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Postmortem Aging Time and Marbling Class Effects on Flavor of Three Muscles From Beef Top Loin and Top Sirloin Subprimals

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Abstract: This study evaluated postmortem aging time and marbling class effects on flavor attributes of *longissimus lumborum*, *gluteus medius*, and *biceps femoris* steaks. Carcasses selected to have Lower Small (Small^{00} to Small^{49}; $n = 50$) or Upper Slight (Slight^{50} to Slight^{99}; $n = 50$) marbling were assigned to aging treatments (14, 21, 28, or 35 d) in an incomplete block arrangement. A trained sensory panel evaluated *longissimus lumborum*, *gluteus medius*, and *biceps femoris* steaks for tenderness, juiciness, and 31 flavor notes. Tenderness increases with aging time were linear ($P < 0.001$) in *longissimus lumborum* and *gluteus medius* steaks and quadratic ($P = 0.001$) in *biceps femoris* steaks. Aging response of rancid flavor in *longissimus lumborum* steaks was cubic ($P = 0.01$), whereas the aging response of bloody/serumy flavor in *biceps femoris* steaks was quadratic ($P = 0.03$). Compared with Upper Slight marbling, carcasses with Lower Small marbling produced *longissimus lumborum* steaks with greater ($P < 0.01$) beef flavor and lesser ($P = 0.001$) bitter flavor, *gluteus medius* steaks with greater ($P = 0.05$) brown/roasted flavor, and *biceps femoris* steaks with greater ($P = 0.02$) fat-like flavor, although differences were small. Principal component analysis indicated that bloody/serumy, sour, metallic, and bitter flavor attributes were the strongest contributors to a factor explaining 38% of *longissimus lumborum* flavor variation. Barnyard, bitter, sour, rancid, and bloody/serumy were the greatest contributors to a principal component explaining 41% of *gluteus medius* flavor. Barnyard, rancid, sour, bloody/serumy, and bitter were contributors to a component explaining 63% of *biceps femoris* sirloin cap flavor variance. Sample score plots indicated that neither aging time nor marbling class was associated with principal components and identified production lot as contributing to principal components explaining flavor variation in all 3 muscles. Results indicate that, in strip loin and top sirloin subprimals from carcasses with Upper Slight and Lower Small marbling scores, aging time and marbling class had little impact on beef flavor. Thus, increased aging times could be used to enhance tenderness with no adverse effects on other important palatability attributes.

Key words: aging, beef, flavor, marbling, tenderness
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Introduction

Meeting consumers' expectations for beef palatability continues to be a challenge for foodservice and retail operators. Insufficient tenderness has been identified as a primary challenge in meeting these expectations (Boleman et al., 1997; Neely et al., 1998; Miller et al., 2001; Shackelford et al., 2001). Thus, strategies for ensuring the tenderness of meat products continue to be heavily utilized. Of these strategies, postmortem aging is among the simplest and most effective available, and extended aging times (beyond 14 d postmortem) are widely used (Voges et al., 2007; Martinez et al., 2017), particularly in premium product lines. Previous research from our laboratory has demonstrated degradation of cytoskeletal proteins resulting in increased tenderization through 42 d of refrigerated storage (King et al., 2009a, 2009b, 2009c).

Despite such emphasis on aging as a method to improve tenderness, relatively little effort has been directed to the effects of aging on other important meat quality attributes, particularly for aging times greater than 21 d. Beef flavor attributes are of importance in determining eating satisfaction (Goodson et al., 2002; Behrends et al., 2005). The majority of studies using trained sensory panels to evaluate beef palatability only report beef flavor intensity and off-flavor intensity, making it difficult to fully characterize the effects of certain treatments on beef flavor. The development of a standardized lexicon (Adhikari et al., 2011) enables greater characterization of beef flavor. The present experiment was conducted to examine the effects of postmortem aging of 14 to 35 d on beef flavor, tenderness, and juiciness attributes in 3 muscles from carcasses representing 2 classes of marbling scores.

Materials and Methods

Chilled carcasses used in this experiment were selected from a commercial packing facility. Thus, animal care and use approval was not obtained for this experiment.

Sample selection and handling

Carcasses ($N = 100$) were selected from a commercial packing facility, approximately 36 h postmortem, as they were presented for grading. Using the output of the US Meat Animal Research Center beef image analysis grading system (VBG 2000, E + V Technology GmbH, Oranienburg, Germany; Shackelford et al., 2003), carcasses were selected to have marbling scores that were either between Slight^{50} and Slight^{99} (Upper Slight; $n = 50$) or between Small^{00} and Small^{49} (Lower Small; $n = 50$). Carcasses were selected on 3 production days (2 to 3 wk apart, $n = 40$, 40, and 20, respectively), and although production lot was not considered during carcass selection, this information was recorded for each carcass. The beef, loin, strip loin (similar to Institutional Meat Purchase Specifications [IMPS] #180) and beef, loin, top sirloin butt (similar to IMPS #184 [USDA, 2014]) from both sides of the carcass were assigned to postmortem aging times of 14, 21, 28, or 35 d in an incomplete block arrangement so that each pair-wise combination of aging times occurred an equal number of times within a carcass. Moreover, carcass sides were assigned to aging times so that, within each aging time comparison, the number of left and right sides assigned to each aging time was as balanced as possible. For example, 17 carcasses had cuts assigned to both the 14- and 28-d aging times, of which 8 carcasses had cuts from the left side assigned to the 14-d aging period. After fabrication, each subprimal was vacuum packaged, sorted into its respective aging time, boxed, palletized, and shipped under refrigeration (−2°C) to the US Meat Animal Research Center abattoir, where they were aged (−1°C) for the prescribed time.

