 ± 17.0	428.0 ± 17.0
USDA Select	1.0 ± 0.1	365.2 ± 36.5	89.1 ± 6.0	2.5 ± 0.3	2.8 ± 0.5	169.0 ± 9.2	374.0 ± 13

[1]USDA Choice carcasses were selected to have marbling scores ranging from Small^{00} to Small^{50}; USDA Select carcasses were selected to have marbling scores ranging from Slight^{50} to Slight^{99}.

[2]A maturity = 100 to 200.

[3]300 to 399 = Slight, 400 to 499 = Small.

HCW = hot carcass weight; KPH = kidney, pelvic, and heart fat; REA = rib rye area.

for their designated aging period. Following each aging period, sections were removed from storage, faced, and hand-cut into 3 (2.54-cm-thick) steaks with a maximum of 0.32 cm of external fat remaining. Of the 3 steaks cut, 1 steak was randomly designated for Warner-Bratzler shear force (WBSF) determination and served as the 0 h of retail display. This steak was immediately vacuum packaged and frozen (−20°C) for subsequent WBSF procedures, along with the steaks that had been displayed for 72 h. The remaining 2 steaks were placed into the same foam tray with a soaker pad and overwrapped with polyvinylchloride film (15,500 to 16,275 cm^3/m^2 per 24 h oxygen transmission rate at 23°C). The packages of overwrapped steaks were then placed into a multideck retail display case (Hussman Model No. M3X8GEP) equipped with light emitting diodes (900 ± 184 lux) at a temperature of 2°C (±1°C) for 72 h. To account for any variation of light intensity or temperature, trays were rotated within the display case every 8 h as color measurements were taken.

Color evaluation

Steaks were evaluated by a minimum of 8 trained panelists for lean color, fat color, and percent lean discoloration every 8 h during the 72 h display period. Training sessions were conducted following AMSA guidelines with products being viewed in the multideck retail display (King et al., 2022). Panelists quantified the predominant lean and fat color of each steak using 150 mm unstructured line scales anchored at both ends with descriptive terms. For predominant lean color and lean discoloration, 0 mm denoted very dark red and 100% discoloration, whereas 150 mm denoted bright cherry red and 0% discoloration. For predominant external fat color, 0 mm denoted dark tan or brown/green, with 150 mm indicating bright, creamy white. After each scoring session, individual panelist ratings were averaged to obtain a single panel rating for each visual attribute of each sample. In addition, objective lean color measurements were obtained with a portable spectrophotometer (Miniscan Model 4500S, HunterLab, Reston, VA) equipped with a 6 mm measurement port (illuminant D65 and 10° standard observer) that was standardized before each use. A total of 9 readings of Commission Internationale de l´Eclairage (CIE) L^* (lightness), a^* (redness), b^* values (yellowness) for each steak were collected through the overwrap film and averaged for each package. Following the 72-h display, one randomly selected steak from each package was designated for WBSF testing, and the other steak was assigned to sensory evaluation. Both steaks were then immediately vacuum sealed and frozen (−20°C) until the completion of all aging and display periods.

Warner-Bratzler shear force determination

Upon completion of each designated aging and display period (0 and 72 h), WBSF was conducted on thawed, previously frozen steaks following established protocols (AMSA, 2016). Steaks were allowed to thaw for 24 h at 2°C to 4°C to ensure all steaks were between 0°C and 4°C prior to cooking. All steaks designated to WBSF were cooked on electric grills (model GGR64, Salton, Inc., Lake Forest, IL) that heated steaks from both sides simultaneously to a peak internal temperature of 71°C, measured in the geometric center of the steak, using a Type K thermocouple thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation, Middlefield, CT). Following removal from the heat source, peak post-cooking temperatures were recorded for use as a covariate in the statistical analyses. After cooking, steaks were allowed to equilibrate to room temperature (22°C). Following equilibration, 6 to 10 cores (1.27 cm in diameter) were removed from each steak parallel to the muscle fiber orientation. Each core was sheared once, perpendicular to the muscle fiber orientation, using a universal testing machine (model 4443, Instron, Norwood, MA) fitted with a Warner-Bratzler shear head (cross head speed: 200 mm/min, load cell capacity: 100 kg; AMSA, 1995). Peak shear force measurements (kilograms) were recorded for individual cores and averaged to obtain a single WBSF value for each steak.

Sensory analysis

Descriptive sensory analysis was conducted at Colorado State University. Panelists were trained to characterize sensory attributes outlined in the lexicon of descriptive attributes for beef, developed using guidelines provided by AMSA (2016) and Adhikari et al. (2011). The attributes included tenderness (myofibrillar, connective tissue tenderness, and overall), juiciness, and the following beef flavor descriptors: beef flavor intensity, buttery/beef fat flavor, oxidized, sour/acidic, livery/organy, and bloody/metallic. Sensory panel sessions consisting of 8 trained panelists per panel were conducted and samples (both strip loin and sirloin) were randomly assigned to a sensory session to ensure that all aging periods for each cut were represented in a single sensory panel session. Twelve samples were evaluated in each session.

Frozen strip loin and sirloin steaks used for each panel session were thawed and cooked in identical fashion to the procedures described for WBSF. Steaks were cut into cuboids (1.3 cm × 1.3 cm × cooked steak thickness) that were placed in a ceramic bowl, covered with aluminum foil, and held in a warming cabinet (60° C) for a maximum of 30 min prior to being served to panelists. Panelists were served in individual cubicles under red incandescent light to prevent bias among the different samples. Each panelist received 2 cuboids from each sample as well as distilled water, apple juice, and unsalted crackers as palate cleansers.

Panelists evaluated each sample on a 150 mm line scale anchored at both ends with descriptive terms. For juiciness and all tenderness attributes (myofibrillar, connective, overall), 0 mm indicated extremely dry and extremely tough, respectively, whereas 150 mm indicated extremely juicy and extremely tender, respectively. For tenderness, the midpoint of the line (75 mm) was considered a neutral response (i.e., neither tough nor tender). Beef flavor notes were similarly noted, with 0 mm signifying "no presence" and 150 mm signifying "very strong presence."

