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The Effects of Aging Period and Freezing Sequence on Consumer Palatability Ratings, Tenderness, and Color Stability of *Longissimus Dorsi, Semitendinosus,* and *Biceps Femoris* Steaks

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Abstract
The objective of this study was to examine the effect that freezing and aging sequence has on palatability, overall tenderness, and color readings of three different beef muscles and two aging periods. The *longissimus dorsi* (LD), *semitendinosus* (ST), and *biceps femoris* (BF) were fabricated, sliced into 1-in steaks and assigned to one of the following treatment combinations: age (21 days) then freeze, freeze then age (21 days), age (28 days) then freeze, or freeze then age (28 days). For all assays, samples were cooked to a peak internal temperature of 160˚F. The consumers (n = 192) evaluated samples for flavor, juiciness, tenderness, and overall liking, as well as acceptability for each sensory trait. The next day, steaks were cooked for Warner-Bratzler shear force and color evaluation. Before steaks were cooked, each sample was allowed 20 minutes to bloom for raw color evaluation. Cooked and raw color readings were taken using a spectrophotometer. The freezing treatment did not affect ($P > 0.05$) consumer sensory rating of tenderness, flavor, or overall liking. There was a three-way interaction in juiciness between muscle, age, and freezing treatment ($P < 0.05$). As expected, the LD resulted in the highest ($P < 0.05$) tenderness rating for the consumer. The LD resulted in the lowest ($P < 0.05$) shear force values, indicating it was the most tender. There was a two-way interaction between aging period and muscle ($P < 0.05$). For raw and cooked color, the L^* (lightness) values differed ($P < 0.05$) among all main effects including freezing treatments (Age Freeze > Freeze Age), aging periods (21 days > 28 days), and muscle (ST > LD > BF). These results showed that freezing and then aging or aging and then freezing does not impact palatability or shear force values. This indicates that reversing the freezing order is not an effective way to improve tenderness of historically tough muscles.

Introduction
In 2022, the United States produced 28.2 billion lb of beef. To maintain quality and extend shelf life, beef is often frozen across the meat industry (Kim et al., 2015). Postmortem aging of beef enhances proteolytic systems, which improves its palatability.

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Numerous studies have explored how post-mortem freezing affects consumer perceptions of various beef cuts. Most of the beef industry ages meat after harvest and before freezing, but this process can lead to ice crystal formation which is linked to increased purge loss (Beyer et al., 2024, Setyabrata et al., 2019). Research has shown that the freezing process influences the shape and distribution of ice crystals within the muscle, resulting in variations in the gaps between muscle fibers and increased extracellular drip channels leading to increased tenderness (Setyabrata et al., 2019). In previous studies, it has been shown that calcium-dependent protease inhibitors lose their activity rapidly through the freezing process, thus increasing the tenderness of post-mortem muscles (Koohmaraie 1990). However, there has been little research done since to determine if the freezing sequence affects consumer ratings, instrumental tenderness, or objective color readings of muscles. This study aimed to assess how freezing and aging sequences influence consumer perception, tenderness, and objective color readings of three different beef muscles.

Experimental Procedures

Beef carcasses (n = 12) were selected from a midwestern beef plant and graded U.S. Department of Agriculture Choice and A maturity. The trimmed strip loins (Institutional Meat Purchase Specifications [IMPS] #180) and goosenecks (IMPS #170) were collected from the right side of the carcasses (NAMI, 2014). The strip loins and goosenecks were transported to North Dakota State University (NDSU) and were fabricated the day after the collection. The s*emitendinosus* (ST) and *biceps femoris* (BF) were separated from the rest of the gooseneck. The strip loins (LD), ST, and BF were denuded and sliced into 1-in steaks. Each steak was randomly assigned a 4-digit code with a tag and assigned to either age and then freeze (AF) for 21 or 28 days or freeze and then age (FA) for 21 or 28 days. Each steak was assigned to one of the following assays: consumer sensory panels, shear force, or lab assays. All steaks were aged at 34-40°F in the absence of light. After treatment, steaks were blast frozen and held at -4°F for 91 days before being placed in a refrigerator to thaw for 24 hours before the time of use (if applicable).

Consumers (n = 96 per aging period, n = 192 total) were fed all treatment combinations within a single aging period. Samples were presented to consumers for tasting one aging period at a time due to the freezing logistics and consumer panel capability. Samples were cooked to a peak temperature of 160°F as outlined by the American Meat Science Association sensory guidelines (AMSA 2015) on a Cuisinart Clamshell griddle and monitored using a Thermapen temperature probe. The consumers evaluated each sample for flavor, juiciness, tenderness, and overall liking. Each trait was ranked on a line scale of 0 to 100, with anchors set at 0, 50, and 100 with 0 being undesirable and 100 being the most desirable.

Consumers also rated each sample as acceptable or unacceptable for each sensory trait. The consumer panel data were collected on electronic tablets using Qualtrics software. The day after the samples from specific aging periods were evaluated by the consumer panels, one steak from each muscle and treatment combination was evaluated for Warner-Bratzler shear force. Before the steaks were cooked, each sample was allowed 20 minutes to bloom, and raw L^* (lightness), a^* (redness), and b^* (yellowness) color readings were taken using a HunterLab Miniscan spectrophotometer (Illuminant A/10, 1 in aperture). Steaks were cooked following the procedures described above. After the peak temperatures were recorded, each steak was sliced to expose a 1-in internal surface, and a cooked color reading was taken after a 3-minute bloom time.

After 24 hours of chilling, six cores were taken parallel to the muscle fiber according to AMSA sensory guidelines (AMSA, 2015). The six cores were sheared perpendicular to the muscle fibers on the Warner-Bratzler shear force machine, and the six readings were recorded as average lb.