After aging, subprimals were unpackaged, and the top sirloin butt was separated into the *gluteus medius* (with the *gluteus accessorius* removed; similar to IMPS #184B [USDA, 2014]) and the sirloin cap (i.e., proximal portion of the *biceps femoris*; similar to IMPS #184D [USDA, 2014]). A 1.27-cm-thick steak and a 2.54-cm-thick steak were removed from the anterior aspect of the *gluteus medius* for use in a concurrent experiment. A 2.54-cm-thick steak was removed from the most posterior aspect of each *biceps femoris* sirloin cap for use in a concurrent experiment. A 1.27-cm-thick steak and two 2.54-cm-thick steaks were removed from the anterior portion of each *longissimus lumborum* for use in a concurrent experiment. The remaining portion of each muscle was re-vacuum packaged and frozen (−20°C). Frozen muscles were subsequently unpackaged and cut into 2.54-cm-thick steaks ($n = 2$ [*longissimus lumborum*], $n = 2$ [*biceps femoris* sirloin cap], and $n = 1$ [*gluteus medius*]) on a band saw. Frozen steaks were then vacuum packaged and stored frozen (−20°C) until sensory analysis.

Sensory panel analysis

To limit the samples that had to be evaluated on each day, sensory analysis was conducted separately for *longissimus lumborum*, *gluteus medius*, and *biceps femoris* sirloin cap steaks. On each of 60 sensory panel evaluation days (one session per day), panelists were presented samples from each aging time and marbling class combination for one of the muscles. All samples of one muscle were evaluated before beginning evaluation of the next muscle.

Two steaks from each *longissimus lumborum* and *biceps femoris* sirloin cap were combined to provide samples for sensory panel analysis of those muscles. One *gluteus medius* steak from each top sirloin was evaluated. Steaks were thawed (5°C) for 24 h before cooking to an internal temperature of 70°C on an electric, conveyorized belt grill as described by Wheeler et al. (1998) for sensory panel analysis. Internal steak temperatures were monitored before and after cooking by inserting a needle thermocouple probe attached to a handheld thermometer (Cole-Parmer, Vernon Hills, IL) into the geometric center of the steak. After cooking, exterior fat and connective tissue were removed, and steaks were sectioned into 1.27 cm × 1.27 cm × steak thickness cubes, which were mixed before 2 were randomly selected for each panelist. Steaks were sampled and served to panelists immediately after reaching maximum cooked temperature.

A highly experienced descriptive attribute panel (at least 8 panelists on a given sensory evaluation day) that had been recruited and trained in accordance with the guidelines of Cross et al. (1978) and the American Meat Science Association (2016) received additional training in evaluating beef flavor using the lexicon, references, and definitions described by Adhikari et al. (2011) during 22 1-h sessions. Panelists rated overall tenderness and juiciness on an 8-point scale (1 = extremely tough or dry; 8 = extremely tender or juicy). Panelists also evaluated the flavor attributes of beef flavor identity, brown/roasted, bloody/serumy, fat-like, metallic, liver-like, green-hay-like, umami, overall sweet, sweet, sour, salty, bitter, barnyard, burnt, rancid, heated oil, chemical, apricot, green, asparagus, cumin, floral, beet, chocolate/cocoa, dairy, buttery, cooked milk, sour milk/sour dairy, stale refrigerator, and warmed over on a 15-point scale (0 = not detectable; 15 = extremely strong; Table 1). To avoid panel fatigue, panelists were not asked to evaluate the odor attributes described by Adhikari et al. (2011) in this study. On each of 60 panel evaluation days, panelists were given a warm-up sample of the same muscle being evaluated that day. Panelists then rated 5 samples, were given a 10-min break, and then rated 5 additional samples. Only one panel session was conducted on each evaluation day. Sample order was randomized within

Table 1. Description of beef flavor lexicon attributes evaluated

Attribute	Description
Beef identity	Amount of beef flavor identity in the sample.
Brown/roasted	Round, full aromatic generally associated with beef suet that has been broiled.
Bloody/serumy	Aromatic associated with blood on cooked meat products. Closely related to metallic aromatic.
Fat-like	Aromatic associated with cooked animal fat.
Metallic	Impression of slightly oxidized metal.
Liver-like	Aromatic associated with cooked organ meat/liver.
Green-hay-like	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley, and tea leaves.
Umami	Flat, salty, somewhat brothy. Taste of glutamate, salts of amino acids, and other nucleotides.
Overall sweet	Combination of sweet taste and sweet aromatics.
Sweet	Aromatics associated with the impression of sweet or the fundamental taste factor associated with a sucrose solution.
Sour	Fundamental tase factor associated with a citric acid solution.
Salty	Fundamental taste factor of which sodium chloride is typical.
Bitter	Fundamental taste factor associated with a caffeine solution.
Barnyard	Combination of pungent, slightly sour, hay-like aromatics associated with farm animals and the inside of a horn.
Burnt	Sharp/acrid flavor note associated with overroasted beef muscle, something overbaked, or excessively browned in oil.
Rancid	Aromatic commonly associated with oxidized fat and oils.
Heated oil	Aromatics associated with oil heated to a high temperature.
Chemical	Aromatic associated with garden hose, hot Teflon pan, plastic packaging, and petroleum-based products such as charcoal lighter fluid.
Apricot	Fruity aromatics that can be described as specifically apricot.
Green	Sharp, slightly pungent aromatics associated with green/plant/vegetable matter such as parsley, spinach, pea pod, fresh cut grass, etc.
Asparagus	Slightly brown, slightly earthy green aromatics associated with cooked green asparagus.
Cumin	Aromatics commonly associated with cumin and characterized as dry, pungent, woody, and slightly floral.
Floral	Sweet, light, slightly perfumed impression associated with flowers.
Beet	Dark damp-musty-earthy note associated with canned red beets.
Chocolate/cocoa	Aromatics associated with cocoa beans and powdered cocoa and chocolate bars.
Dairy	Aromatics associated with products made from cow's milk.
Buttery	Sweet, dairy-like aromatic associated with natural butter.
Cooked milk	Combination of sweet, brown flavor notes, and aromatics associated with heated milk.
Sour milk/sour dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream.
Stale refrigerator	Aromatics associated with products left in a refrigerator for an extended period of time.
Warmed over	Perception of a product that has been previously cooked and reheated.

each panel session. Because there was no delay between cooking and serving, all panelists evaluated samples in the same order.