Statistical methods

A split-split plot design was utilized for data analysis. Analysis of variance was conducted using the restricted maximum likelihood method in the mixed procedure of SAS (Statistical Analysis Software, Version 9.3, Cary, NC). Data for strip loins and sirloins were analyzed separately. Sample collection group (retail display groups) and carcasses were included as a block in each model. The analysis of variance model included fixed effects of quality grade (grade) and postmortem aging treatment (aging) and their two-way interaction. The data for the retail display were analyzed as a repeated measure. When the dependent variable was measured multiple times during the retail display period, time (hour) was also included in the model as a fixed effect. The Kenward-Roger approximation was used to calculate denominator degrees of freedom, and peak internal steak temperature served as a covariate when analyzing WBSF and sensory data. In each model, main effects and interactions were analyzed for each fixed effect ($\alpha = 0.05$).

Results

The sample means of carcass traits of the samples collected for this study are presented in Table 1. Among the effects evaluated (aging, grade, and aging × grade), aging was the only significant ($P < 0.05$) variable identified for both strip loin and sirloin steaks. The lack of significance with quality grade is not unexpected, as marbling scores ranged from (Slight[50] to Small[50]), resulting in a close degree of marbling.

Color evaluation

Trained panelists evaluated each sample every 8 h for a 72-h period. USDA quality grade did not impact the color during retail display ($P > 0.05$). There was an aging × hour interaction ($P < 0.05$; Table 2) for trained panel lean color scores of strip loin steaks. Additionally, there was an aging × hour interaction ($P < 0.05$; Table 3) for lean discoloration scores for strip loin steaks. When looking at individual aging periods, there were no differences ($P > 0.05$) in percent lean discoloration scores over the 72-h display for steaks aged from 14 to 49 d; however, steaks aged 63 d had discoloration scores that increased ($P < 0.05$) over the 72-h aging period. There was also an aging × hour interaction ($P < 0.05$; Table 4) for trained panelists scores for external strip loin steak fat color with a decrease ($P < 0.05$) in external fat color ratings as display and aging time increased.

Trained color panelist ratings for sirloin steaks indicated there was an aging × hour interaction ($P < 0.05$) for lean color, percent discoloration, and external fat color scores. In general, lean color ratings for sirloin steaks decreased ($P < 0.05$; Table 5) as both aging time and display time increased, and there was an increase ($P < 0.05$; Table 6) in lean discoloration as both aging time and display time increased for 14, 28, 49, and 63 d aged steaks. Additionally, as both aging time and display time increased, panelist ratings showed a decrease ($P < 0.05$; Table 7) in external fat color scores as sirloin steak external fat became darker.

There was an aging × display interaction ($P < 0.05$) for CIE L^*, a^*, and b^* color readings of strip loin steaks (Tables 8, 9, and 10). Overall, there was a decrease ($P < 0.05$; Table 9) in a^* values as aging and display time increased as strip loin steaks became less red. A similar trend was noted in the b^* values of strip loin steaks as they became less ($P < 0.05$; Table 10) yellow in color with aging. There were no meaningful trends in L^* values for both strip loin and sirloin steaks (Table 11) over aging or display time. Similar to strip loins, there was a decrease ($P < 0.05$; Tables 12 and 13) in both a^* and b^* values in sirloin steaks as aging time and display time increased, indicating steaks became less red and less yellow in color.

Warner-Bratzler shear force

There was no interaction observed ($P > 0.05$) for WBSF values. The shear force of both strip loins

Table 2. Trained color panel lean color scores[1] for strip loin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	110.49^{az}	95.4^{cy}	89.39^{abx}	84.24^{dw}	84.58^{cdxw}	95.10^{ay}	0.72
8	107.62^{az}	98.04^{by}	94.29^{ay}	95.36^{by}	96.71^{ay}	93.94^{ay}	0.63
16	109.87^{az}	102.2^{ay}	92.00^{ax}	98.99^{ay}	93.64^{abx}	90.34^{bx}	0.72
24	103.64^{bz}	100.43^{az}	92.84^{ay}	87.07^{dx}	88.91^{cyx}	86.91^{bx}	0.72
32	106.57^{abz}	97.34^{by}	90.89^{ax}	91.23^{cx}	84.25^{dw}	89.28^{bxw}	0.81
40	99.00^{cz}	96.54^{bzy}	81.43^{dv}	86.37^{dwv}	92.48^{byx}	89.39^{bxw}	0.80
48	101.97^{bz}	94.87^{cy}	86.95^{bxw}	82.94^{dwv}	78.79^{ev}	89.22^{byx}	0.89
56	106.45^{bcz}	96.9^{cy}	85.12^{bcx}	88.26^{dx}	84.25^{dx}	87.68^{bx}	0.89
64	105.01^{bz}	98.41^{ay}	80.68^{dx}	86.26^{dx}	94.19^{ay}	80.99^{cx}	0.88
72	100.72^{cz}	96.5^{bz}	84.89^{cyx}	87.28^{dy}	86.24^{cy}	80.46^{dx}	0.84
SEM	1.59	1.59	1.59	1.59	1.59	1.59	

[1]Panelist marked a 150 mm line scale to indicate their response. 0 mm = very dark red and 150 mm = bright cherry red.

$^{a–c}$Within column, means lacking a common superscript differ ($P < 0.05$).

$^{v–z}$Within row, means lacking a common superscript differ ($P < 0.05$).

SEM = standard error of the mean.