Results and Discussion

Overall, the freezing treatment and aging period did not affect the consumer's juiciness, tenderness, flavor, or overall liking scores. The consumers rated the LD as the juiciest ($P < 0.05$) compared to the ST and BF. As expected, the tenderness scores were significant for muscle as the LD was rated as the most tender ($P < 0.05$) followed by the ST and BF. Within flavor, the consumers rated the LD as the most flavorful ($P < 0.05$) followed by the ST, and then the BF. Supporting the consumer data, the shear force analysis found the LD to have the lowest shear force ($P < 0.05$) value compared to BF (Table 1).

The raw color readings (Table 1) indicated that all three main effects were influenced ($P < 0.05$) for L^* values including the freezing treatment (AF > FA), aging period (21 days > 28 days), and muscle (ST > BF > LD). There was also a two-way interaction in a^* between the freezing treatment and the different muscles ($P < 0.05$), with the frozen then aged ST having the highest a^* value, resulting in being the brightest, most cherry red in appearance. For cooked color, all three main effects impacted ($P < 0.05$) L^* values including among the freezing treatments (AF > FA), aging periods (21 days > 28 days), and muscles (ST > LD > BF). There were no differences in a^* values ($P > 0.05$) for cooked color. Finally, only the aging period was significant ($P < 0.05$) for b^* values as the 21-day aged steaks had higher ($P < 0.05$) b^* values.

Implications

The results indicate reversing the typical age and freezing order does not improve tenderness and therefore is not a valid way to improve palatability of historically tough muscles.

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Table 1. Warner-Bratzler shear force (WBSF) and objective raw color readings of two freezing treatments, two aging periods and three muscles

Parameter	WBSF[1], lb	L*[2]	a*[3]	b*[4]
Freezing treatment				
Age then freeze	8.33	45.79[a]	19.82	16.66
Freeze then age	9.11	44.59[b]	19.95	16.63
SEM[5]	0.35	0.37	0.34	0.18
P-value	0.48	0.02	0.79	0.92
Aging period				
21 Days	8.25	45.79[a]	19.58	16.46
28 Days	9.19	44.59[b]	20.20	16.84
SEM[5]	0.35	0.37	0.34	0.18
P-value	0.37	0.02	0.79	0.92
Muscle[6]				
LD[6]	6.31[b]	43.62[c]	19.28[b]	15.86[b]
ST[6]	8.69[ab]	46.23[a]	21.88[a]	18.02[a]
BF[6]	11.16[a]	45.31[b]	18.51[b]	16.05[b]
SEM[5]	0.42	0.45	0.42	0.22
P-value	0.0016	<0.0001	<0.0001	<0.001

[abc] Means within the same column without a common superscript differ ($P < 0.05$).
[1]Warner-Bratzler shear force; lb.
[2]L* (lightness): 0 = black, 100 = white.
[3]a* (redness): -60 = green, 60 = red.
[4]b* (yellowness): -60 = blue, 60 = yellow.
[5]Standard error of the mean (largest) of the least squares means.
[6]LD: *longissimus dorsi, ST: semitendinosus,* BF: *biceps femoris.*

Table 2. Objective cooked color readings of two freezing treatments, two aging periods and three muscles

Parameter	L^{*1}	a^{*2}	b^{*3}
Freezing Treatment			
Age then freeze	56.32[a]	19.69	19.01
Freeze then age	55.48[b]	19.43	18.80
SEM[4]	0.29	0.39	0.19
P-value	0.04	0.65	0.44
Aging Period			
21 Days	56.25	19.63	19.17
28 Days	55.55	19.49	18.64
SEM[4]	0.29	0.39	0.19
P-value	0.09	0.79	0.05
Muscle[5]			
LD[5]	55.97[b]	19.91	19.16
ST[5]	58.05[a]	18.98	18.82
BF[5]	53.69[c]	189.79	18.74
SEM[4]	0.35	0.47	0.33
P-value	<0.0001	0.33	0.24

[abc] Means within the same column without a common superscript differ ($P < 0.05$).
[1] L^*: 0 = black, 100 = white.
[2] a^*: -60 = green, 60 = red.
[3] b^*: -60 = blue, 60 = yellow.
[4] SE (largest) of the least squares means.
[5] LD: *longissimus dorsi, ST: semitendinosus,* BF: *biceps femoris*.

Table 3. Consumer rankings of two freezing treatments, two aging periods and three muscles

Parameter	Juiciness	Tenderness	Flavor	Overall Liking
Freezing Treatment				
Age then Freeze	62.33	58.30	64.22	62.62
Freeze then Age	61.98	61.01	65.21	64.62
SEM[4]	1.12	1.50	0.85	1.01
P-value	0.82	0.11	0.37	0.23
Aging Period				
21 Days	61.22	59.27	63.60	63.31
28 Days	63.08	60.03	65.60	63.74
SEM[4]	1.12	1.22	0.78	1.08
P-value	0.24	0.66	0.11	0.77
Muscle[5]				
LD[5]	70.16[a]	76.39[a]	73.39[a]	75.26[a]
ST[5]	60.01[b]	57.66[b]	61.53[b]	61.69[b]
BF[5]	56.29[b]	44.91[c]	59.23[c]	53.62[c]
SEM[4]	1.37	1.49	0.96	1.32
P-value	<0.0001	<0.0001	<0.001	<0.001

[abc] Means within the same column without a common superscript differ ($P < 0.05$).
[4]SE (largest) of the least squares means.
[5]LD: *longissimus dorsi, ST: semitendinosus,* BF: *biceps femoris.*