Statistical analysis

Analyses were conducted separately for each muscle. A previous experiment in which our sensory panel used the flavor lexicon (R. K. Miller, 2011, unpublished data) suggested that the sensitivity of our panel for these flavor attributes was approximately 0.5 units on the 15-point scale used in the present experiment. Thus, flavor attributes that did not have a grand mean of at least 0.5 for at least one of the 3 muscles evaluated in the present experiment were excluded from all statistical analyses. The liver-like attribute was included in all analyses despite not meeting this criterion because this attribute has, for some time, been of interest, particularly with regard to the *gluteus medius* (Yancey et al., 2005, 2006).

Data were analyzed as a split-plot design using the PROC GLIMMIX procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC). Carcass was considered the whole plot experimental unit with the treatment of marbling class. Carcass side was considered the sub-plot experimental unit, and aging time was assigned in a completely randomized incomplete block design. Random effects of carcass (marbling class), selection day, and trained sensory panel evaluation day were included in the model. Orthogonal polynomial contrasts were generated to evaluate trends associated with the aging treatment. Correlations of tenderness, juiciness, and flavor attributes between muscles were evaluated using Pearson correlation coefficients using the PROC CORR procedure of SAS. Because muscles were not evaluated on the same panel days, these correlation coefficients likely underestimate the true relationships of attributes among muscles. A predetermined level of type I error (α) of 0.05 was used for all determinations of statistical significance.

To further understand interrelationships among flavor attributes, the PROC PRINCOMP procedure of SAS was used to decompose flavor attribute scores into principal components independently for each muscle. These analyses supported the results of the analysis of variance, which indicated that neither aging nor marbling class had substantial effects on flavor attributes. To simplify the score plots, the means of the sensory panel ratings from the 2 sides of each carcass were calculated for each attribute and used in another iteration of principal component analysis that was used to investigate relationships among flavor attributes and—to the extent possible—sources of variation in flavor profiles.

Results and Discussion

The interaction of aging time and marbling class was not a source of variation for any of the palatability attributes evaluated in any of the muscles studied in this experiment ($P > 0.05$). Least-squares means for the main effects of aging time and marbling class on overall tenderness, juiciness, and flavor attributes of *longissimus lumborum* steaks are presented in Table 2. Tenderness increased linearly ($P < 0.05$) with increased aging from 14 to 35 d postmortem. Juiciness of *longissimus lumborum* steaks was not affected ($P > 0.05$) by aging time. Very few flavor attributes were affected by aging time or marbling class. The only *longissimus lumborum* flavor attribute affected ($P < 0.05$) by aging time was rancid flavor, which showed evidence of a cubic trend ($P < 0.05$), with steaks aged for 21 and 28 d receiving the highest and lowest ratings for rancid flavor, respectively. *Longissimus lumborum* steaks from carcasses with marbling scores in the Lower Small class received slightly greater ($P < 0.01$) scores for beef flavor identity and slightly lesser ($P < 0.01$) scores for bitter flavor than *longissimus lumborum* steaks from carcasses with marbling scores in the Upper Slight class.

Least-squares means for palatability attributes of *gluteus medius* steaks are presented in Table 3. Increasing aging time resulted in linear ($P < 0.001$) increases in overall tenderness ratings. None of the other palatability traits evaluated in *gluteus medius* steaks was affected ($P > 0.05$) by aging time. Marbling class only affected the brown/roasted flavor attribute ($P = 0.05$) for *gluteus medius* steaks. *Gluteus medius* steaks from carcasses with marbling scores in the Lower Small class had slightly greater brown/roasted flavor than *gluteus medius* steaks from carcasses with marbling scores in the Upper Slight class.

Least-squares means for the effects of aging time and marbling class on tenderness, juiciness, and flavor attributes of the sirloin cap portion of the *biceps femoris* are presented in Table 4. Increasing aging time resulted in significant ($P < 0.001$) effects on tenderness ratings. However, unlike *longissimus lumborum* and *gluteus medius* steaks, the aging response was quadratic ($P < 0.01$) for *biceps femoris* sirloin cap steaks. Increasing aging time from 14 to 21 d postmortem increased ($P < 0.05$) overall tenderness ratings, but further increases in aging time did not result in further increases

Table 2. Least-squares means for aging and marbling class effects on overall tenderness, juiciness, and flavor attributes of *longissimus lumborum* steaks

			Flavor attributes[1]												
Treatment	Overall tenderness[2]	Juiciness[2]	Beef	Brown/roasted	Bloody/serumy	Fat-like	Metallic	Liver-like	**Grass**	**Umami**	**Sour**	**Salty**	**Bitter**	**Barnyard**	**Rancid**
Aging effect ($n = 50$ per aging time)															
14 d	5.67	5.92	4.10	0.62	4.52	1.98	2.41	0.25	0.91	1.15	4.89	1.69	3.06	0.45	0.67
21 d	5.81	5.96	4.04	0.58	4.59	1.93	2.56	0.19	0.82	1.13	4.92	1.75	3.24	0.36	0.81
28 d	6.04	6.02	4.19	0.68	4.46	1.67	2.48	0.20	0.78	1.10	4.82	1.79	3.10	0.38	0.56
35 d	6.13	6.10	4.29	0.72	4.46	1.81	2.45	0.22	0.85	1.08	4.80	1.78	3.10	0.39	0.66
SEM	0.09	0.08	0.17	0.05	0.14	0.13	0.12	0.05	0.07	0.05	0.14	0.06	0.12	0.07	0.06
$P > F$	<0.001	0.10	0.15	0.14	0.47	0.22	0.31	0.73	0.35	0.81	0.58	0.24	0.23	0.48	0.01
Linear $P > F$	<0.001	0.01	0.05	0.05	0.31	0.13	0.86	0.68	0.39	0.33	0.25	0.07	1.00	0.39	0.22
Quadratic $P > F$	0.69	0.67	0.32	0.37	0.56	0.41	0.13	0.32	0.12	0.93	0.72	0.37	0.17	0.28	0.59
Cubic $P > F$	0.44	0.93	0.44	0.33	0.27	0.23	0.28	0.76	0.78	0.93	0.46	0.84	0.12	0.46	<0.01
Marbling class effect ($n = 100$ per marbling class)															
Lower Small[3]	6.00	6.05	4.29	0.66	4.47	1.77	2.46	0.25	0.82	1.12	4.81	1.77	3.01	0.37	0.63
Upper Slight[4]	5.82	5.95	4.02	0.64	4.55	1.92	2.49	0.19	0.86	1.11	4.91	1.73	3.24	0.42	0.72
SEM	0.10	0.07	0.16	0.04	0.14	0.10	0.11	0.04	0.06	0.04	0.14	0.05	0.11	0.06	0.05
$P > F$	0.18	0.17	<0.01	0.62	0.26	0.19	0.60	0.14	0.58	0.83	0.24	0.32	<0.01	0.24	0.09

[1]0 = not detectable; 15 = extremely strong.