Table 3. Trained color panel percent lean discoloration scores[1] for strip loin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	0.01	0.06	0.09	0.01	0.01	0.01^{d}	0.02
8	0.07	0.05	0.15	0.07	0.05	0.76^{c}	0.16
16	0.01	0.05	0.11	0.08	0.06	0.84^{c}	0.16
24	0.12	0.15	0.16	0.01	0.13	0.75^{c}	0.14
32	0.18^{yz}	0.07^{z}	0.10^{z}	0.09^{z}	0.04^{z}	1.11^{bcy}	0.21
40	0.14^{z}	0.06^{z}	0.16^{z}	0.06^{z}	0.02^{z}	1.21^{bcy}	0.24
48	0.08^{z}	0.18^{z}	0.12^{z}	0.10^{z}	0.11^{z}	1.31^{by}	0.26
56	0.15^{z}	0.12^{z}	0.07^{z}	0.07^{z}	0.21^{z}	1.25^{bcy}	0.24
64	0.06^{z}	0.18^{z}	0.34^{z}	0.02^{z}	0.34^{z}	1.84^{ay}	0.35
72	0.14^{z}	0.12^{z}	0.27^{z}	0.03^{z}	0.27^{z}	2.22^{ay}	0.60
SEM	0.58	0.58	0.58	0.58	0.58	0.58	

[1]Panelist marked a 150 mm line scale to indicate their response. 0 mm = 0% discoloration and 150 mm = 100% discoloration.

$^{a–d}$Within column, means lacking a common superscript differ ($P < 0.05$).

^{y,z}Within row, means lacking a common superscript differ ($P < 0.05$).

SEM = standard error of the mean.

and sirloins improved ($P < 0.05$; Table 14) during aging. Strip loins aged for 49 and 63 d had the lowest ($P < 0.05$) WBSF, but the steaks after 21, 28, and 35 d aging had similar ($P > 0.05$) shear force values. The shear force values were highest ($P < 0.05$) for 14 d aged strip loins. For sirloin steaks, differences ($P < 0.05$) were observed for WBSF between 14 and 35 d aged steaks, with 21 and 28 d aged steaks being similar ($P > 0.05$) to both previously mentioned aging periods. Additionally, sirloin steaks aged for 35 and 63 d were found to be different ($P < 0.05$), with 49 d aged steaks serving as an intermediate for the 2 groups ($P > 0.05$). Both strip loin and sirloin steaks exhibited a decrease ($P < 0.05$; Table 15) in WBSF values after being displayed for 72 h in the retail case regardless of the aging period, indicating only a slight numerical improvement in tenderness as a result of retail display. In summary, tenderness was found to decrease over aging periods, but strip steaks aged 21 to 35 d and sirloins aged 21 and 28 d had no tenderness advantages present, with 63 d being the highest for both treatments.

Table 4. Trained color panel external fat color scores[1] for strip loin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	126.99^{av}	113.07^{aw}	106.39^{axy}	108.98^{bx}	103.01^{cy}	104.36^{ay}	0.39
8	120.00^{cv}	108.14^{cwx}	105.09^{abx}	105.48^{cx}	110.86^{aw}	100.97^{by}	0.42
16	124.31^{bv}	112.96^{abw}	102.89^{by}	115.49^{aw}	108.39^{bx}	102.2^{aby}	0.40
24	112.08^{ev}	112.19^{bv}	103.60^{bw}	104.07^{cw}	105.30^{cw}	98.39^{cx}	0.42
32	116.08^{dv}	115.00^{av}	107.25^{aw}	109.53^{bw}	103.40^{cx}	98.59^{cy}	0.47
40	112.09^{ev}	113.30^{av}	96.42^{cx}	100.48^{dw}	100.16^{dwx}	97.33^{cx}	0.53
48	114.83^{dev}	106.45^{cw}	94.45^{cdx}	103.13^{cw}	97.21^{ex}	94.83^{dx}	0.58
56	117.07^{dv}	110.35^{bcw}	96.13^{cdx}	98.75^{dx}	92.23^{fy}	88.75^{ey}	0.67
64	114.60^{dev}	109.10^{cw}	91.57^{dy}	93.02^{exy}	96.68^{ex}	86.84^{ex}	0.62
72	112.98^{ev}	107.34^{cw}	93.11^{dx}	91.80^{exy}	88.13^{gy}	89.05^{ey}	0.64
SEM	0.93	0.93	0.93	0.93	0.94	0.93	

[1]Panelist marked a 150 mm line scale to indicate their response. 0 mm = 0% discoloration and 150 mm = 100% discoloration.

[a–d]Within column, means lacking a common superscript differ ($P < 0.05$).

[y,z]Within row, means lacking a common superscript differ ($P < 0.05$).

SEM = standard error of the mean.

Table 5. Trained color panel lean color scores[1] for sirloin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	109.64^{aw}	94.01^{ax}	87.20^{aby}	80.37^{bz}	84.2^{bcyx}	92.29 ^{ax}	0.55
8	103.49^{bw}	94.13^{ax}	91.63^{ax}	86.84^{axy}	90.58^{axy}	85.11^{by}	0.58
16	105.97^{abw}	92.76^{abx}	90.83^{abxy}	85.96^{ay}	84.59^{by}	80.11^{cz}	0.61
24	93.66^{cdw}	88.21^{bx}	90.24^{abwx}	77.21^{bcy}	79.76^{cy}	75.97^{cdy}	0.59
32	95.70^{cw}	80.97^{cdy}	86.96^{bx}	78.27^{bcy}	72.09^{dz}	76.97^{cdyz}	0.63
40	87.53^{dw}	82.85^{cx}	75.89^{dy}	74.60^{cy}	80.84^{bcx}	73.85^{dy}	0.74
48	89.54^{dw}	77.05^{dxy}	80.85^{cx}	66.89^{dz}	64.15^{ez}	73.66^{dy}	0.86
56	88.42^{dw}	78.22^{dx}	79.30^{cdx}	68.99^{dz}	65.05^{ez}	71.48^{dy}	0.73
64	88.04^{dw}	79.37^{cdx}	75.96^{dx}	73.92^{cdy}	75.41^{cdxy}	63.15^{ez}	0.72
72	88.14^{dw}	77.64^{dx}	77.34^{cdx}	69.61^{dy}	67.70^{ey}	60.64^{ez}	0.79
SEM	1.32	1.31	1.31	1.31	1.28	1.28	

[1]Panelist marked a 150 mm line scale to indicate their response. 0 mm = very dark red and 150 mm = bright cherry red.

[a–e]Within column, means lacking a common superscript differ ($P < 0.05$).

[v–z]Within row, means lacking a common superscript differ ($P < 0.05$).

SEM = standard error of the mean.

Sensory analysis

Trained sensory panelists ratings indicated that as the steaks were aged there were differences in many of the palatability characteristics. For strip loins, trained panelists' ratings indicated that there was tenderness improvement ($P < 0.05$; Table 16) for all 3 tenderness attributes (myofibrillar, connective tissue, and overall) from 14 d aged to 63 d aged. Juiciness ratings in strip loin steaks decreased ($P < 0.05$) by 21 d aging period, and the 49 and 63 d aging period were similar to 14 d ($P > 0.05$). The flavor attributes of strip loin steaks indicated there were no differences ($P > 0.05$) between aging periods for both beef flavor and buttery/beef fat flavor; however, panelists found differences ($P < 0.05$) in sour/acidic, oxidized, and livery/organy flavors. Strip loin steaks aged for 49 and 63 d were similar ($P > 0.05$), with the greatest ($P < 0.05$) presence of sour acidic flavor. Trained panelist ratings for metallic/bloody flavor showed panelists detected the greatest amount ($P < 0.05$) of metallic/bloody flavor in strip

Table 6. Trained color panel percent lean discoloration scores[1] for sirloin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	0.01^{c}	0.03^{b}	0.02^{b}	0.01^{a}	0.01^{c}	0.07^{cd}	0.01
8	0.03^{c}	0.04^{b}	0.10^{b}	0.08^{a}	0.01^{c}	0.21^{cd}	0.04
16	0.12^{c}	0.15^{ab}	0.09^{b}	0.01^{a}	0.01^{c}	0.12^{cd}	0.04
24	0.09^{c}	0.19^{ab}	0.19^{b}	0.06^{a}	0.01^{c}	0.06^{d}	0.04
32	0.15^{c}	0.30^{ab}	0.31^{ab}	0.05^{a}	0.18^{c}	0.11^{cd}	0.05
40	0.19^{c}	0.11^{bz}	0.19^{de}	0.06^{a}	0.09^{c}	0.1^{cd}	0.04
48	0.11^{c}	0.38^{ab}	0.11^{b}	0.08^{a}	0.19^{c}	0.49^{c}	0.06
56	1.26^{awx}	0.30^{aby}	0.12^{by}	0.04^{axy}	0.98^{bx}	1.61^{bw}	0.14
64	1.57^{ax}	0.11^{bz}	0.59^{ay}	0.04^{axy}	1.53^{ax}	2.15^{aw}	0.18
72	0.81^{bx}	0.57^{ax}	0.39^{abx}	0.40^{ax}	1.83^{aw}	2.10^{aw}	0.16
SEM	0.13	0.13	0.13	0.13	0.13	0.13	

[1]Panelist marked a 150 mm line scale to indicate their response. 0 mm = 0% discoloration and 150 mm = 100% discoloration.

[a–d]Within column, means lacking a common superscript differ ($P < 0.05$).

[w–z]Within row, means lacking a common superscript differ ($P < 0.05$).

SEM = standard error of the mean.

Table 7. Trained color panel external fat color scores[1] for sirloin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	117.20^{av}	103.29^{aw}	100.34^{ax}	94.76^{by}	93.27^{ay}	93.69^{ay}	0.34
8	113.11^{bv}	100.49^{abw}	100.83^{aw}	94.00^{bw}	96.06^{ax}	87.17^{by}	0.54
16	116.58^{av}	101.37^{abw}	100.30^{av}	98.43^{ax}	94.75^{ax}	84.49^{by}	0.47
24	103.52^{dv}	97.57^{bx}	101.60^{aw}	88.75^{cx}	89.88^{by}	80.05^{cz}	0.48
32	108.13^{cv}	95.93^{bcw}	101.03^{ax}	92.75^{bx}	84.8^{cx}	78.50^{cy}	0.53
40	104.58^{cdv}	98.85^{bw}	88.90^{bcw}	87.06^{cx}	88.55^{bcx}	73.95^{dy}	0.71
48	105.4^{cdv}	91.88^{cw}	89.98^{bcw}	81.66^{dx}	77.43^{dy}	71.20^{dey}	0.66
56	102.49^{dv}	92.85^{cw}	90.79^{bw}	77.80^{dx}	68.33^{ey}	66.90^{ey}	0.74
64	99.81^{dv}	96.32^{cv}	85.73^{cw}	81.71^{dw}	74.86^{dx}	61.45^{fy}	0.71
72	101.22^{dv}	91.81^{dw}	84.98^{cx}	71.57^{ey}	67.47^{ey}	65.88^{ey}	0.77
SEM	1.16	1.15	1.15	1.15	1.12	1.12	

[1]Panelist marked a 150 mm line scale to indicate their response. 0 mm = 0% discoloration and 150 mm = 100% discoloration.

[a–f]Within column, means lacking a common superscript differ ($P < 0.05$).

[v–z]Within row, means lacking a common superscript differ ($P < 0.05$).

SEM = standard error of the mean.

loin steaks aged 14 d with all other treatments being lower. For both oxidized and livery/organy flavors, panelist ratings increased as aging time increased, wherein strip loin steaks aged to 63 d exhibited the greatest ($P < 0.05$) oxidized and livery/organy flavors.