[2]1 = extremely tough or dry; 8 = extremely tender or juicy.

[3]Small^{00} to Small^{49}.

[4]Slight^{50} to Slight^{99}.

Table 3. Least-squares means for aging and marbling class effects on overall tenderness, juiciness, and flavor attributes of *gluteus medius* steaks

			Flavor attributes[1]												
Treatment	Overall tenderness[2]	Juiciness[2]	Beef	Brown/roasted	Bloody/serumy	Fat-like	Metallic	Liver-like	Grass	Umami	Sour	Salty	Bitter	Barnyard	Rancid
Aging effect ($n = 50$ per aging time)															
14 d	4.95	5.71	3.11	0.33	4.97	2.15	3.09	0.20	1.48	1.15	5.25	1.93	3.66	1.53	0.75
21 d	5.13	5.74	3.26	0.27	4.85	2.11	3.10	0.22	1.30	1.25	5.28	1.91	3.69	1.46	0.73
28 d	5.37	5.85	3.28	0.27	4.82	2.12	3.10	0.22	1.29	1.19	5.33	2.01	3.70	1.36	0.64
35 d	5.60	5.82	3.24	0.31	4.88	2.14	3.11	0.29	1.38	1.13	5.28	1.94	3.74	1.44	0.78
SEM	0.07	0.05	0.09	0.05	0.07	0.09	0.09	0.05	0.18	0.07	0.07	0.05	0.11	0.28	0.11
$P > F$	<0.001	0.13	0.19	0.33	0.31	0.96	1.00	0.27	0.33	0.43	0.83	0.18	0.88	0.34	0.38
Linear $P > F$	<0.001	0.04	0.15	0.66	0.27	0.91	0.88	0.09	0.34	0.54	0.64	0.37	0.44	0.15	0.87
Quadratic $P > F$	0.71	0.50	0.11	0.08	0.13	0.64	1.00	0.45	0.12	0.16	0.51	0.44	0.95	0.33	0.16
Cubic $P > F$	0.83	0.29	0.78	0.82	0.99	0.80	0.95	0.52	0.76	0.52	0.64	0.06	0.80	0.59	0.31
Marbling class effect ($n = 100$ per marbling class)															
Lower Small[3]	5.31	5.78	3.24	0.32	4.89	2.13	3.09	0.24	1.37	1.16	5.29	1.95	3.66	1.44	0.74
Upper Slight[4]	5.22	5.78	3.21	0.26	4.87	2.13	3.11	0.22	1.36	1.20	5.29	1.94	3.74	1.46	0.71
SEM	0.06	0.04	0.08	0.03	0.06	0.05	0.08	0.03	0.10	0.04	0.06	0.04	0.07	0.14	0.06
$P > F$	0.28	0.92	0.69	0.05	0.88	0.98	0.79	0.61	0.98	0.57	0.95	0.86	0.31	0.82	0.65

[1]0 = not detectable; 15 = extremely strong.

[2]1 = extremely tough or dry; 8 = extremely tender or juicy.

[3]Small^{00} to Small^{49}.

[4]Slight^{50} to Slight^{99}.

in overall tenderness ratings. Aging time also affected ($P = 0.03$) bloody/serumy flavor in a quadratic ($P = 0.05$) manner. Bloody/serumy flavor was greatest ($P < 0.05$) in steaks aged for 28 d and was least ($P < 0.05$) in *biceps femoris* sirloin cap steaks aged for 35 d; *biceps femoris* sirloin cap steaks aged for

Table 4. Least-squares means for aging and marbling class effects on overall tenderness, juiciness, and flavor attributes of *biceps femoris* sirloin cap steaks

			Flavor attributes[1]												
Treatment	Overall tenderness[2]	Juiciness[2]	Beef	Brown/ roasted	Bloody/ serumy	Fat-like	Metallic	Liver-like	Grass	Umami	Sour	Salty	Bitter	Barnyard	Rancid
Aging effect ($n = 50$ per aging time)															
14 d	5.89	6.18	3.39	0.76	4.23	1.69	2.01	0.39	1.17	1.26	4.31	1.46	2.18	1.79	1.64
21 d	6.22	6.24	3.32	0.75	4.23	1.77	2.01	0.44	1.04	1.16	4.18	1.53	2.20	1.83	1.67
28 d	6.34	6.24	3.38	0.76	4.37	1.62	1.90	0.48	1.02	1.21	4.34	1.49	2.25	1.94	1.65
35 d	6.24	6.17	3.33	0.81	4.10	1.62	2.02	0.41	0.98	1.15	4.23	1.58	2.26	1.98	1.63
SEM	0.08	0.05	0.12	0.08	0.15	0.08	0.08	0.07	0.09	0.08	0.18	0.06	0.11	0.21	0.16
$P > F$	<0.001	0.64	0.83	0.82	0.03	0.35	0.49	0.58	0.10	0.53	0.53	0.21	0.80	0.48	0.98
Linear $P > F$	<0.001	0.82	0.67	0.46	0.44	0.26	0.81	0.66	0.02	0.28	0.86	0.08	0.34	0.12	0.87
Quadratic $P > F$	<0.01	0.21	0.90	0.57	0.04	0.56	0.37	0.22	0.39	0.70	0.92	0.83	0.89	1.00	0.76
Cubic $P > F$	0.97	0.92	0.42	0.86	0.05	0.19	0.22	0.64	0.59	0.37	0.14	0.24	0.78	0.76	0.84
Marbling class effect ($n = 100$ per marbling class)															
Lower Small[3]	6.14	6.25	3.35	0.76	4.23	1.77	1.99	0.47	1.01	1.23	4.28	1.54	2.19	1.96	1.71
Upper Slight[4]	6.20	6.16	3.36	0.78	4.23	1.58	1.98	0.39	1.09	1.16	4.24	1.49	2.25	1.82	1.59
SEM	0.08	0.05	0.12	0.07	0.15	0.07	0.07	0.06	0.08	0.07	0.17	0.05	0.10	0.20	0.15
$P > F$	0.62	0.23	0.92	0.82	1.00	0.02	0.95	0.21	0.19	0.30	0.69	0.31	0.46	0.24	0.25

[1]0 = not detectable; 15 = extremely strong.