Similarly to strip loin steaks, sirloin steak ratings for myofibrillar tenderness and connective tissue tenderness increased ($P < 0.05$; Table 17) from 14 to 63 d aged, indicating that steaks became more tender as aging time increased. However, this was not replicated in overall tenderness ratings because there were no differences ($P > 0.05$) between aging periods. Panelist ratings showed a decrease ($P < 0.05$) in juiciness from 21 d aged to 49 and 63 d aged. There were no differences ($P > 0.05$) in panelist ratings for buttery/beef fat flavor and metallic/bloody flavor across the aging periods. Beef flavor decreased ($P < 0.05$) from aging period 35 to 63 d for sirloin steaks. Additionally, livery/organy and oxidized flavor increased ($P < 0.05$) from 14 to 63 d aged for sirloin steaks. Overall, sirloin

Table 8. Lean L^{*1} values for strip loin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	34.50^{cy}	37.62^{ax}	35.99^{by}	34.51^{aby}	40.70^{aw}	34.80^{ay}	0.22
8	35.31^{bcw}	34.90^{bwx}	35.62^{bw}	34.25^{bwx}	33.62^{bcx}	34.68^{awx}	0.21
16	35.69^{bw}	34.52^{bwx}	35.79^{bw}	34.39^{abwx}	33.41^{bcx}	34.79^{awx}	0.23
24	34.39^{aw}	34.71^{bx}	37.69^{aw}	31.76^{cy}	33.20^{cxy}	34.74^{ax}	0.26
32	34.07^{cw}	34.98^{bw}	34.86^{bw}	32.26^{cx}	33.82^{bcwx}	34.04^{aw}	0.25
40	38.54^{aw}	35.01^{bxy}	35.69^{bx}	33.63^{by}	34.37^{bcxy}	34.44^{axy}	0.24
48	34.18^{cxy}	38.15^{aw}	35.36^{bx}	33.19^{bcy}	34.04^{bcxy}	34.47^{axy}	0.24
56	35.00^{bcw}	34.32^{bw}	35.54^{bw}	35.60^{aw}	34.50^{bw}	34.78^{aw}	0.23
64	34.31^{cw}	33.96^{bw}	35.37^{bw}	31.24^{cx}	33.93^{bcw}	34.17^{aw}	0.24
72	37.51^{aw}	34.66^{bx}	35.47^{bx}	32.01^{cy}	33.81^{bcx}	34.19^{ax}	0.24
SEM	0.43	0.43	0.43	0.43	0.43	0.43	

[1]L^* = lightness; 0 = black and 100 = white.

$^{a–c}$Within column, means lacking a common superscript letter differ ($P < 0.05$).

$^{w–z}$Within row, means lacking a common superscript letter differ ($P < 0.05$).

SEM = standard error of the mean.

Table 9. Lean a^{*1} values for strip loin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	11.96^{cw}	12.08^{aw}	12.65^{bw}	11.48^{bwx}	13.23^{aw}	10.98^{ax}	0.13
8	13.25^{a}	12.49^{a}	13.58^{a}	12.59^{a}	12.24^{b}	11.40^{a}	0.13
16	12.80^{b}	12.15^{a}	13.07^{ab}	11.83^{b}	11.4^{c}	10.99^{a}	0.12
24	12.87^{bw}	11.93^{bw}	13.14^{aw}	11.44^{bw}	11.67^{cw}	10.46^{bx}	0.12
32	11.93^{cw}	11.91^{bw}	12.16^{bcwx}	11.34^{bx}	11.03^{cdw}	9.79^{cx}	0.11
40	12.72^{bw}	11.36^{bcx}	12.02^{cwx}	10.99^{bcx}	10.57^{dx}	9.43^{cy}	0.1
48	11.46^{dwx}	11.97^{abw}	11.76^{cwx}	10.91^{cwx}	10.53^{dx}	9.34^{cdy}	0.09
56	11.04^{dewx}	11.11^{cwx}	11.27^{dwx}	12.24^{aw}	10.23^{dx}	8.87^{ey}	0.1
64	11.19^{dw}	11.01^{cww}	11.29^{dw}	10.23^{dwx}	9.54^{ex}	8.61^{ey}	0.09
72	12.04^{cw}	10.95^{cwx}	10.93^{dex}	10.05^{dy}	9.35^{ey}	8.41^{efz}	0.08
SEM	0.22	0.22	0.22	0.22	0.22	0.22	

[1]a^* = redness; −60 = green and 60 = red.

$^{a–c}$Within column, means lacking a common superscript letter differ ($P < 0.05$).

$^{w–z}$Within row, means lacking a common superscript letter differ ($P < 0.05$).

SEM = standard error of the mean.

steaks had higher panelist ratings for off-flavor notes, namely oxidized, than strip loin steaks aged the same number of days.

Discussion

Beef color is often used as an indicator of both wholesomeness and freshness, with a bright cherry red color appearing most attractive to consumers in retail settings (Henchion et al., 2017).

In the current study, both aging and retail display time were key components in the color stability of both strip loin and sirloin steaks, regardless of carcass quality grade (USDA Choice vs. Select). Previous research had reported quality grade × display day interaction for L^* (lightness), a^* (redness), visual panel surface redness, and discoloration scores of beef semitendinosus muscle (Van Bibber-Krueger et al., 2020). However, these samples were aged up to 18 d only, unlike in the current study, in which the muscles were aged up to 63 d. Moreover, in the current study, only a small range of quality grades were examined (Slight[50] to Small[50]), which might have contributed to the fact that there were no differences observed among the quality grades.

Table 10. Lean *b**[1] values for strip loin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	13.66^{cdxy}	14.03^{abx}	14.64^{abwx}	13.63^{bxy}	15.14^{aw}	13.19^{ay}	0.08
8	15.42^{aw}	14.13^{ax}	15.03^{aw}	14.19^{ax}	13.92^{bxy}	13.34^{ay}	0.09
16	13.91^{cwx}	13.55^{bcx}	14.42^{bw}	13.56^{bx}	13.11^{cx}	13.08^{abx}	0.09
24	14.54^{bwx}	13.47^{bcx}	14.69^{abw}	12.83^{cxy}	13.47^{bcx}	12.61^{by}	0.09
32	13.34^{dwx}	13.58^{bcwx}	13.77^{cw}	12.68^{cdx}	13.14^{cx}	11.90^{cy}	0.09
40	14.33^{bw}	13.24^{cx}	13.94^{cw}	12.94^{cx}	12.91^{cx}	11.73^{cdy}	0.08
48	13.16^{deex}	13.69^{bw}	13.72^{cw}	12.76^{cx}	12.78^{cz}	11.74^{cy}	0.07
56	12.78^{ex}	12.94^{cdx}	13.26^{dx}	13.82^{abw}	12.86^{cx}	11.49^{cdy}	0.08
64	13.01^{dew}	12.93^{cdw}	13.28^{dw}	12.30^{dx}	11.92^{ex}	11.31^{dy}	0.08
72	13.75^{cdw}	12.83^{dx}	13.12^{dx}	12.25^{dy}	11.96^{dy}	11.23^{ez}	0.07
SEM	0.15	0.15	0.15	0.15	0.15	0.15	

[1]*b** = yellowness; −60 blue and 60 = yellow.

$^{a–e}$Within column, means without a common superscript letter differ ($P < 0.05$).

$^{w–z}$Within row, means without a common superscript letter differ ($P < 0.05$).

SEM = standard error of the mean.

Table 11. Lean *L**[1] values for sirloin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	37.33^{dey}	39.64^{cw}	36.64^{dy}	35.45^{bz}	43.30^{cw}	36.42^{y}	0.27
8	37.48^{d}	$36.29^{ de}$	36.62^{d}	36.03^{b}	36.48^{d}	36.63	0.24
16	38.53^{cw}	36.90^{dwy}	36.36^{dy}	35.41^{by}	35.11^{ey}	36.66^{y}	0.23
24	40.03^{bw}	36.46^{dewy}	38.29^{cy}	33.97^{cdy}	35.41^{dey}	36.19^{y}	0.25
32	37.01^{de}	36.20^{de}	35.87^{de}	35.33^{bc}	35.99^{de}	36.38	0.26
40	41.38^{aw}	36.29^{dex}	35.05^{ex}	35.06^{bcx}	35.6^{dex}	35.85^{x}	0.24
48	36.82^{dew}	40.48^{cx}	35.70^{dex}	34.19^{cx}	36.65^{dx}	36.94^{x}	0.27
56	36.54^{de}	36.27^{de}	35.79^{de}	37.45^{a}	36.10^{de}	35.99	0.26
64	36.39^{ew}	35.59^{ew}	35.69^{dew}	31.65^{ey}	36.14^{dw}	36.36^{w}	0.24
72	39.55^{bw}	36.47^{dex}	35.58^{dex}	33.23^{dy}	36.25^{dx}	36.87^{x}	0.25
SEM	0.49	0.49	0.49	0.49	0.48	0.48	

[1]*L** = lightness; 0 = black and 100 = white.

$^{a–e}$Within column, means lacking a common superscript letter differ ($P < 0.05$).

$^{w–z}$Within row, means lacking a common superscript letter differ ($P < 0.05$).

SEM = standard error of the mean.

Both strip loin and sirloin steaks generally presented a slight increase in *a** values in the first 8 h measurement, and then the *a** values began to decline. Generally, as aging and display time increased, there was a decrease in redness (*a** values) for both cuts. Although the steaks in this study had adequate bloom time, Lee et al. (2008) suggested that *gluteus medius* steaks could bloom up to 120 min postfabrication. Previously, Colle et al. (2015) observed that the *a** value and visual lean color of *gluteus medius* decreased with aging time with no increase on day 1. Although neither strip loin nor sirloin steaks experienced extensive surface discoloration during the study, there was an increase in visible lean discoloration, and the external fat became darker as aging time and display period increased. King et al. (2012) also reported that steaks aged for 35 d and packaged in polyvinyl chloride had lower *a** values when compared with 14-d aged samples under 11-d retail display conditions. Similarly, English et al. (2016) reported lower redness (*a** values) for steaks aged for 62 d compared to steaks aged for 21 d. Overall, these results indicate that aging adversely affected the redness of steaks during retail display.

Table 12. Lean a^{*1} values for sirloin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	16.23^{bcvw}	15.74^{abw}	13.92^{bx}	14.77^{bx}	16.87^{av}	14.20^{ax}	0.36
8	17.79^{av}	16.12^{aw}	14.59^{ax}	15.66^{awx}	14.97^{bx}	14.38^{ax}	0.14
16	16.06^{cv}	15.29^{w}	13.73^{bxy}	14.39^{bx}	14.00^{cx}	13.08^{by}	0.13
24	16.57^{bv}	14.84^{bw}	13.65^{bx}	13.71^{cx}	13.36^{dx}	12.34^{cy}	0.13
32	14.47^{ev}	14.35^{cv}	12.66^{cw}	12.85^{dw}	12.51^{ew}	11.41^{dx}	0.1
40	15.23^{dv}	13.53^{dw}	12.26^{dx}	12.57^{dx}	11.56^{y}	10.96^{ez}	0.1
48	13.41^{fv}	13.78^{dv}	12.08^{ew}	12.09^{ew}	11.46^{fx}	10.28^{fy}	0.1
56	12.80^{gv}	12.46^{ev}	11.57^{fw}	12.74^{dv}	10.85^{gx}	9.80^{gy}	0.1
64	16.23^{bcvw}	15.74^{abw}	13.92^{bx}	14.77^{bx}	16.87^{av}	14.20^{ax}	0.09
72	17.79^{av}	16.12^{aw}	14.59^{ax}	15.66^{awx}	14.97^{bx}	14.38^{ax}	0.08
SEM	0.24	0.24	0.24	0.24	0.24	0.24	

[1]a^* = redness; –60 = green and 60 = red.

[a–i]Within column, means without a common superscript letter differ ($P < 0.05$).

[v–z]Within row, means without a common superscript letter differ ($P < 0.05$).

SEM = standard error of the mean.