[2]1 = extremely tough or dry; 8 = extremely tender or juicy.

[3]Small^{00} to Small^{49}.

[4]Slight^{50} to Slight^{99}.

14 or 21 d received scores for bloody/serumy flavor that were intermediate. Marbling class only affected fat-like flavor ($P = 0.02$) in *biceps femoris* sirloin cap steaks. Steaks from the carcasses in the Lower Small marbling class received greater ratings for fat-like flavor than steaks from carcasses in the Upper Slight class.

In the present experiment, 14 to 35 d of postmortem aging resulted in linear increases in tenderness of *longissimus lumborum* and *gluteus medius* steaks, whereas the effectiveness of postmortem storage in improving tenderness of *biceps femoris* sirloin cap steaks diminished with prolonged aging times. Previous work in our laboratory indicated that aging times up to 42 d postmortem resulted in continued degradation of cytoskeletal proteins (King et al., 2009a, 2009b, 2009c), which contributed to tenderization. However, in previous studies, increases in tenderness were not generally linear and were not necessarily detected with each incremental increase in aging time (Gruber et al., 2006; King et al., 2009b, 2009c). Thus, the linear increases in tenderness with increased aging from 14 to 35 d detected in *longissimus lumborum* and *gluteus medius* steaks in the present experiment were unexpected.

In the present experiment, aging time had very small effects on one flavor attribute in *longissimus lumborum* and *biceps femoris* sirloin cap steaks, and the trends associated with aging time effects were not indicative of progressive flavor development with increased aging time. Moreover, the differences detected in association with aging time were very small, and likely of little practical importance. Yancey et al. (2005) reported that metallic, rancid, and sour flavor attributes generally increased with longer (21 to 35 d) aging times and this trend was greater in beef with high ultimate pH. Additionally, those investigators indicated that beef flavor identity of *gluteus medius* or *infraspinatus* steaks with normal pH was unaffected by postmortem aging time but that beef flavor identity was lessened in *psoas major* steaks aged for 35 d compared to those aged for shorter times. Gorraiz et al. (2002) found that increasing aging time from 4 d to 7 d increased beef flavor and aftertaste in *longissimus lumborum* samples. In contrast, neither Brewer and Novakofski (2008) nor Laster et al. (2008) detected differences in consumer ratings for beef flavor intensity associated with aging time. The present experiment is consistent with other reports of minimal effects of aging times up to 35 d on beef flavor. However, other investigators have reported changes in flavor corresponding to aging times beyond 35 d postmortem (Lepper-Blilie et al., 2016).

Marbling class had little effect on palatability traits of *longissimus lumborum*, *gluteus medius*, and *biceps femoris* sirloin cap steaks in the present experiment.

In agreement with the present experiment, Legako et al. (2015) reported very few differences in flavor attributes and volatile compounds between steaks from USDA Low Choice and USDA Select carcasses for both *longissimus lumborum* and *gluteus medius* muscles. Although the 2 marbling classes studied represent 2 different USDA quality grades—and, consequently, differences in carcass value—the actual difference in the amount of marbling between the 2 marbling classes is small. Yancey et al. (2005) found cuts from carcasses with a small degree of marbling (Small^{00} to Small^{99}) to have greater rancid flavor than those from carcasses with a slight degree of marbling (Slight^{00} to Slight^{49}). Those investigators also reported carcasses with a small degree of marbling and normal muscle pH to have greater brown/roasted flavor than those with a slight degree of marbling and normal muscle pH, although in carcasses with high muscle pH, marbling class did not affect brown/roasted flavor. Consumers were unable to detect differences in beef flavor intensity between ribeye steaks from USDA Top Choice subprimals and those from USDA Select subprimals (Laster et al., 2008).

The advent of tenderness claim standards by the USDA Agricultural Marketing Service has raised the question of classifying muscles for palatability traits based on measurements determined on other muscles from the same carcass. Thus, relationships among muscles within carcasses is of particular importance, and little data describing these relationships are currently available. Thus, despite the present experiment not being specifically designed for these comparisons, correlation coefficients for palatability attribute ratings among muscles are presented in Table 5. It should be noted that panel evaluations of these muscles were conducted at different times, and therefore the degree of correlation among muscles is likely underestimated. Overall tenderness ratings were moderately correlated ($r = 0.40$ to 0.46) among the 3 muscles evaluated in the present experiment. Bitter flavor notes also had low correlation ($r = 0.18$ to 0.22) among the 3 muscles. Juiciness had low ($P < 0.05$) correlation between *longissimus lumborum* and *biceps femoris* sirloin cap, as well as between *gluteus medius* and *biceps femoris* sirloin cap. However, juiciness was not correlated between *longissimus lumborum* and *gluteus medius*. Rancid flavor ratings had low correlation ($r = 0.20$ and 0.19; $P < 0.05$) between the *gluteus medius* and *biceps femoris* sirloin cap and *longissimus lumborum*, respectively. Ratings for barnyard flavor were positively correlated ($P < 0.05$) between the *gluteus medius* and *biceps femoris* sirloin cap steaks but were negatively correlated ($P < 0.05$) between *longissimus lumborum* and *biceps femoris* sirloin cap steaks.

Table 5. Pearson correlation coefficients for overall tenderness, juiciness, and flavor attributes between *longissimus lumborum*, *gluteus medius*, and *biceps femoris* sirloin cap steaks

	Correlation		
Attribute	*Longissimus lumborum* to *Gluteus medius*	*Longissimus lumborum* to *Biceps femoris* sirloin cap	*Gluteus medius* to *Biceps femoris* sirloin cap
Overall tenderness	0.40*	0.46*	0.42*
Juiciness	0.12	0.27*	0.21*
Beef	−0.25*	−0.07	0.32*
Brown/roasted	0.01	0.01	0.30*
Bloody/serumy	0.01	0.33*	0.12
Fat-like	−0.07	−0.01	0.05
Metallic	0.18*	−0.04	0.14
Liver-like	0.18*	0.01	0.13
Grass	−0.09	−0.07	0.25*
Umami	0.14*	0.05	−0.05
Sour	0.12	0.35*	0.01
Salty	0.03	−0.08	−0.08
Bitter	0.18*	0.22*	0.18*
Barnyard	−0.19*	−0.01	0.31*
Rancid	0.19*	−0.02	0.20*

*$P < 0.05$.

Sensory panelist ratings for metallic, liver-like, and umami attributes had low correlation ($P < 0.05$) between *longissimus lumborum* and *gluteus medius* steaks. Ratings for bloody/serumy and sour notes were moderately correlated ($P < 0.05$) between *longissimus lumborum* and *biceps femoris* sirloin cap steaks. Beef, brown/roasted, and grass flavor notes were moderately correlated ($P < 0.05$) between *gluteus medius* and *biceps femoris* sirloin cap steaks. Generally, correlation coefficients for flavor traits between *gluteus medius* and *biceps femoris* sirloin cap steaks were greater than those between steaks of either of these muscles and *longissimus lumborum* steaks. This may be due to the proximity of these muscles within the carcass, the fact that the 2 muscles were still attached during aging, or possibly to greater similarity in metabolic characteristics. Our previous research has indicated a moderate to high correlation among many muscles within a carcass with regard to tenderness (Wheeler et al., 2000; Rhee et al., 2004) and color stability traits (King et al., 2011). Although relationships existed in the flavor attributes across the muscles evaluated in this experiment, these relationships were not as strong as the relationships that existed for tenderness. These correlation coefficients suggest that animal effects do impact flavor attributes of beef muscles and that some of these effects are consistent across muscles within a carcass, possibly as a result of diet. However, some of these differences are muscle specific. Thus, large-scale investigations of a single muscle across many animals may not be indicative of variation existing in other muscles in those carcasses.

Very few of the flavor attributes evaluated in the present experiment were affected by aging time or marbling class in any of the 3 muscles evaluated in the present experiment. However, substantial variation occurred in many of these attributes (coefficients of variation ranged from 15.8 to 119.3 for the flavor attributes evaluated, data not shown). Thus, it was important to attempt to gain understanding of sources of this variation, as well as understand interrelationships among the flavor attributes. Therefore, principal component analysis was conducted using the flavor attribute scores for each muscle.

Principal component analysis reveals relationships in multivariate data by deriving orthogonal, linearly uncorrelated variables (principal components), with a mean of 0, explaining decreasing proportions of the variance in the data. Eigenvalues indicate the variance described by each principal component, and the first principal component will have a larger eigenvalue than subsequent principal components. A variable's contribution to a given principal component is called its loading or eigenvector, and the greater the distance from 0, the greater the contribution the variable has to the principal component. Two principal components are generally plotted against each other, and relationships among variables can be visually determined. Variables plotted closely together are similar, and those in opposite quadrants (diagonally across the origin) are negatively correlated. Sample scores can be plotted in a similar manner, and groups of samples can be identified that correspond to a principal component. The loading plots and sample scores for the 2 principal components accounting for the greatest variation in *longissimus lumborum*, *gluteus medius*, and *biceps femoris* sirloin cap steaks are presented in Figures 1, 2, and 3, respectively. The loading plots represent the contribution of each flavor attribute to the first 2 principal components. The sample scores plots (coded by sampling day and production lot) are plotted by their contribution to the principal components. Thus, the plots can be used to identify flavor attributes contributing to the principal components and to identify groups of samples that are driving those contributions.

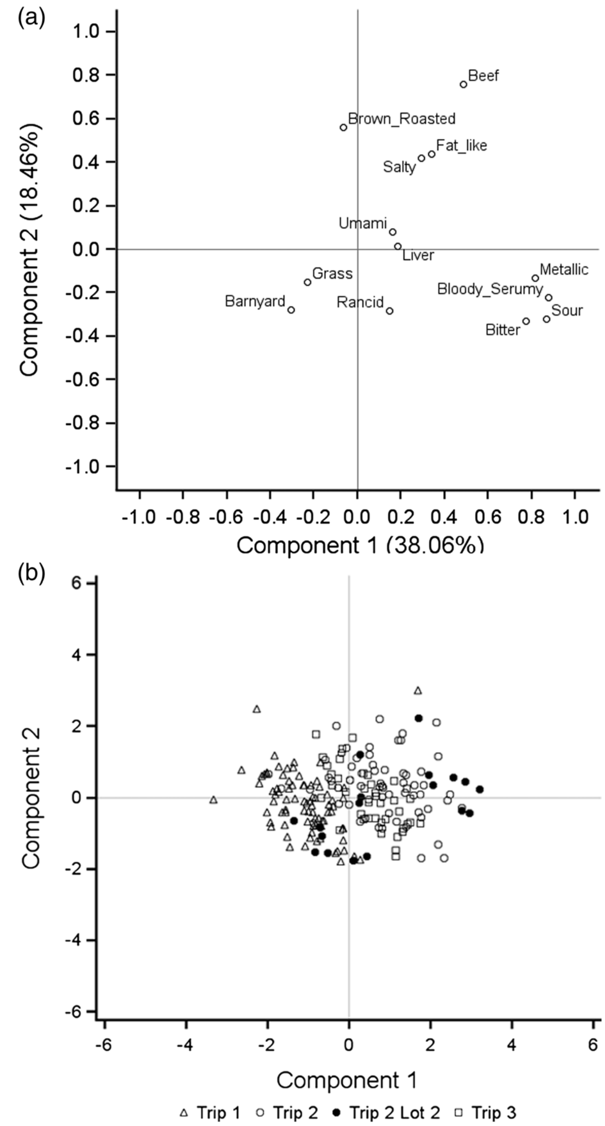

Figure 1. Attribute loadings (panel A) and sample scores (panel B) for principal component analysis of flavor attributes of *longissimus lumborum* steaks. In the sample scores plot, differing symbols represent selection days.