Table 13. Lean b^{*1} values for sirloin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Aging period (d)						
Display period (h)	14	21	28	35	49	63	SEM
0	17.50^{cx}	17.34^{ax}	15.58^{aby}	16.25^{aby}	18.32^{aw}	16.02^{ay}	17.50^{cx}
8	19.04^{aw}	17.33^{ax}	15.93^{ay}	16.77^{axy}	16.43^{by}	16.23^{ay}	19.04^{aw}
16	17.41^{cw}	16.60^{bx}	15.28^{by}	15.90^{by}	15.77^{cy}	15.29^{by}	17.41^{cw}
24	18.20^{bw}	16.40^{bcx}	15.34^{bxy}	15.30^{cxy}	15.46^{cdy}	14.92^{by}	18.20^{bw}
32	16.23^{dw}	16.07^{cw}	14.51^{cxy}	14.66^{dxy}	15.10^{dx}	14.23^{cxy}	16.23^{dw}
40	17.48^{cw}	15.70^{cx}	14.18^{cdyz}	14.65^{dy}	14.45^{eyz}	13.92^{cdz}	17.48^{cw}
48	15.76^{dew}	16.23^{bcw}	14.21^{cdxy}	14.48^{dx}	14.53^{ex}	13.61^{dy}	15.76^{dew}
56	15.35^{ew}	15.13^{dw}	13.94^{dxy}	15.40^{cw}	14.19^{ex}	13.32^{dey}	15.35^{ew}
64	15.32^{ew}	15.09^{dw}	13.62^{dx}	13.62^{ex}	13.69^{fx}	13.07^{ex}	15.32^{ew}
72	16.07^{dw}	14.84^{dx}	13.60^{dy}	13.49^{ey}	13.44^{fy}	12.45^{fz}	16.07^{dw}
SEM	17.50^{cx}	17.34^{ax}	15.58^{aby}	16.25^{aby}	18.32^{aw}	16.02^{ay}	17.50^{cx}

[1]b^* = yellowness; −60 blue and 60 = yellow.

[a–e]Within column, means without a common superscript letter differ ($P < 0.05$).

[w–z]Within row, means without a common superscript letter differ ($P < 0.05$).

SEM = standard error of the mean.

Table 14. Warner-Bratzler shear force (WBSF) value (kilograms) of strip loin and sirloin steaks aged for 14, 21, 28, 35, 49, or 63 d

	Aging period (d)							
Muscle	14	21	28	35	49	63	SEM	P value
Strip loin	3.86^{a}	3.49^{b}	3.44^{b}	3.27^{b}	2.99^{c}	2.93^{c}	0.15	<0.01
Sirloin	4.08^{a}	4.21^{ab}	4.02^{ab}	3.78^{b}	3.48^{bc}	3.20^{c}	0.13	<0.01

[a–c]Within muscle, means lacking a common superscript differ ($P < 0.05$).

SEM = standard error of the mean.

There were no discernable trends across all aging periods over the display period in L^* values for both strip loin and sirloin steaks regardless of aging time or display period. In a similar study by Colle et al. (2015), assessing color of aged strip loin and sirloin steaks over a 4-d display period reported an

Table 15. Warner-Bratzler shear force (WBSF) values (kilograms) of strip loin and sirloin steaks displayed for 0 or 72 h

	Display time (h)		
Muscle	0	72	P value
Strip loin	3.3 ± 0.1^{a}	3.1 ± 0.1^{b}	<0.0001
Sirloin	3.8 ± 0.1^{a}	3.5 ± 0.1^{b}	<0.0001

^{a,b}Within muscle, means lacking a common superscript differ ($P < 0.05$).

aging × display interaction for L^* value of strip loin steaks. These researchers reported that L^* values generally increased from 0 to 1 d of display in product aged less than 14 d, and there was a general decrease in L^* values over the display period with the longer aging times. This varies slightly from the current study, in which only aging periods 21, 35, and 49 d showed a decrease in L^* values over the display period in strip loin steaks. The steaks aged 14 d had increasing L^* values, and steaks aged for both 28 and 63 d had no differences in L^* values over the 72-h display period. In a study by Lee et al. (2008) that evaluated the effect of vacuum aging on bloom development of sirloin steaks, there were no differences in L^* values of steaks aged up to 35 d.

The WBSF results of this study are in agreement with previous studies that have demonstrated that shear force decreases with an increase in aging time (Gruber et al., 2006; Dixon et al., 2012; Colle et al., 2015). Interestingly, all the steaks evaluated showed improvement in tenderness regardless of the quality grade or cut utilized over the display period. These results are in agreement with previous studies that reported that USDA Select strip loin aged for 14 d receive a benefit in tenderness. Although WBSF values decreased ($P <$ 0.05) over aging periods, no tenderness improvements could be identified with panels. Similar results have been reported, suggesting that extended aging for sirloins may not result in tenderness differences for the consumers (Bratcher et al., 2005; Gruber et al., 2006; Colle et al., 2015). In addition, Bratcher et al. (2005) reported that quality grade influenced WBSF of muscles during 28 d aging. Furthermore, Miller et al. (1997) reported that USDA quality grade did not affect WBSF of beef strip loin aged for 7 or 14 d. During the trained sensory panels in the current study, the panelists were unable to detect overall differences in tenderness of sirloin steaks with aging (Table 17). Similar results have been reported by Laster et al. (2008), wherein consumer sensory attributes were not affected by aging period for top sirloin steaks. Instead, there is potential for the negative flavor notes to be more detectable to consumers. Because there was less than a 1 kg reduction of WBSF values in steaks aged 63 d compared to 14 d aged steaks, the off-flavor development may not be worth the slight increases in tenderness in strip loin and sirloin steaks. Although there was a statistically significant decrease ($P < 0.05$; Table 15) in WBSF values during the 3 d of the retail display, these were numerically small differences and may not have an impact on consumer perception of tenderness. However, these data demonstrate that tenderness continues to improve during the display period.