The first principal component explained 38% of the variation in flavor attributes in *longissimus lumborum* steaks (Figure 1A). Loadings for flavor attributes indicate that this principal component is largely explained by bloody/serumy, sour, metallic, and bitter notes. The second principal component explained 18% of the variation and was associated with beef flavor identity, brown/roasted, fat-like, and salt flavors. These 2 components contrast *longissimus lumborum* steaks with 2 differing flavor profiles. Metallic, bloody/serumy, bitter, and sour flavor attributes are associated with one another, whereas beef, brown roasted, fat-like, and salty flavor attributes often appear together. In agreement with the mixed model analysis, neither aging time nor marbling class was associated

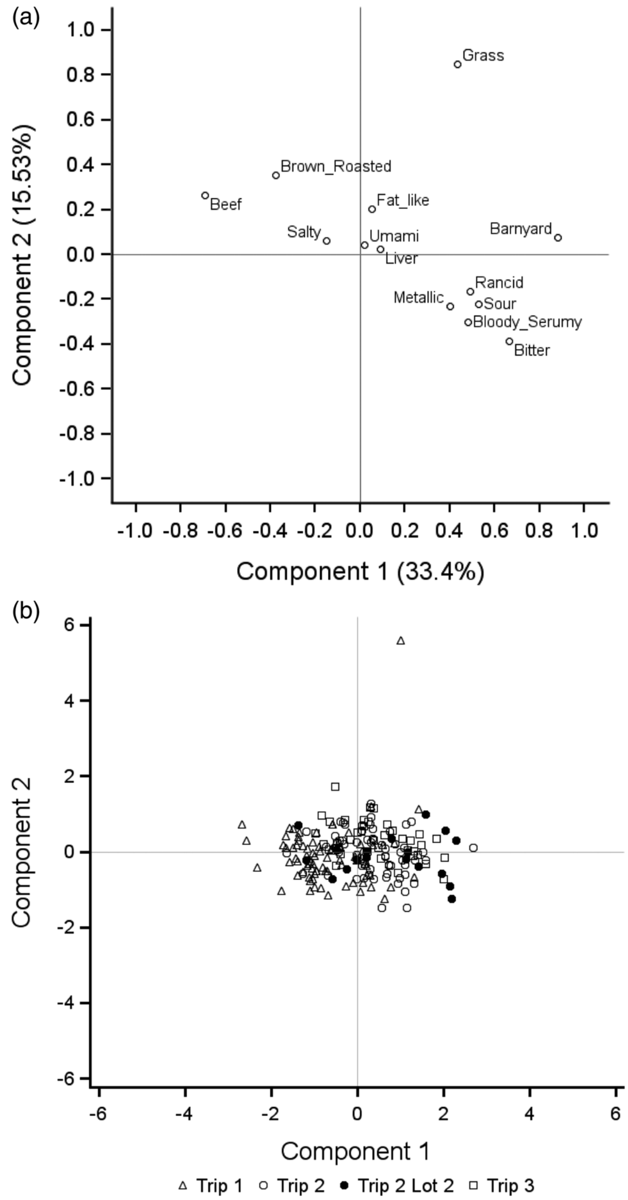

Figure 2. Attribute loadings (panel A) and sample scores (panel B) for principal component analysis of flavor attributes of *gluteus medius* steaks. In the sample scores plot, differing symbols represent selection days.

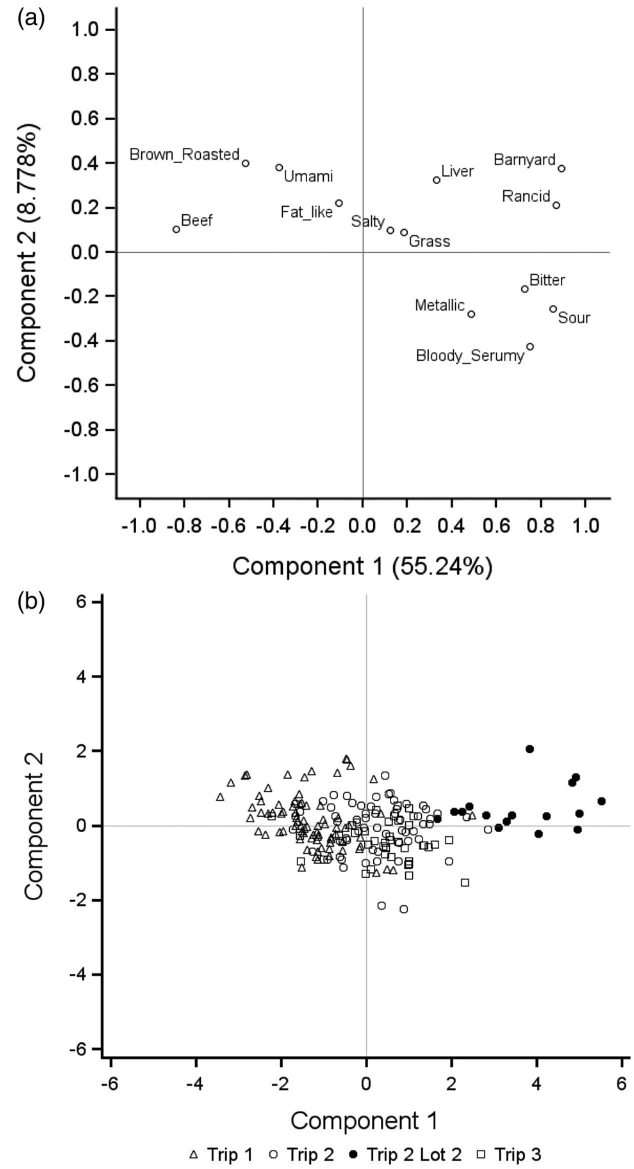

Figure 3. Attribute loadings (panel A) and sample scores (panel B) for principal component analysis of flavor attributes of *biceps femoris* sirloin cap steaks. In the sample scores plot, differing symbols represent selection days.

with any of the principal components generated by this analysis. We then generated plots of individual sample scores for the first 2 principal components describing variation in flavor attributes for that muscle coded by factors known about each sample that may have been contributing to the variation in flavor profile. These factors were examined for relationships to the loadings for flavor attributes for the first 2 principal components describing variation in flavor attributes. Of the information available, production lot (essentially feedlot pen) was the factor that corresponded most to the variation associated with these flavor attributes, and consequently with the first principal component in *longissimus lumborum* steaks, although substantial overlap in scores occurred among production lots (Figure 1B).