Some recent studies indicated that flavor is also very important in providing a quality eating experience. For example, O'Quinn et al. (2018) reported that

Table 16. Trained sensory panel ratings[1] for strip loin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Sensory attribute									
Aging period (d)	Myofibrillar tenderness	Connective tissue tenderness	Overall tenderness	Juiciness	Beef flavor	Buttery/beef fat flavor	Sour/acidic	Oxidized	Metallic/bloody	Livery/organy
14	88.76^{c}	96.09^{b}	98.17^{b}	80.04^{a}	83.09	58.09	8.36^{b}	15.42^{c}	4.06^{c}	1.75^{c}
21	86.34^{c}	98.76^{b}	89.84^{b}	75.85^{b}	84.03	60.45	7.79^{b}	17.23^{bc}	2.09^{ab}	0.66^{c}
28	87.60^{c}	97.45^{b}	89.69^{b}	73.31^{b}	84.47	57.36	8.4^{b}	17.82^{bc}	2.00^{ab}	1.17^{c}
35	93.78^{b}	105.6^{a}	99.56^{a}	77.36^{ab}	82.09	59.61	11.1^{b}	21.71^{bc}	3.09^{ab}	1.5^{b}
49	96.73^{ab}	105.13^{a}	98.12^{a}	78.77^{ab}	84.24	59.72	16.73^{a}	22.22^{b}	3.70^{a}	1.8^{b}
63	98.74^{a}	108.87^{a}	101.51^{a}	76.71^{ab}	81.96	56.53	22.13^{a}	31.42^{a}	1.68^{b}	3.84^{a}
SEM	1.60	1.46	1.55	1.38	1.17	1.26	1.00	2.37	0.52	0.29
***P*value**	<0.01	<0.01	<0.01	<0.01	0.55	0.15	<0.01	<0.01	0.04	0.01

[1]Panelists marked a 150 mm line scale to indicate their response. 0 mm = extremely tough, extremely dry, no flavor presence and 150 mm = extremely tender, extremely juicy, very strong flavor presence.

$^{a–e}$Within column, means lacking a common superscript differ ($P < 0.05$).

SEM = standard error of the mean.

Table 17. Trained sensory panel ratings[1] for sirloin steaks aged for 14, 21, 28, 35, 49, or 63 d and displayed for 72 h

	Sensory attribute									
Aging period (d)	Myofibrillar tenderness	Connective tissue tenderness	Overall tenderness	Juiciness	Beef flavor	Buttery/beef fat flavor	Sour/ acidic	Oxidized	Metallic/ bloody	Livery/ organy
14	82.31[b]	89.11[c]	85.95	75.93[ab]	80.32[a]	47.97	15.97[c]	31.42[b]	4.70	2.52[d]
21	85.25[b]	95.64[b]	87.53	84.25[a]	79.99[a]	47.72	16.04[c]	32.81[b]	5.66	5.70[bc]
28	85.4[b]	97.81[ab]	88.31	73.43[ab]	79.29[a]	46.84	17.37[c]	36.50[ab]	5.30	4.42[cd]
35	85.37[b]	94.87[b]	91.3	74.12[ab]	79.54[a]	47.67	18.25[c]	37.52[ab]	5.77	7.72[ab]
49	86.41[b]	95.98[b]	88.3	72.18[b]	78.36[ab]	46.34	23.69[b]	39.95[ab]	5.72	7.04[abc]
63	91.57[a]	101.65[a]	93.51	71.53[b]	75.87[b]	45.65	32.97[a]	41.39[a]	7.63	9.85[a]
SEM	1.76	2.00	1.57	3.40	1.02	1.96	1.76	2.32	0.68	0.62
***P* value**	0.01	<0.01	0.10	0.02	0.03	0.15	<0.01	0.01	0.45	<0.01

[1]Panelists marked a 150 mm line scale to indicate their response. 0 mm = extremely tough, extremely dry, no flavor presence and 150 mm = extremely tender, extremely juicy, very strong flavor presence.

[a–e]Within column, means lacking a common superscript differ ($P < 0.05$).

SEM = standard error of the mean.

flavor accounted for 49.4% of the overall palatability compared to tenderness (43.3%) and juiciness (7.4%). Interestingly, quality grade did not influence the flavor profile of strip loin and sirloins during the extended aging. Although Miller et al. (1997) found a difference between USDA Select and Choice steaks, the current investigation examined a narrow range of marbling scores (Slight^{50} to Small^{50}), which might have contributed to the lack of differences due to quality grade. In the current study, as aging time increased, there was an increase in certain flavors reported by trained panelists. In both strip loin and sirloin steaks, there was a significant increase in sour/acidic, oxidized, and livery/organy flavors as aging time increased. Although Colle et al. (2015) assessed flavor of aged strip loins and sirloins using consumer panelists, they found no differences in flavor likeness in either cut over the aging periods. Garmyn et al. (2020) evaluated strip loins aged up to 84 d and reported a significant decrease in flavor liking and overall liking as postmortem aging time increased. Similar decrease in flavor liking and overall liking have been reported in previous studies as well (Juárez et al., 2010), which is also in agreement with the results of the current study.

Conclusions

Meat color, tenderness, and flavor are important attributes determining consumer purchase decisions and eating satisfaction. Although extended aging could improve the tenderness of beef products, it could adversely affect the shelf life and eating quality. The results of the current study indicated that quality grade did not affect aging response during extended aging. Overall, there was an improvement in tenderness with aging with only limited improvement beyond 14 d for the Choice and Select strip loins and sirloins used in the current study. However, the retail display shelf life (color) was adversely affected by aging. Moreover, the incidence of off-flavor increased with aging, especially after 49 d for strip loin steaks (oxidized and sour/acidic flavors) and after 21 d for sirloin steaks (livery/organy flavor). Interestingly, although not statistically compared, both strip loin steaks and sirloin steaks behaved in a similar way throughout the study for lean discoloration. However, the sirloin steaks of all aging treatments following retail display had increased off-flavor and oxidation. The beef industry needs to consider all these factors when aging beef muscles for an extended period to ensure proper utilization of products.

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