In *gluteus medius* muscles, the first principal component explained 33% of the flavor variation (Figure 2A). Barnyard flavor was the greatest contributor to the positive loadings of this component, with bitter, sour, rancid, bloody/serumy, green-grass-like, and metallic flavor attributes contributing to a lesser degree. Brown/roasted and beef flavor identity mapped to the negative loadings of the first principal component. The second principal component, explaining 15% of the variance, was driven by grassy flavor on the positive loadings and bitter, bloody/serumy, sour, and metallic flavors for negative loadings. When plotted together (Figure 2A), these 2 components indicate that 2 distinct flavor profiles existed among these samples. One profile characterized by beef flavor identity, brown/roasted, and salty flavors was negatively correlated with another profile characterized by metallic, rancid, sour, bloody/serumy, and bitter flavors. As was noted in the results for *longissimus lumborum* steaks, none of the experimental treatments was associated with the first 2 principal components, and of the available information, production lot was most associated with the first principal component (Figure 2B).

Results of the principal component analysis of flavor attributes of *biceps femoris* sirloin cap steaks were similar to those in *longissimus lumborum* and *gluteus medius* steaks. The first principal component explained 55% of the variation in *biceps femoris* sirloin cap steak flavor (Figure 3A). As evidenced by the loadings plot, the flavor attributes most strongly contributing to positive loadings of the first principal component were barnyard, rancid, sour, bloody/serumy, bitter, and metallic, whereas brown/roasted, beef flavor identity, and umami flavors contributed to negative loadings. The second principal component explained 9% of the variation in flavor attributes of *biceps femoris* sirloin cap steaks. Bloody/serumy, metallic, and sour flavors contributed to negative values of principal component 2. Brown/roasted, umami, liver, and barnyard flavors contributed to positive loadings for principal component 2. When plotted against one another, the first 2 principal components identified 3 distinct flavor profiles for *biceps femoris* sirloin cap steaks. A profile characterized by beef, brown/roasted, and umami flavors was negatively correlated to a profile driven by sour, bloody/serumy, metallic, and bitter flavors. A third profile was associated with barnyard, rancid, and liver flavors. As noted for the *gluteus medius* and *longissimus lumborum*, neither aging time nor marbling class contributed greatly to any of the principal components generated by this analysis. In agreement with the results of the other 2 muscles, production lot was the factor that had the greatest association with flavor attributes (Figure 3B). One lot (identified by filled circles) stood out in the plot of sample scores for *biceps femoris* sirloin cap steaks. The same lot had some *longissimus lumborum* and *gluteus medius* samples that were extreme as well, but as a whole, the entire lot did not stand out from the other samples to the same degree in those muscles. This is generally consistent with the correlation coefficients between these attributes across muscles.

In all 3 muscles, 2 distinct contrasting profiles were identified, which were inversely related to one another. One of the profiles was characterized by beef, brown/roasted, and fat-like flavor attributes, which are generally considered to be favorable attributes. The second profile was characterized by metallic, bloody/serumy, sour, and bitter flavor attributes, which are generally considered to be unfavorable off-flavors. The inverse relationship of these 2 profiles may suggest that factors contributing to off-flavors may diminish perception of favorable flavor attributes. Unfortunately, none of the factors examined in the present experiment sufficiently explained the source of these flavor profiles.

It must be noted that the present experiment was not designed with production lot as an experimental factor and production lots were not equally represented in the experiment. However, the fact that flavor attributes segregated, to some extent, with production lots in all 3 muscles included in the present experiment is an interesting finding. Moreover, this segregation was associated with flavor attributes generally considered to be undesirable. Thus, it is apparent that some factor or factors associated with producing certain lots result in flavor attributes that may be detrimental to consumer satisfaction. Incidence of liver-like flavor has been reported to vary among production lots. Moreover, during sensory panel data collection in previous experiments, we have observed increased off-flavor scores associated with certain production lots unrelated to treatments of the experiment (D. A. King, unpublished data). Incidence of off-flavor attributes, including liver-like flavor, has been reported to be related to various factors, such as muscle pH, fatty acid profile, lipid oxidation, heme iron content, and sodium content (Yancey et al., 2005; Meisinger et al., 2006; Yancey et al., 2006; Jenschke et al., 2007). These factors, in turn, have been reported to be affected by genetics (Huerta-Leidenz et al., 1993; Zhang et al., 2008, 2010; Duan et al., 2012), diet (Huerta-Leidenz et al., 1991; Liu et al., 1996; Tipton et al., 2007; Jenschke et al., 2008; Buttrey et al., 2012), and other management practices, which vary across production lots. O'Quinn et al. (2016) reported differences in flavor attributes in *longissimus* from sources differing in cattle genetics, diet, and growth promotion strategies. Further investigation of the interaction of genetics and environmental factors that affect beef flavor attributes is warranted.

Conclusions

These results indicate that aging up to 35 d postmortem and marbling scores between Slight^{50} and

Small[50] had little effect on flavor attributes of beef *longissimus lumborum*, *gluteus medius*, and *biceps femoris* sirloin cap steaks. Thus, aging time could be used to increase tenderness of these muscles without detrimental effects on other important palatability traits. Moreover, these results suggest that antemortem management may have a profound influence on beef flavor attributes, particularly the incidence of undesirable flavor attributes, and that further investigation into the sources of off-flavors is warranted to prevent erosion of consumer satisfaction with beef.

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